Name (please print clearly): ____________________

CBE 30338: Quiz 2 (40 pts)

Chemical Process Control

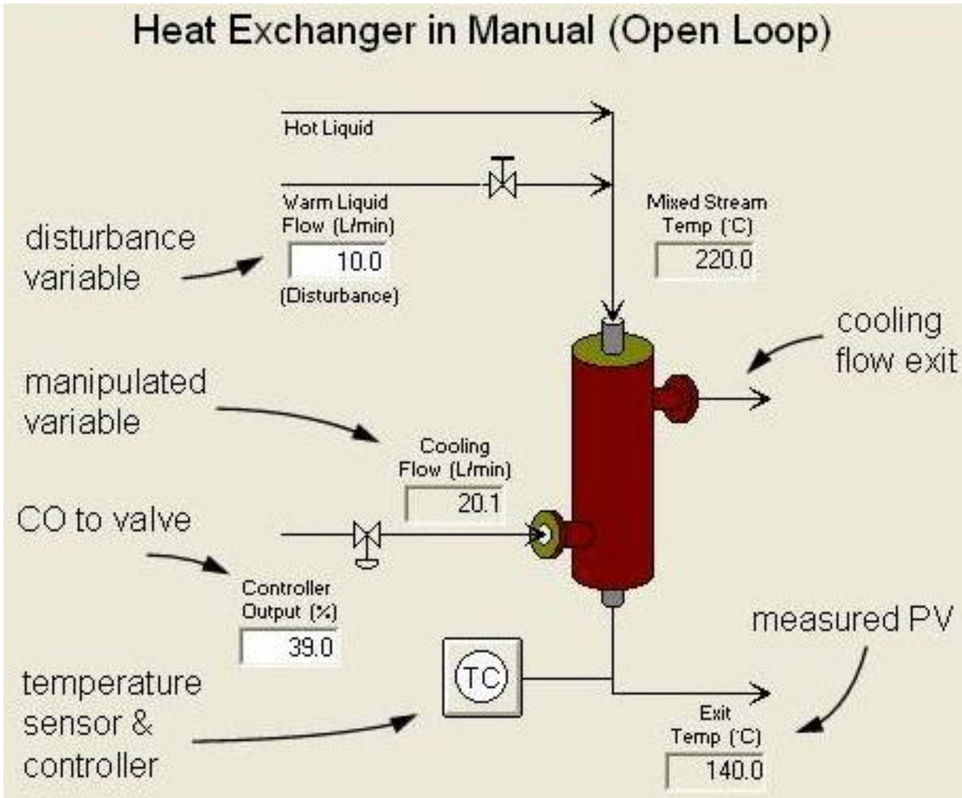
April 4, 2023

- This is a closed-book, no electronics exam. You are allowed a pencil/pen and one page of notes (8.5 x 11-inch paper, both sides, personally handwritten, no copies). Turn your notes in with the quiz.
- You may take the pages apart but then print your name at the top of every page.
- Show your work on the quiz paper. Indicate your answer by enclosing it in a box. Always show relevant units.

