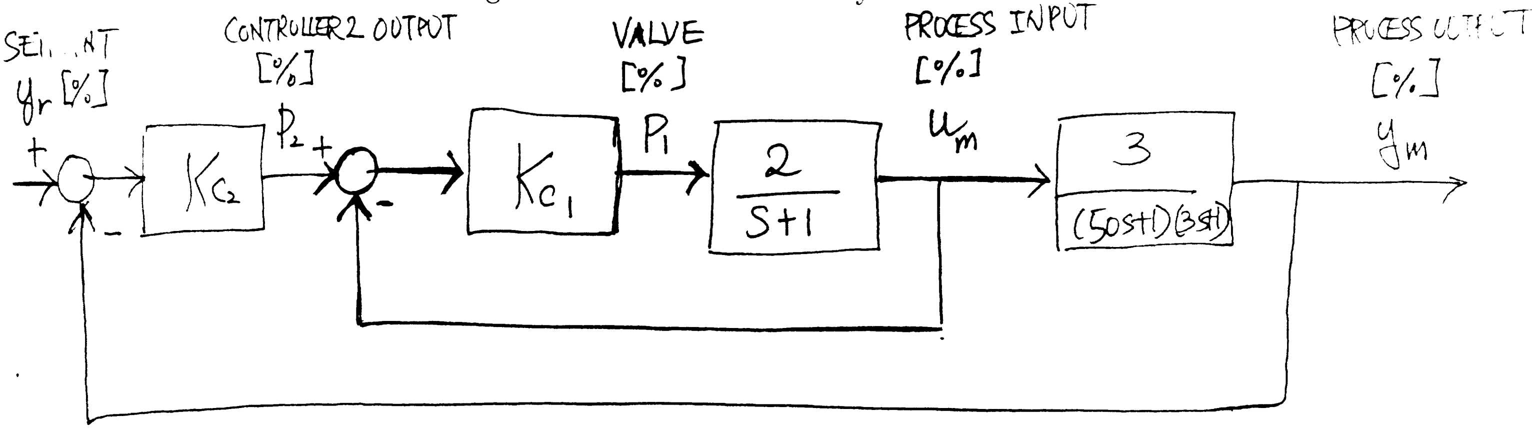
Quiz V, CHE456

November 22, 1999

Below is a block diagram of a cascade control system:



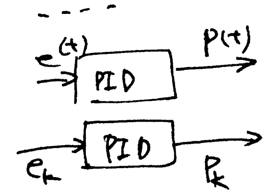
1. Determine the *range* of k_{c_1} for which the *inner-loop* is stable.
2. Assume that you have set $k_{c_1} = 5$. Derive the closed-loop transfer function from y_r to y_m.
3. Again, assuming $k_{c_1} = 5$, determine the *range* of k_{c_2} for which the overall closed-loop system is stable.

1. Explain the difference between *analog control* and *digital control.*

   (a) (4pts) Draw block diagrams showing all the needed components for both types of control. For digital control, differentiate between analog and digital signals.

   (b) (3pts) Write the PID control laws for analog control and digital control.

   (c) (3pts) List at least three advantages of digital control over analog control.



2. What is *windup* in PI control and what are the ways to fight it?

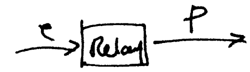
   (a) (4pts) What causes windup? Discuss at least one specific case when this happens.

   (b) (3pts) What harmful effect does it bring to control?

   (c) (3pts) What are some remedies ("anti-windup")?

3. Explain the *relay-based tuning* of PI(D) controller.

   (a) (3pts) What is a relay? draw a relay function e vs. P.



