CHE 4600
Fall 2018

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I certify that the work being submitted is my own, and that no unauthorized assistance was obtained.

Name (please print):

Signature:

Exam #1
(Closed book, closed notes, no electronic resources)

1. A continuous vaporizer shown below is a cylindrical pressure vessel of crossectional area ***A***. The feed is a pure organic liquid with a molecular weight of ***M***. The liquid is fed at molar flowrate N_{in} and temperature T_{in} to the vaporizer that operates at pressure ***P*** and temperature ***T***. Heat added to the vaporizer at a rate of ***Q*** generates a vapor stream with molar flowrate N_{out}. During operation, the liquid holdup of the vessel is N_L moles of liquid with a density of ρ_L.

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(a) Develop a mathematical model of the system that can be solved to predict the effects of disturbances in liquid feed rate and heat addition rate on the liquid level (h_L) in the vaporizer. Assume that the specific heat capacities of the liquid and vapor are both known ~~and ignore the~~ (20 pts) 15

(b) Determine how many variables and parameters must be specified to make the model fully solvable. (5 pts) 3

(c) On the diagram, draw proposed arrangements for the minimum number of control systems (i.e. sensor/controller + actuator) that would ensure safe operation of this system if significant fluctuations in heating rate and feed rate are expected. Briefly explain your rationale for each control system – i.e. what kind of problem(s) would it prevent. (15 pts) 5

A = cross sectional area

No reaction

$MW_{liq} \Rightarrow M$

Feed molar flow rate, $\frac{mol}{s} = N_{in}$

T_{in} = T to vaporizer

P, T = pressure, T of vaporizer

unnecessary

$Q = UA\Delta T$ for heat transfer through boundary

Heat/Energy balance: $\frac{dQ}{dt} = (FC_p\Delta T)_{in} - (FC_p\Delta T)_{out} + Q$

$\frac{dQ}{dt}$?? $= F_{in}C_p(T_{in}-T_{ref}) - (F_{out}C_p(T_{out}-T_{ref})) + UA(T_2 - T_{tank})$, $T_{tank} = T$

*assume $T_{ref} = 0°C$

$A = V/h_L$

1) $\frac{dQ}{dt} = F_{in}C_pT_{in} - F_{out}C_pT_{out} + UA(T_2 - T) = \frac{MC_p dT}{dt}$

$Q_{vaporizer}$

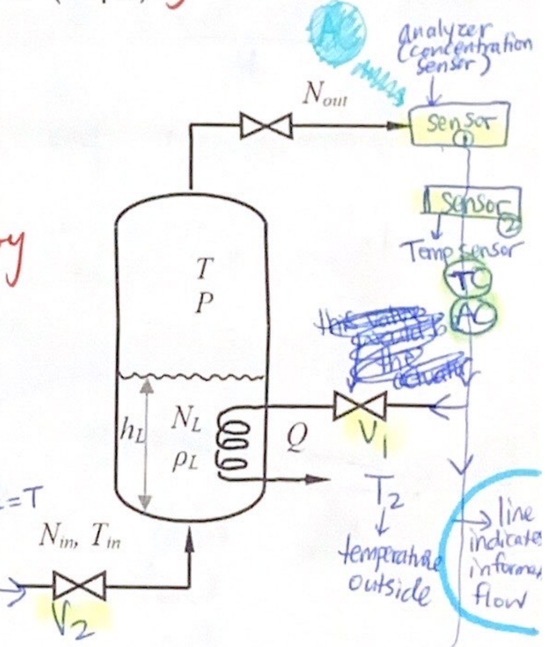
BACK SIDE

2) Mass balance: $\frac{d(\rho V)}{dt} = \rho F_{in} - \rho F_{out}$

$\frac{d(\rho_L \cdot (A \cdot h_L))}{dt} = (\rho_L F_{in}) - (\rho_L F_{out})$
Volume

(assume constant ρ and A) $\rightarrow$ $A\frac{d(h_L)}{dt} = F_{in} - F_{out}$

(Back side)



~~Not clear what measurement used to control what valve!~~ valve!

c) Sensor ①: ~~(analyzer)~~ Concentration sensor – senses fluctuations in feed rate ??

