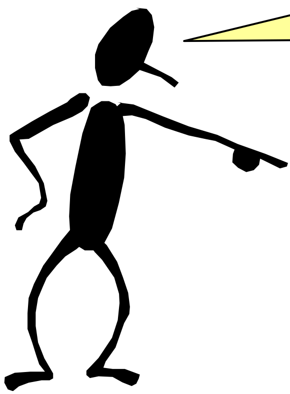
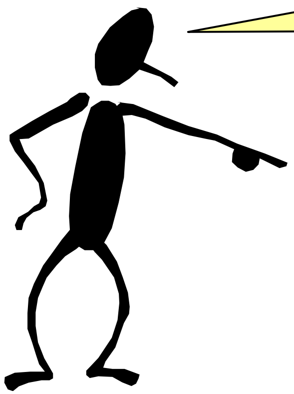
CHAPTER 14: CASCADE CONTROL



When I complete this chapter, I want to be able to do the following.

- **Identify situations for which cascade is a good control enhancement**
- **Design cascade control using the five design rules**
- **Apply the tuning procedure to cascade control**

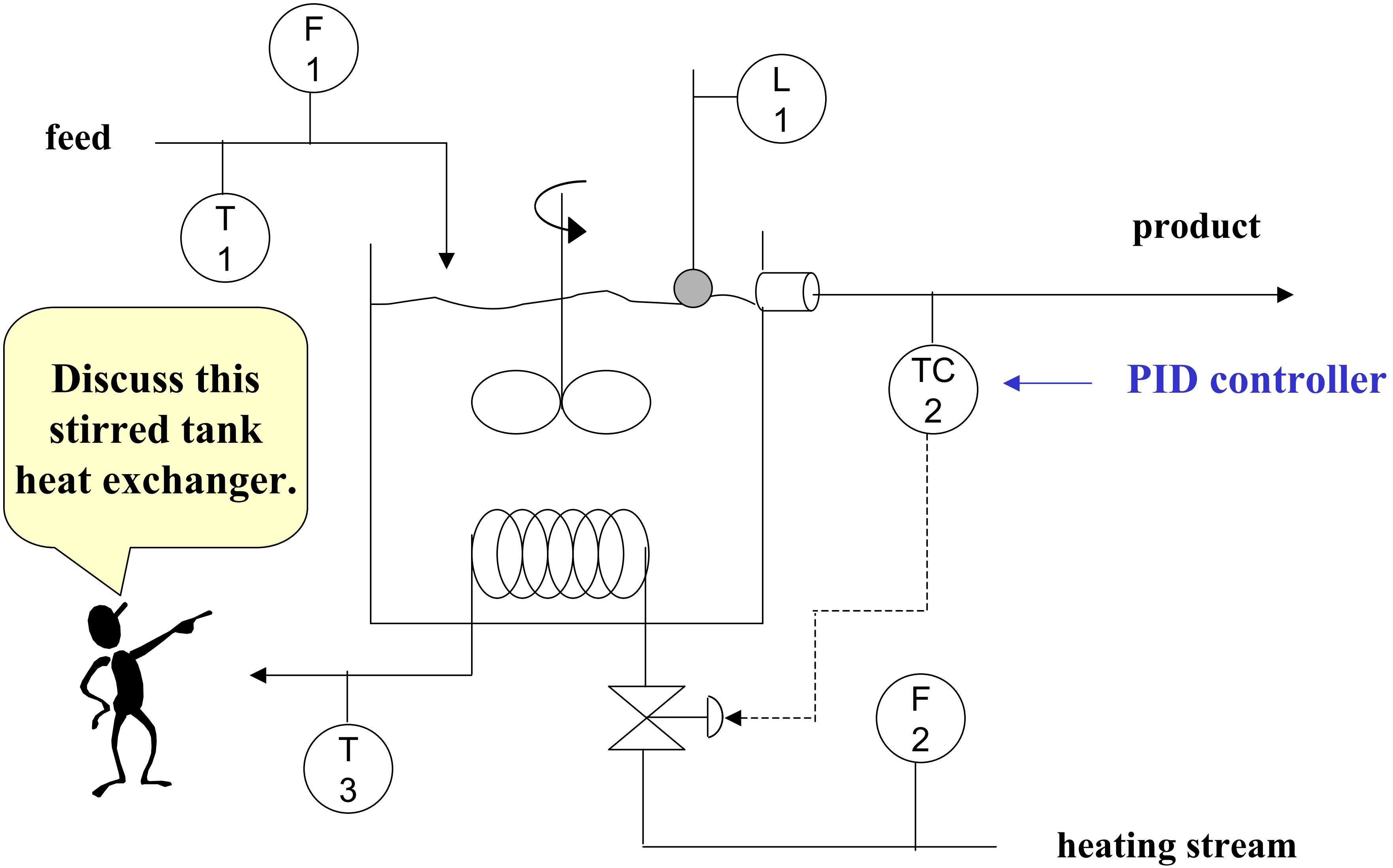
CHAPTER 14: CASCADE CONTROL



Outline of the lesson.

