Solutions for Tutorial 14
Cascade Control

Cascade control can dramatically improve the performance of feedback control systems, when it is designed and implemented correctly. This tutorial provides exercises on the proper design of cascade control. Recall that the **cascade design criteria** provide the basis for the proper selection of cascade control; these criteria should be used during this tutorial.

14.1 Furnace *coil outlet temperature* control in Figure 14.1.

a. Determine whether the cascade control is *possible* as designed. If not, make appropriate changes to achieve cascade control.

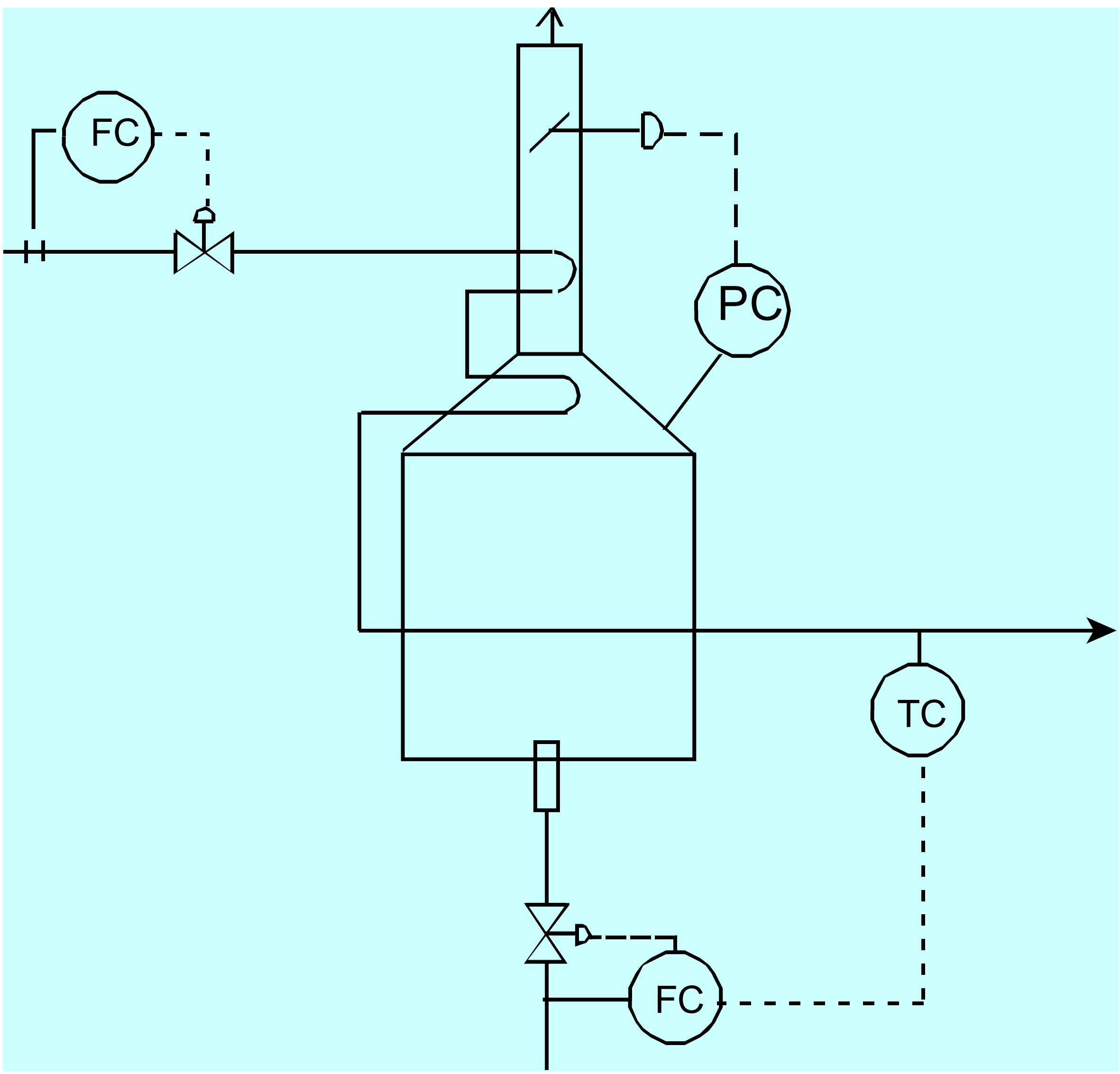

Figure 14.1 Fired heater process with simplified control.

a. **Yes,** cascade is possible because the design satisfies the cascade design criteria.