Sensor ②: Temperature sensor – senses heat fluctuation in the ~~feed~~ outlet stream

Actuator: V_1: valve controls heat in → by controlling this valve, you can control the heat added to system to increase or decrease temperature.

Actuator: V_2: By controlling this valve, you can control flow into the system by increasing or decreasing it.

The controllers are placed after the sensors to provide the actuators with information about the setpoint. → TC: Temp. controller AC: Concentration controller (analyzer)

Mole balance ~~(component balance with feed of pure liquid being component~~

$\cancel{\frac{dN_A}{dt}}$

(Total mole balance = component mole balance because of pure feed stream.)

$$\underbrace{\frac{dN_L}{dt}}_{\text{acc. of } N_L \text{ moles}} = \frac{d(C\cdot V)}{dt} = \frac{d(C\cdot(A\cdot h_L))}{dt} = \text{In} - \text{out}$$

$$\cancel{\frac{dN_L}{dt}} = \cancel{d}\ \cancel{\frac{dN_L}{dt}}$$

$$\frac{dN_L}{dt} = \frac{A\,d(C\cdot h_L)}{dt} = F_{in}C_{in} - F_{out}C_{out} = \underbrace{N_{in} - N_{out}}_{\text{molar flow rates}}$$

(mol/time units) $F_{in} \to \frac{L}{s}$, $C_{in} \to \frac{mol}{L}$

$$\boxed{\frac{dN_L}{dt} = N_{in} - N_{out}}$$ ✓

→ heat eqn continued

$$\frac{dQ}{dt} = \frac{d(MC_p\Delta T)}{dt} = \frac{MC_p\,dT}{dt}$$

heat of system

$$\frac{dQ_{overall}}{dt} = MC_p\frac{dT}{dt} = F_{in}C_p T_{in} - F_{out}C_p T_{out} + Q_{[illegible]}$$

not constant

When you need a level sensor (mass is changing)

Simplified with given variables

variable Q

b) # ~~Variables:~~ ~~Specified var~~

~~N_L~~

- ~~N_{in}~~
- ~~N_{out}~~
- F_{in}
- ~~C_p~~
- ~~T_{in}~~
- T_{out}
- F_{out}
- ~~U (heat trans. coeff.)~~
- M
- ~~T~~
- ~~Q~~
- h_L

} 11 variables ~~but 8 are given, so 3 unknown variables~~

Ignore the crossed out variables. There are 11 unknowns but Cp is "specified" so 10 unknowns.

eqns

3 balances → – heat/energy balance – mass balance – mole balance (same)

$$\text{DOF} = 10 - 3 = 7$$

The system is ~~solvable~~ underspecified and you need to know 7 variables more to solve it

2. BASF Engineering Intern Heinrich Plaumann (no relation to Dr. Heinz Plaumann), was ordered to do a dynamic analysis of outlet temperature in a two-CSTRs-in-series system after a sudden increase in feed concentration. His modeling produced the differential equation below. Mr Plaumann reported to his supervisor that he had analayzed the system using Laplace's Final Value Theorem and had concluded that the reactor temperature would quickly stabilize after the feed disturbance.

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$$\frac{d^2T}{dt^2} - 5\frac{dT}{dt} + 6T - 5 = 0 \qquad \frac{dT}{dt}(0) = 0\,,\ T(0) = 300$$

4 (a) Find the Laplace transform T(s). (10 pts) 10 $y'(0)=0$ $y(0)=300$

4 (b) What does the Final Value Theorem predict about temperature as $t \to \infty$? (10 pts) 10

(c) By comparing T(s) with your transform tables, determine what kinds of time functions should appear in T(t) and discuss Mr. Kastle's prediction. (10 pts) 4

