20.1. Some multiple-loop control designs are given in the following. For each design, explain whether the control design is correct and will function, i.e., the controllers can maintain their measured variables near their set points. If the control design can not function, suggest a modification that will achieve all or part of the desired function.

a. Heat exchanger with by-pass.

We will analyze the design using the controllability test in textbook Chapter 20. The system is controllable if we can achieve independent values of the two controller variables by adjusting the two manipulated variables. The linearized, steady-state model for the process is given in the following.

\[
\begin{bmatrix}
K_{11} & K_{12} \\
K_{21} & K_{22}
\end{bmatrix}
\begin{bmatrix}
v_1 \\
v_2
\end{bmatrix} =
\begin{bmatrix}
F \\
T
\end{bmatrix}
\]

The process is controllable if the equations are linearly independent. Formally, we test the gain matrix for (non) singularity. The system is non-singular if

\[K_{11} K_{22} - K_{12} K_{21} \neq 0\]

We should be able to answer this question for many processes without quantitative analysis, by applying our process understanding. We note that the first valve adjusts a variable resistance to total flow. In contrast, the second three-way valve adjusts the split of the total flow between the heat exchanger and the by-pass; adjusting the three-
way valve does not substantially change the total resistance to total flow. From the qualitative analysis, we see that

- Valve 1 has a strong effect on total flow and a weak effect of temperature
- Valve 2 has a strong effect on temperature and a weak effect on total flow

Without quantitative values, we can conclude that this system is controllable.

Note that we have not concluded that interaction is absent; a controllable multivariable system can (and usually does) have interaction. Also, we require detailed calculations (or plant experience) to determine the operating window, to be sure that the process will operate over the required range of conditions.

b. Flow and pressure of a gas in closed vessels.

Again, we will analyze this system using qualitative process principles. We note that the flow can be adjusted by changing the resistance to flow using any one of the valves shown; valve 1 is acceptable. If other valves change their resistance, the flow controller can return the total flow to the desired valve by adjusting valve 1.

Next, we note that we want to control the pressure $P_1$ and $P_2$, which are in adjacent vessels. When we control the two pressures, we implicitly determine the pressure difference between the two vessels.
However, the pressure difference depends on the opening of valve 3 and the total flow rate, neither of which is adjusted by the control system! Thus, setting the total flow rate and the pressures P1 and P2 (or the pressure difference P1-P2) is not consistent. Therefore, the proposed design is not controllable.

In a correct the design, we must adjust valves that can achieve the desired total flow, P1 and P2 independently, even when the total flow is determined independently. For example, we can do this by changing the valve manipulated by the P2 controller, so that the pressure difference between P1 and P2 is affected by an adjusted valve. The acceptable control design is shown in the following.

Note: v4 is partially open.

Note that we have not concluded that interaction is absent; a controllable multivariable system can (and usually does) have interaction. Also, we require detailed calculations (or plant experience) to determine the operating window, to be sure that the process will operate over the required range of conditions.
Again, we will analyze this system using qualitative process principles. We note that the reactor temperature is controlled by two controllers with the same set point values. This is not acceptable: they will “fight” and essentially never reach a steady state because many combinations of precooling and jacket cooling will result in the same reactor temperature. No unique operating condition exists.

Here, we suggest that one of the reactor temperature controllers be removed.

Other approaches are introduced in textbook Chapter 22; they use split range control to adjust either cooler (but not both at the same time) to extend the operating window.

Note that we have not concluded that interaction is absent; a controllable multivariable system can (and usually does) have interaction. Also, we require detailed calculations (or plant experience) to determine the operating window, to be sure that the process will operate over the required range of conditions.
d. Flash drum.

This is a more involved process, with a poor initial design. Before beginning to consider the control design, we should be sure to understand the control objectives. This flash process is similar to the process considered in Chapters 2 and 24. A complete summary of control objectives is given in textbook Table 24.1. The reader is asked to review this table before proceeding.

We will be concerned with only the basic control, not alarms and safety valves. The proposed design is deficient in several respects.

1. The liquid level in the drum is not controlled.
2. The quality of the flash product is not controlled.
3. The feed flow is measured after the valve, where the fluid has two phases.

To correct each of these deficiencies, we recommend the following changes.

1. Measure the liquid level in the tank, and control it by adjusting the liquid flow rate.
2. Measure the temperature in the flash, and control it by adjusting the heat transfer in the heat exchanger. (An analyzer could be included, if justified.)
3. Locate the flow sensor before the heat exchanger, where the temperature is low and the pressure high.
The proposed control system is shown in the following sketch.