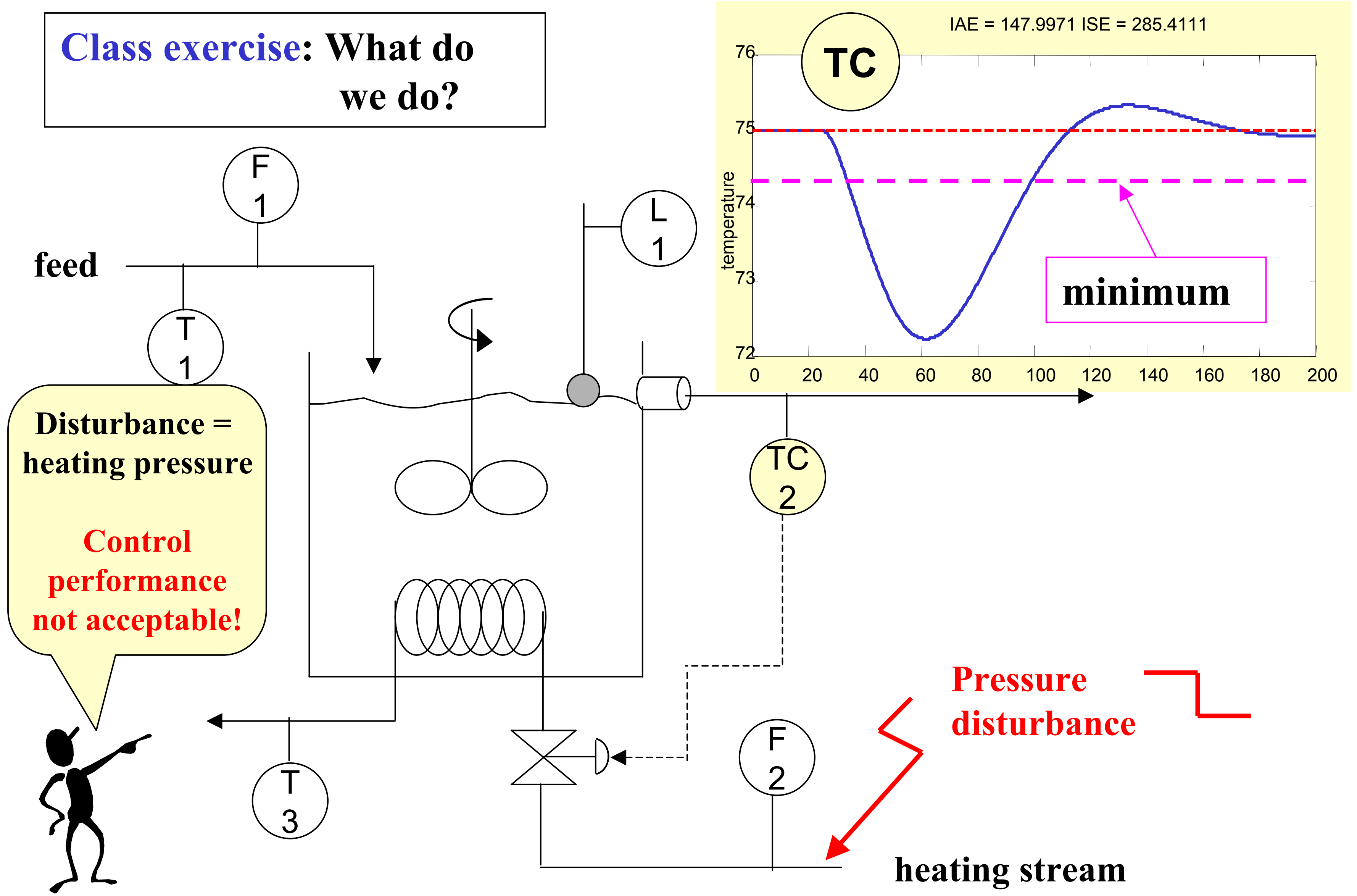
- **A process challenge - improve performance**
- **Cascade design rules**
- **Good features and application guidelines**
- **Several process examples**
- **Analogy to management principle**