~~(for ease of solving)~~

$$\frac{d^2T}{dt^2} - 5\frac{dT}{dt} + 6T - 5 = 0$$

~~* Y(s) = T(s)~~

→ ~~Y(s) I mean T(s) *~~

Laplace transform of each term:

$$\left(s^2F(s) - sf(0) - \left[\frac{df}{dt}\right]_{t=0}\right) - 5\left(sF(s) - f(0)\right) + \left[6\left(F(s)\right)\right] - \left[\frac{5}{s}\right] = 0$$

$$\left(s^2Y(s) - s\underset{300}{y(0)} - \underset{0}{y'(0)}\right) - 5\left(sY(s) - \underset{300}{y(0)}\right) + 6(Y(s)) - \frac{5}{s} = 0$$

$$\left(s^2Y(s) - s\underset{300}{y(0)}\right) - 5\left(sY(s) - 300\right) + 6(Y(s)) - \frac{5}{s} = 0$$

$$s^2Y(s) - 300s - 5sY(s) + 1500 + 6Y(s) - \frac{5}{s} = 0$$

~~Y(s) = T(s) * used Y(s) for ease of solving so I would not mix up T and t *~~

~~$s^2(T(s)) - 300s - 5sT(s) + 1500 + 6T(s)$~~

$$Y(s) = \frac{\frac{5}{s} - 1500 + 300s}{(s^2 - 5s + 6)} \Rightarrow$$

$(s-2)(s-3)$

a)

$$\boxed{T(s) = \frac{5}{s(s-2)(s-3)} - \frac{1500}{(s-2)(s-3)} + \frac{300s}{(s-2)(s-3)}}$$

b) Final value theorem

$$\lim_{t\to\infty} f(t) = \lim_{s\to 0} sF(s) \longrightarrow \lim_{s\to 0}\left(\frac{5\cancel{s}}{\cancel{s}(s-2)(s-3)} - \frac{1500s}{(s-2)(s-3)} + \frac{300s^2}{(s-2)(s-3)}\right)$$

$$\hookrightarrow \frac{5}{(0-2)(0-3)} - 0 + 0 \Rightarrow \frac{5}{(-2)(-3)} = \boxed{\frac{5}{6}}$$

b) is the final steady state value of the ~~reaction~~ system

$T(t) \rightarrow$ what kind of functions?

$$T(s) = \underbrace{\frac{5}{s(s-2)(s-3)}}_{①} - \underbrace{\frac{1500}{(s-2)(s-3)}}_{②} + \underbrace{\frac{300s}{(s-2)(s-3)}}_{③}$$

Taking Inverse of each term would give $T(t)$ functions such as:

For ① $5\mathcal{L}^{-1}\left\{\frac{1}{s(s-2)(s-3)}\right\}$: A similar Laplace transform is $n!/(s+a)^{n+1} \rightarrow$ a constant on top, and if $n=2$ then s will be cubed, since many of the other transforms did not have a constant in the numerator and an s^3 in the denominator. The inverse is $t^n e^{-at}$. This is exponential (decreasing exponential)

For ② $1500\mathcal{L}^{-1}\left\{\frac{1}{(s-2)(s-3)}\right\}$: if you try to take the inverse, it is similar to the Laplace transform

$\frac{1}{(s+a_1)(s+a_2)}$ where a_1, a_2 are -2 and -3 ✓ ✓

$f(t)$ is $\frac{1}{a_1 - a_2}\left(e^{-a_2 t} - e^{-a_1 t}\right)$

~~which is an exponential graph because~~ which has an exponential component to the decreasing exponential graph

For ③ $300\mathcal{L}^{-1}\left\{\frac{s}{(s-2)(s-3)}\right\}$

A similar Laplace transform is $\frac{s+a}{(s+a)^2+\omega^2}$, if $a=0$. There is an s on the top, and s^2 on bottom. The inverse gives $e^{-at}\cos(\omega t)$, which is exponential and oscillatory

Mr. Plaumann was wrong because the temperature will not quickly stabilize after the disturbance, due to the exponential and oscillatory time functions

what #s are a_1, a_2 ??

only if quadratic cannot be factored $(s+a_1)(s+a_2)$

Too much overthinking!

$$T(s) = \frac{A}{s} + \frac{B}{s-2} + \frac{C}{s-3}$$

$\frac{A}{s} \rightarrow$ constant

$\frac{B}{s-2} \rightarrow e^{2t} \rightarrow \infty$

$\frac{C}{s-3} \rightarrow e^{3t} \rightarrow \infty$