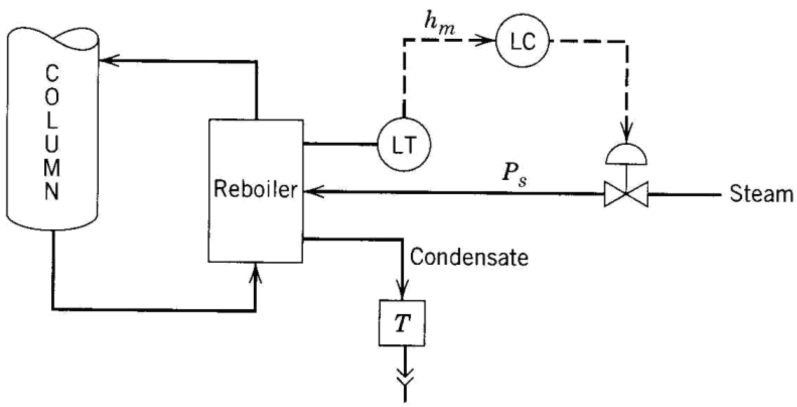
Exercise Questions for Chapter 5: Model Based Control

1. The liquid level in a reboiler of a steam-heated distillation column is to be controlled by adjusting the control valve on the steam line, as shown in Fig. Q1, The process transfer function has been empirically determined to be

$$\frac{H(s)}{P_s(s)} = \frac{-1.6(1-0.5s)}{s(3s+1)}$$

where H denotes the liquid level (in inches) and P_s is the steam pressure (in psi). The level transmitter and control valves have negligible dynamics and steady state gains of $K_m=0.5$ psi/in and $K_v=2.5$ (dimensionless), respectively. Design a *PI* level controller using the Direct Synthesis method. Justify your choice of τ_c.



2. A process stream is heated using a shell and tube heat exchanger. The exit temperature is controlled by adjusting the steam control valve shown in Figure Q3. During an open-loop experimental test, the steam pressure P_s, was suddenly changed from 18 to 20 psig and the temperature data shown Table Q3 were obtained. At the nominal conditions, the control valve and current-to-pressure transducers have gains of K_v = 0.9 psi/psi and K_{IP} = 0.75 psi/mA, respectively. Determine appropriate *PID* controller settings using Internal Model Control method

Table Q3

***t* (min)**	***T_{2m}* (mA)**	***t* (min)**	***T_{2m}* (mA)**
0	12	7	16.1
1	12	8	16.4
2	12.5	9	16.8
3	13.1	10	16.9
4	14.0	11	17.0
5	14.8	12	16.9
6	15.4	--	--

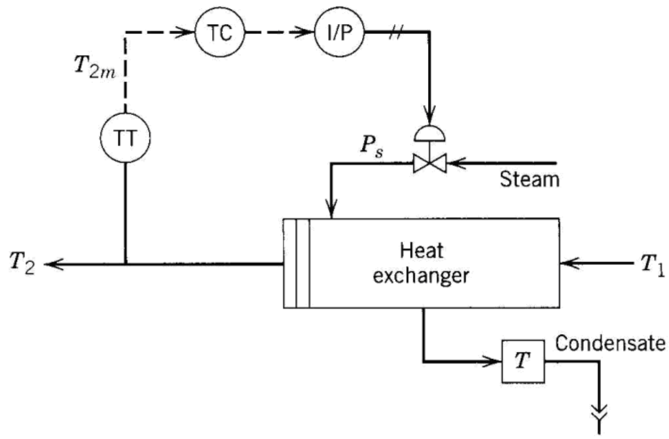


Figure Q3

3. Suggest a modification of the Direct Synthesis approach that will allow it to be applied to open-loop unstable processes. (Hint: First stabilize the process using a proportional-only feedback controller.) Draw a block diagram for your proposed control scheme.

4. The following sixth-order transfer function was obtained by linearizing the original set of ordinary differential equations used to model an industrial chemical reactor:

$$g(s) = \frac{10.3}{(1.5s+1)^5(15s+1)}$$

The indicated time constants are in minutes. For the purposes of designing a practical controller, this model was further simplified to:

$$g_1(s) = \frac{10.3e^{-7.5s}}{15s+1}$$

(a) Design a controller by direct synthesis, using the transfer function $g_1(s)$, for $\tau_r = 5.0$ min . Introduce Pade approximations i) for the time delay in the controller; and ii) for the time delay element in the model before carrying out the controller design. Compare the two resulting controllers. What further approximation will be required in order to reduce the result to a standard PID controller? Can you justify such an approximation?

(b) Design a PID controller for the process, with the specific choice of $\lambda = 5.0$ min . Compare this controller to that obtained in (a). What does this example illustrate about the relationship between the IMC strategy and the direct synthesis strategy for PID controller tuning for systems with time delays?

(c) Repeat (b) using the controller designed by IMC method with $\lambda = 5$.

5. The following transfer function was obtained via an identification experiment performed in a small neighborhood of a particular steady-state operating condition of a non-linear process

$$g = \frac{K}{(3s+1)(5s+1)}$$

while the time constant are relative easy but the gain is very difficult to estimate; it is therefore left indeterminate as a free design parameter.

(a) Use this model along with a first-order desired trajectory with $\tau_r = 4$ to design a controller for this process. Leave your controller in terms of the parameter K

(b) Suppose that the true process has a transfer function of the form

$$g = \frac{K(-\xi s+1)}{(3s+1)(5s+1)}$$

where as a consequence of the nonlinearity, the process sometimes passes through a region of operation in which it exhibits inverse-response behavior not captured by the approximate linear model. The time constants are assumed to be essentially perfectly known. If the controller designed in part (a) is now to be implemented on this process and if it is known that in the worst case $K_p = 2K$, find the maximum value of the unknown right-half plane zero parameter ξ which the closed-loop system can tolerate without going unstable.

(c) If it is now known that for the process in part (b), ξ takes the value of 3.5 in the worst case, and that the worst case for the gain estimate remains as given in part (b), what value of τ_r is required for guaranteeing closed-loop system stability in the worst case?