1. (20) A first order process with

\[ G_p = \frac{2}{3s+1} \quad (\tau \text{ is in minutes}) \quad G_m = 2 \quad G_v = 0.25 \]

is to be controlled by a PI controller, \( G_c = K_c (1 + \frac{1}{10s}) \).

What is the characteristic equation? If \( K_c \) is increased, can this process be made unstable? Why or why not? Show the basis of your answer.

2. (25) A control system has the following transfer functions in its block diagram (see Fig. 11.8):

\[ G_v = 2, \quad G_d = G_p = \frac{2}{(5s+1)(10s+1)} \quad G_m = 1. \]

For a unit step change in \( y_{sp} \), the desired closed-loop transfer function is \( \frac{1}{3s+1} \). Using the direct synthesis method, determine the feedback controller that yields this response. How is it related to a PID controller? How do you know from the closed-loop transfer function that there is no offset?

3. (20) In ratio control of combustion systems, the air flow rate is regulated in order to match some multiple of the natural gas flow rate (e.g., 20% excess air).

a) (5) Can the temperature of this system be controlled effectively using ratio control if the heating value of the natural gas varies? Why?

b) (5) Why does the heating value of natural gas vary over time?

c) (5) How can you modify the control system in order to more effectively control the temperature to set point? Remember ratio control is a type of feedforward control.

d) (5) Give two reasons why a higher excess air flow rate (e.g., 40%) will not be desirable.
4. (20) The figure below shows cascade temperature control of a polymerization reactor, which uses feed heat exchange to adjust the reactor temperature. Using the instrumentation diagram, explain how this cascade control system (both master and slave components) handles the following disturbances (Describe what happens to the reactor temperature). Assume normal temperatures of coolant (70°F), polymerization feed (200°F), exchanger effluent (100°F), and reactor outlet (800°F).

(a) Feed temperature becomes too high

(b) Coolant temperature becomes too high

5. (15) A feedforward controller is to be designed for

\[ G_p = \frac{5}{(10s+1)(2s+1)} \]

\[ G_f = 0.8 \]

\[ G_d = \frac{2}{s+1} \quad \text{Assume } G_m = G_v = 1.0. \]

Calculate \( G_p \). Is it physically realizable? If not, modify \( G_p \) so that it is physically realizable.