1.	Control without cascade is not acceptable.	N/A for determining if cascade is ***possible.*** But, it is important to determine when cascade is recommended!
2.	Secondary variable is measured	**Yes**
3.	Indicates a key disturbance	**see responses for each disturbance**
4.	Influenced by the manipulated valve	**Yes**
5.	Secondary dynamics faster	**Yes**

b. For each of the following disturbances, determine whether the cascade design, after modifications in part a (if needed), will perform **better, the same, or worse** than single loop feedback (TC$\rightarrow$ valve).

1**)** **fuel supply pressure**: **Cascade is better**. The flow controller will compensate for the disturbance. Whether the secondary corrects for the complete disturbance depends on the flow sensor. See the discussion below for a few situations.

Orifice meter (gas fuel): The typical orifice meter is calibrated for a constant pressure, so that the relationship between the pressure difference and the flow is given in the following.

actual flow: $F = K\sqrt{\Delta P/\rho}$ measurement: $F = K\sqrt{\Delta P}$

Since the density changes with pressure, maintaining the flow *measurement* (ΔP) constant does not maintain the actual flow constant. The flow measurement indicates the change in flow, so that the secondary partially compensates for the disturbance. However, the secondary controller cannot compensate *completely* for the pressure disturbance. Some compensation must be made by the primary to correct for the flow measurement error.

Mass flow meter (gas fuel): The mass flow rate can be measured by a mass flow meter, such as a coriolos meter. The total heat release depends on the mass flow rate for light gas hydrocarbon fuels without hydrogen (Duckelow, S., *Intech*, 35-39 (1981)). Therefore, maintaining mass flow rate constant will completely compensate for pressure changes. Cascade control with mass flow control would perform better than with an orifice meter. However, the mass flow meter will be more costly.

Orifice meter (liquid fuel): The density of the liquid does not depend on the pressure. Therefore, the orifice meter provides a good measurement, and the secondary controller can compensate for the pressure disturbance completely. Cascade control will provide good performance.

2) **fuel density (composition): Cascade is better.** Again, the improvement possible using cascade control depends on the sensor used and the change in heating value for changes in density.

Gas fuels: The situation is basically the same as for the pressure disturbance. The orifice meter does not provide complete compensation, and a mass flow meter will provide complete compensation. See Duckelow (*Intech*, 35-39 (1981) for a discussion of this situation.

3) **fuel control valve sticking**: **Cascade is better**. The fuel flow meter will immediately sense the deviation in flow and correct the flow. Note, if the stiction is serious, the flow will oscillate, which would degrade control performance and could lead to unsafe conditions. A valve positioner could correct the effect of moderate stiction, but mechanical correction should be performed to reduce the stiction.

4) **feed temperature**: **Cascade is neither better nor worse**; the performance is the same. The secondary measured variable is not affected by the feed temperature. Therefore, cascade provides no compensation.

Follow-up question: Answer the same question for other disturbances.

1. **Now it's your turn to define the disturbance**! What other variables are likely to change for the process and how would the cascade controller perform?

14.2 *Bottoms composition analyzer* control for distillation in Figure 14.2.

a. Determine whether the cascade control is *possible* as designed. If not, make appropriate changes to achieve cascade control.

b. For each of the following disturbances, determine whether the cascade design, after modifications in part a (if needed), will perform **better, the same, or worse** than single loop feedback (AC→valve)