Problem 1	/10
Problem 2	/20
Problem 3	/10
TOTAL	/40

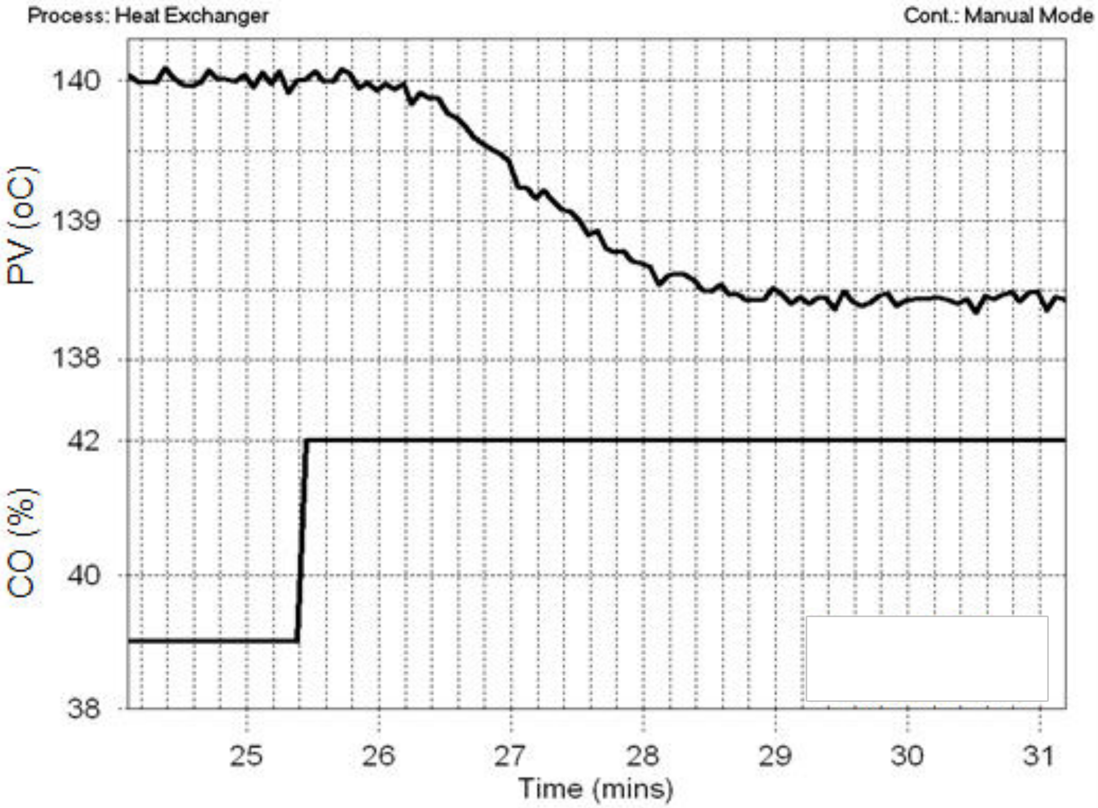
Problem 1 (10 pts)

The following diagram shows a heat exchanger and accompanying control hardware. The system is initially at steady state under manual control. **Note: The controller output denoted "CO" in the diagram corresponds to the manipulated variable "MV" that we use in class.**



The operator conducts a step test on this unit where "CO" is changed from 39% to 42%. The results are:

Open Loop Step Test Data from Heat Exchanger Process



Estimate values for the following quantities (including units). Annotate the chart to show how the two time constants are related to the step test.

1. [3 pts] Sketch your work on the chart above.

2. [3 pts] What is the steady-state gain K ?

3. [2 pts] What is the first-order time constant τ ?

4. [2 pts] What is the time delay θ ?

Problem 2 (20 pts)

The following code has been used to create instances of PI control in a large chemical plant. Assume both K_p and K_I are non-zero unless stated otherwise.

```
def Proprietary_Control(Kp, Ki, MV_bar=0, MV_min=0, MV_max=100):
    MV = MV_bar
    PV_prev = None
    while True:
        t_step, SP, PV, MV = yield MV
        e = PV - SP
        if PV_prev is not None:
            MV = MV - Kp*(PV - PV_prev) - t_step*Ki*e
            MV = max(MV_min, min(MV_max, MV))
        PV_prev = PV

```

1. [2 pts] Is this a P, PI, or PID control?

2. [2 pts] Will this controller exhibit steady-state offset? Why or why not? (Explain why using the equations embedded in the code above.)

3. [2 pts] Suppose there is a sudden change in setpoint SP. Will that cause a sudden change in the manipulated variable MV? Why or why not?

4. [2 pts] Will this controller exhibit anti-reset windup? Why or why not?

5. [2 pts] Locate the yield statement. Why does MV appear on both sides of the equality symbol?

6. [2 pts] Locate the first statement where MV is updated. Why does MV appear on both sides of the equality symbol?