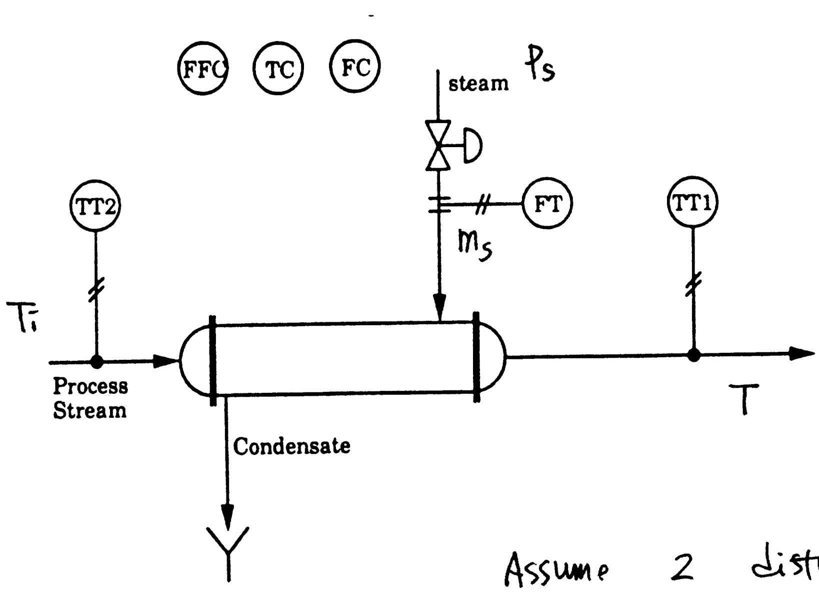
   (b) (4pts) Draw the block diagram of the test you perform. Discuss what input output behavior you expect to observe during the test by drawing the plot of the time behavior of the input and output variables.

   (c) (3pts) How would you use the test result to tune the PI(D) controller?

4. For the process the schematic of which is shown below, you wish to implement a *combined cascade / feedforward / feedback control strategy.*

   (a) (5pts) Draw in the three controllers into the schematic drawing, clearly showing the signal flow.

   (b) (5pts) Draw a corresponding block diagram.



Assume 2 disturbances

(measured) T_i : Process stream inlet temperature

(unmeasured) P_s: Steam supply presure

Indicate which block represents FFC, TC, FC, TT2, TT1, FT etc.

5. Explain the control scheme shown below.

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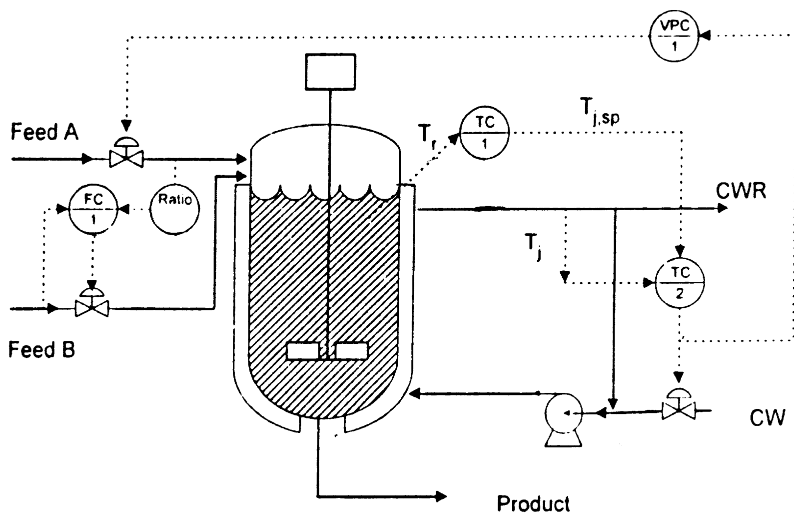
(a) (5pts) Explain the role of each controller (TC1, TC2, VP1, FC1). What's the purpose?

(b) (2pts) For each controller, discuss where the setpoint comes from and <u>how</u> it is determined.

(c) (3pts) For each controller, specify the control type (reverse-acting or direct-acting). Assume that all the valves are air-to-open type.



6. Shown below is an isothermal CSTR with a second-order reaction.

(a) (6pts) By performing the total mass balance and component A mole balance, derive differential equations for h, the height, and C_A, the concentration of A.

(b) (2pts) Write the numerical integration formula for the Explicit Euler method that can used to integrate the above equation from time t to $t + \Delta t$ where Δt is the step size.

