# Exercise Questions for Chapter 1: Fundamental Concepts

1. Consider a home heating system consisting of a natural gas-fired furnace and a thermostat. The process consists of the interior space to be heated. The thermostat contains both the measuring element and the controllers. The furnace is either on (heating) or off. Draw a schematic diagram for this control system. On your diagram, identify the controlled variables, manipulated variables, and disturbance variables. Include as many as possible sources of disturbances that can affect room temperature.

2. In addition to a thermostatically-operated home heating system, identify two other feedback control systems that can be found in most residences. Describe briefly how each of them works: include sensor, actuator, and controller information.

3. Consider the following transfer function:

$$G(s) = \frac{Y(s)}{U(s)} = \frac{5}{10s+1}$$

(a) What is the steady-state gain?

(b) What is the time constant?

(c) If $U(s) = 2/s$, what is the value of the output *y(t)* when $t \to \infty$?

(d) For the same *U(s)*, what is the value of the output when *t = 10*? What is the output when expressed as a fraction of the new steady-state value?

(e) If $U(s) = (1-e^{-s})/s$. that is, the unit rectangular pulse, what is the output when $t \to \infty$?

(f) If $u(t) = \delta(t)$, that is, the unit impulse at t = 0, what is the output when $t \to \infty$?

(g) If $u(t) = 2\sin 3(t)$ what is the value of the output when $t \to \infty$?

4. Discuss the economic benefits achieved by reducing the variability (and, in some cases changing the average value) of the key controlled variable for the situations in the following.

a. Crude oil is distilled, and one segment of the oil is converted in a chemical reactor to make gasoline. The reactor can be operated over a range of temperatures; as the temperature is increased, the octane of the gasoline increases, but the yield of gasoline decreases because of increased by-products of lower value. (It’s not really *this* simple, but the description captures the essence of the challenge.) The customer cannot determine small changes in octane. You are responsible for the reactor operation. Is there a benefit for tight temperature control of the packed bed reactor? How would you determine the correct temperature value?

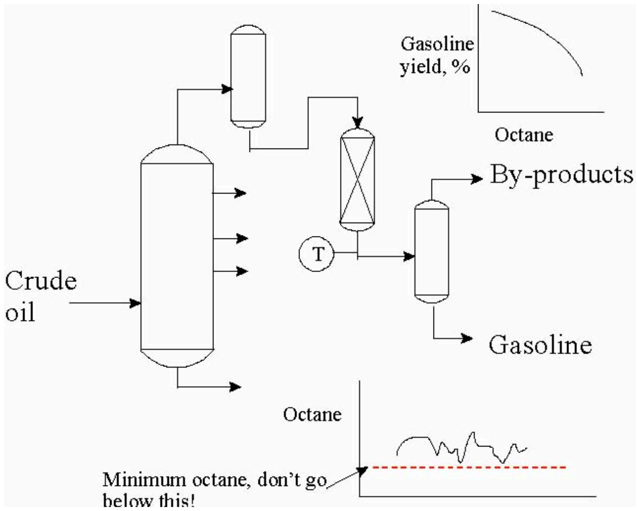


Figure 1.2 Crude oil distillation column

b. You are working at a company that produces large roles of paper sold to newspaper printers. Your client has many potential suppliers for this paper. Your customer can calibrate the printing machines, but after they have been calibrated, changes to paper thickness can course costly paper breaks in the printing machines. Discuss the importance of variance to your customer, what your product quality goal would be. Is this concept different from the situation in part (a) of this question?

5. A certain process whose transfer function is given as:

$$g(s) = \frac{2.0}{(2s-1)(5s+1)}$$

has proved particularly difficult to control. After careful analysis, the following was discovered about the process:

- If either P control or PI control is used on this process, then there are no values of $K_c$, or $\tau_I$ for which it can ever be stabilized.
- This process can only be stabilized with a PD or a PID controller.
- Furthermore, for the PID controller, the parameters must satisfy the following three conditions:

(a) $K_c > \frac{1}{2}$

(b) $\tau_D > \frac{3}{2K_c}$

(c) $\tau_I > \frac{20K_c}{(2K_c\tau_D - 3)(2K_c - 1)}$

Confirm or refute these statements.

6.

(a) Find the range of $K_c$ values for which the system with the following transfer function will remain stable under proportional feedback control:

$$y(s) = \frac{5(1-0.5s)}{(2s+1)(0.5s+1)}u(s)$$

(b) Consider now the situation in which the following unorthodox controller is utilized:

$$g_c(s) = K_c \frac{(\tau_z s+1)}{(\tau_L s+1)}$$

a proportional controller with a Lead-lag element. lf now $\tau_z$ is chosen to be 0.5, find the $\tau_L$ value required to obtain a stability range of $0 < K_c < 4$ for the proportional gain.

(c) Determine whether or not the controller will leave a steady-state offset.