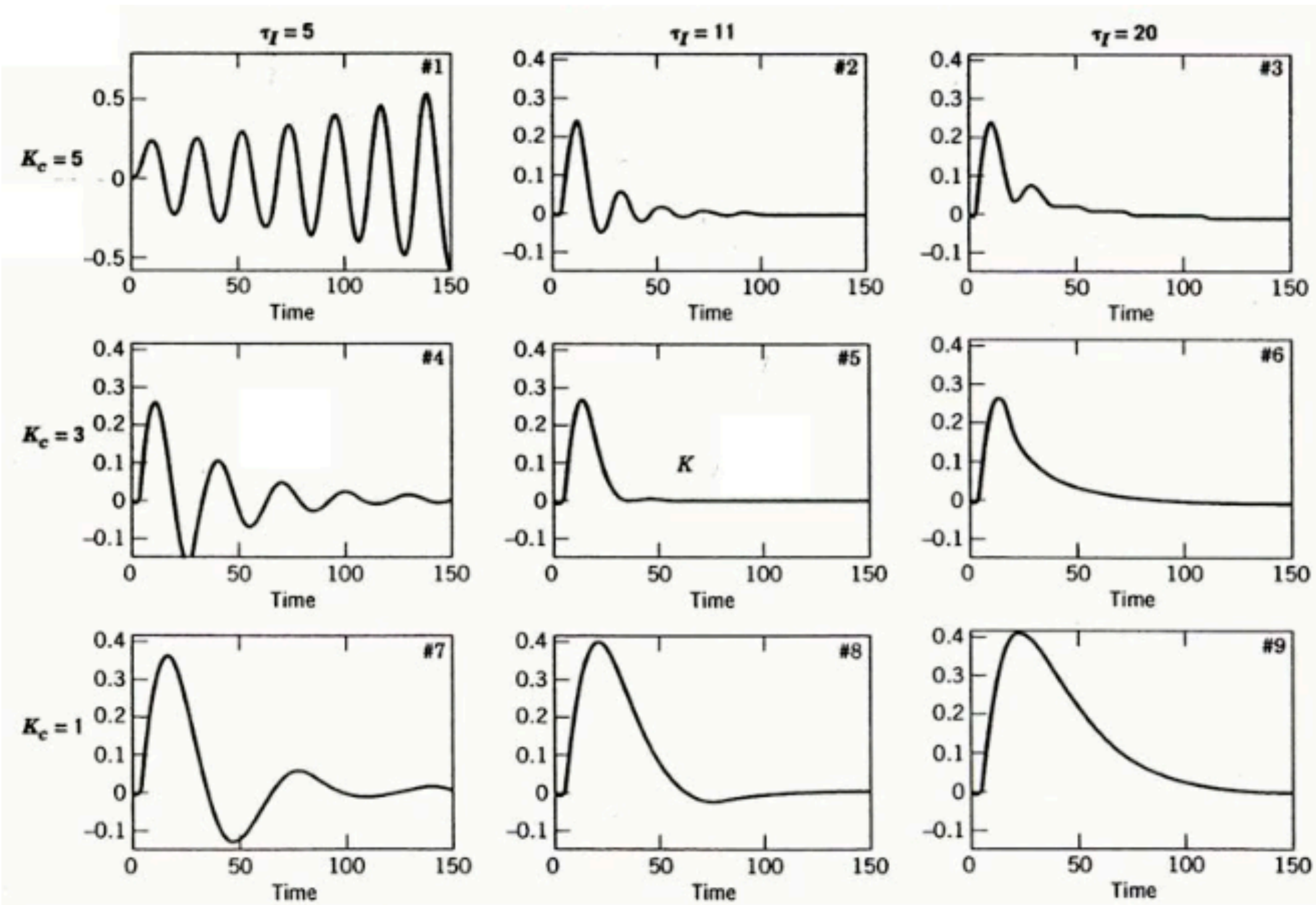
7. [2 pts] Is this in velocity or position form?

8. [2 pts] Suppose the operator sets $K_I = 0$. How will the manipulated variable respond if the setpoint SP changes?

9. [4 pts] Write a generator for a proportional-only controller using the code above as a starting point. The proportional control should be in velocity form, and should respond to set point changes.

Problem 3 (10 pts)

The following chart shows a grid of candidate tunings for PI control. The proportional control gain K_p (called K_c in the chart) is changed along the vertical axis, and the integral time constant τ_I along the horizontal axis. (In our nomenclature, $K_I = K_p/\tau_I$). The chart shows the response of the closed-loop system to a step change in a disturbance.



1. [2 pts] Are there any unstable responses? If so, which one(s)? (Note the number in the upper right corner of each sub-chart).

2. [3 pts] In chart #3 (upper right), is the integral gain too high or too low? Explain what you see.

3. [3 pts] Which of these tunings would you recommend for industrial use?

4. [2 pts] The Ziegler-Nichols rules for PI tuning are $K_p = \frac{0.9\tau}{K\theta}$ and $K_I = \frac{0.3\tau}{K\theta^2}$ where K is the gain measured in a step test, where τ is the time constant, and θ is the dead time. In this chart, $K_P = K_c$ and $K_I = K_c/\tau_I$. Suppose $\tau_I = 12$ minutes provides a satisfactory tuning, then estimate the dead time in the process.