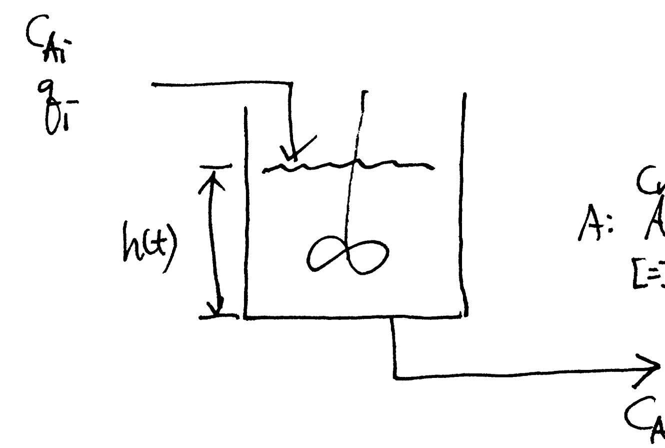
(c) (2pts) Do the same for the Implicit Euler method (employing the Trapezoidal approximation).

$A \rightarrow B$: $r = k C_A^2$ [=] $\frac{kmol}{ft^3 \cdot h}$

q, q_i [=] ft^3/h

C_A, C_{Ai} [=] $kmol/ft^3$

A: Cross-sectional Area of the tank [=] ft^2



(b) & (c) Given: $q_i(t), q(t), (q_i(t+\Delta t), q(t+\Delta t))$, $C_{Ai}(t)$, $(C_{Ai}(t+\Delta t))$, $h(t)$, $C_A(t)$

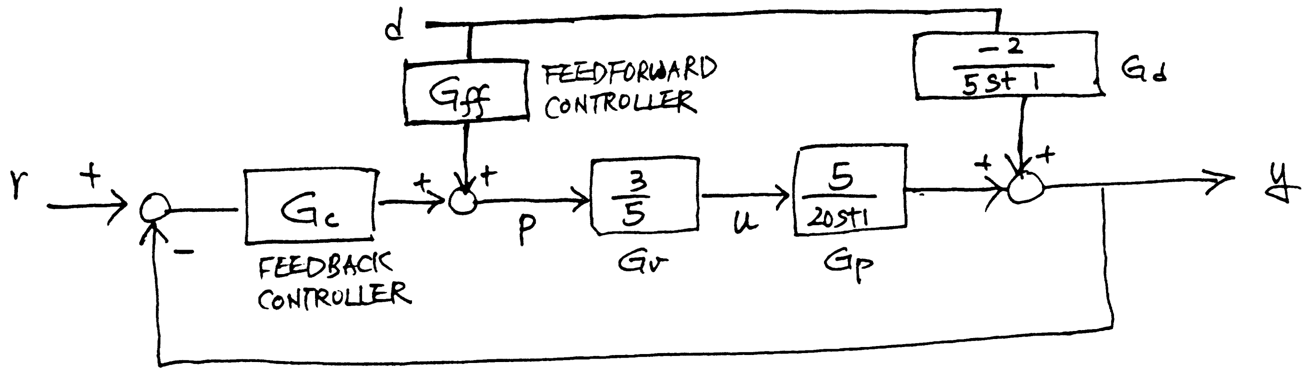
Calculate: $h(t+\Delta t)$, $C_A(t+\Delta t)$

7. Show below is the control-loop with a feedforward controller and a feedback controller.

   (a) (4pts) Calculate the *closed-loop transfer function* from d to y. The expression should contain both G_{ff} and G_c.

   (b) (4pts) Design a feedforward controller that gives *perfect elimination* of the disturbance effect, assuming the model is perfect.

   (c) (2pts) Why would you need a feedback controller on top of the above-designed feedback controller?



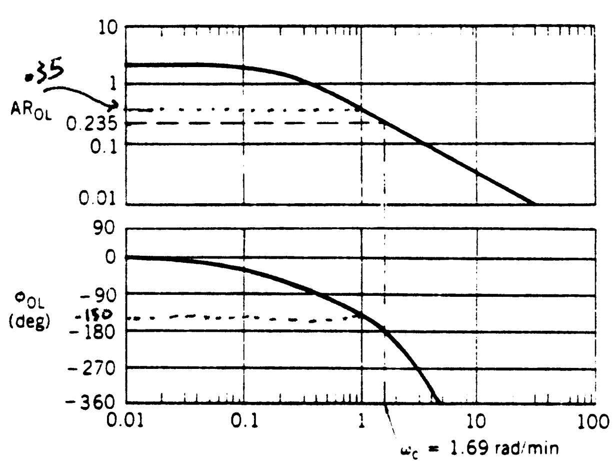
8. Below is a bode diagram of $G = G_p G_v G_m$.