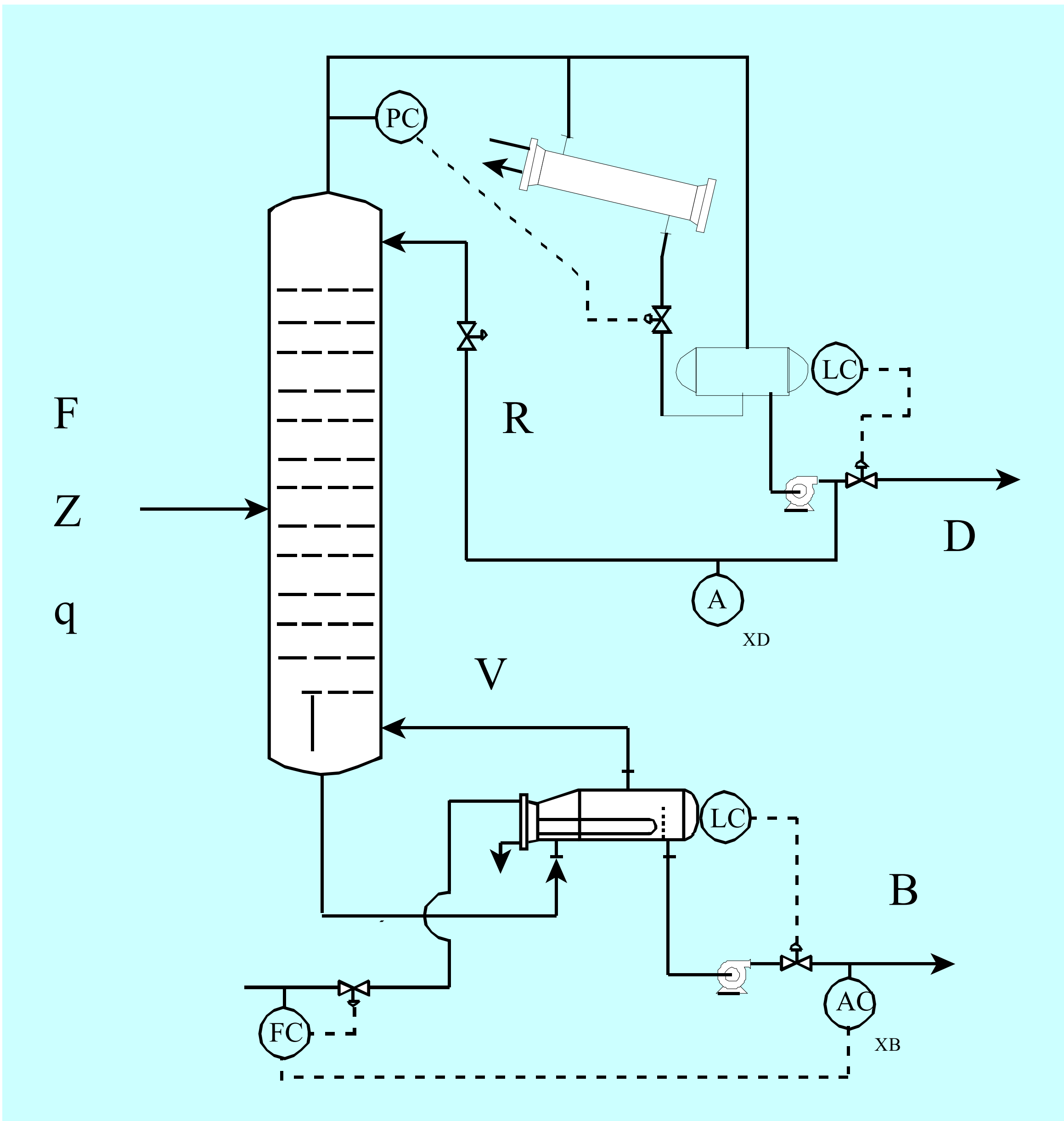

Figure 14.2. Two-product distillation with basic regulatory control.

a. **Yes,** cascade is possible because the design satisfies the cascade design criteria.

1.	Control without cascade is not acceptable.	N/A for determining if cascade is ***possible.*** But, it is important to determine when cascade is recommended!
2.	Secondary variable is measured	**Yes**
3.	Indicates a key disturbance	**see responses for each disturbance**
4.	Influenced by the manipulated valve	**Yes**
5.	Secondary dynamics faster	**Yes**

b. For each of the following disturbances, determine whether the cascade design, after modifications in part a (if needed), will perform **better, the same, or worse** than single loop feedback (AC→ valve).

1. **Heating medium temperature**: **Cascade is the same**. The temperature of the heating medium does not affect the flow measurement significantly. Therefore, the cascade and single-loop controllers would perform essentially the same.

2. **Feed temperature**: **Cascade is not better**. The temperature of the distillation feed does not affect the flow measurement significantly. Therefore, the cascade and single-loop controllers would perform essentially the same.

3. **Reflux flow rate**: **Cascade is not better**. The reflux flow rate does not affect the reboiler heating flow measurement significantly. Therefore, the cascade and single-loop controllers would perform essentially the same.

4. **Heating medium supply pressure**: **Cascade is better**. The pressure influences the heating medium flow rate, which is measured by the flow sensor. The secondary controller can quickly adjust the reboiler valve to correct for pressure disturbances. Whether the secondary flow controller compensates for the disturbance completely depends whether the flow sensor measures the flow accurately for changing pressure. See the discussion for the fired heater for further details.

Follow-up question: Answer the same question for other disturbances.

1. **Now it's your turn to define the disturbance**! What other variables are likely to change for the process and how would the cascade controller perform?

14.3 For a cascade control design, the sensor for the secondary variable should provide good

- ☐ accuracy
- ☐ reproducibility ← **correct** ☺
- ☐ noise moderation

A ***constant bias*** in the secondary measurement will not seriously degrade the control performance. The primary controller will adjust the secondary set point to correct for a small bias. Remember, a sensor with good reproducibility is often less expensive than a highly accurate sensor.

14.4 For a cascade control design, the sensor for the primary variable should provide good

- ☐ accuracy ← **correct** ☺
- ☐ reproducibility
- ☐ noise moderation

Nothing can correct errors in the primary sensor. Therefore, the primary sensor must achieve the accuracy needed for the process application.