   (a) (3pts) What is the ultimate gain and the ultimate period?

   (b) (3pts) What is the controller gain that will give the gain margin of 2?

   (c) (3pts) What is the controller gain that will give the phase margin of 30 degree?

   (d) (1pt) What is the maximum controller gain that will guarantee both the gain margin of 2 and the phase margin of 30 degree?

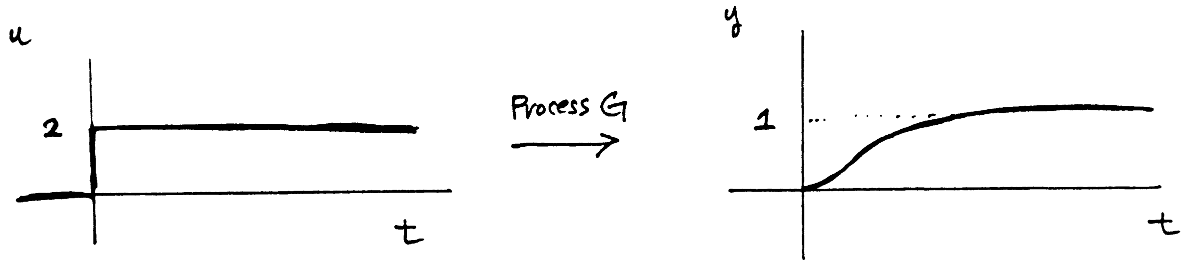


9. Shown below is the result from a step test. You also performed a continuous cycling experiment and found that the ultimate period is 2 minute and ultimate gain is 3. You are asked to use the results from both tests to fit a first order plus time delay (FOPTD) model.

   (a) (3pts) Calculate the gain k using the result from the step test.

   (b) (3pts) From the result of the continuous cycling experiment , what is the critical frequency ω_c and what is the Amplitude Ratio of G at $\omega = \omega_c$?

   (c) (4pts) Calculate the time constant τ and the delay α using the result from the continuous cycling test.



$\frac{k}{\tau s+1} e^{-\alpha s}$ $\quad AR = \frac{k}{\sqrt{\tau^2\omega^2+1}}$ $\quad \phi = -\tan^{-1}(\tau\omega) - \alpha\omega$

10. Consider the blending system below:

   (a) (4pts) Linearize the nonlinear steady-state relationship shown below around the steady state operating point corresponding to $\bar{q}_A = 1 gal/min$ and $\bar{q}_B = 1 gal/min$ and obtain the steady-state gain matrix G:

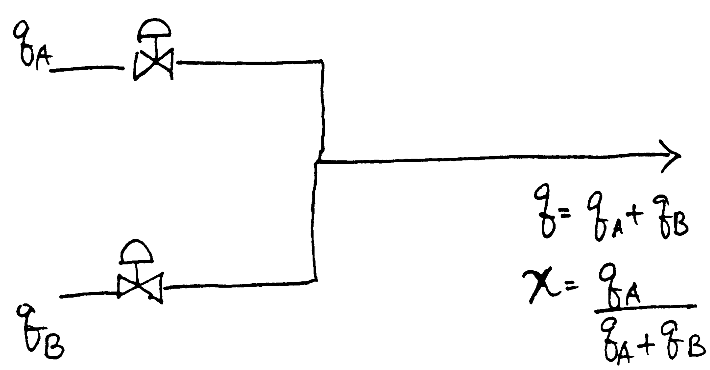
$$\begin{bmatrix} q' \\ x' \end{bmatrix} = G \begin{bmatrix} q_A' \\ q_B' \end{bmatrix}$$

$q' = q - \bar{q}$, $q_A' = q_A - \bar{q}_A$

$x' = x - x'$, $q_B' = q_B - \bar{q}_B$

   (b) (4pts) Calculate the RGA of the above system based on the gain matrix calculated in the above.

   (c) (2pts) Recommend the input-output pairing for multi-loop controller design based on the RGA.



Nominal steady state:
$\bar{q}_A = 5 gal/min$
$\bar{q}_B = 1 gal/min$

change!