CHAPTER 14: CASCADE CONTROL



CHAPTER 14: CASCADE CONTROL

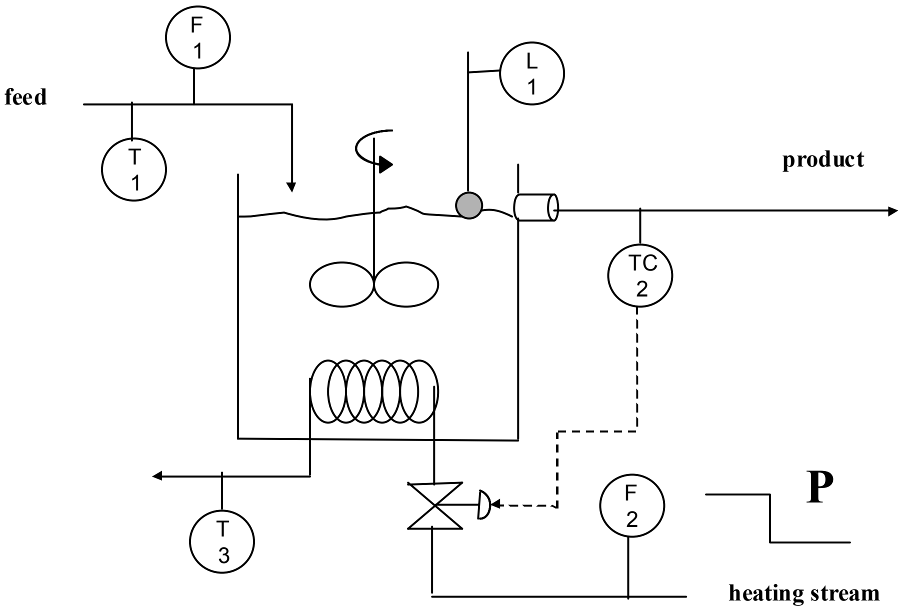
Class exercise: What do we do?



CHAPTER 14: CASCADE CONTROL

<u>**Let's think about the process behavior.**</u>

- **Causal relationship from P disturbance to T (without control)**
- **What measurable effect always occurs when P changes?**



v (valve) → ??? → Q → TC

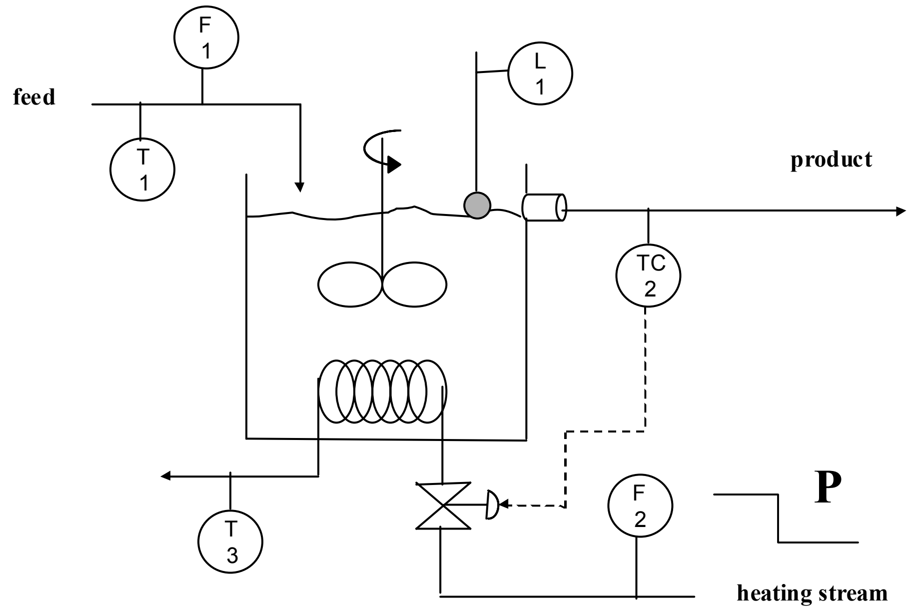
↑

P

(heating oil)

CHAPTER 14: CASCADE CONTROL

Let's think about the process behavior.



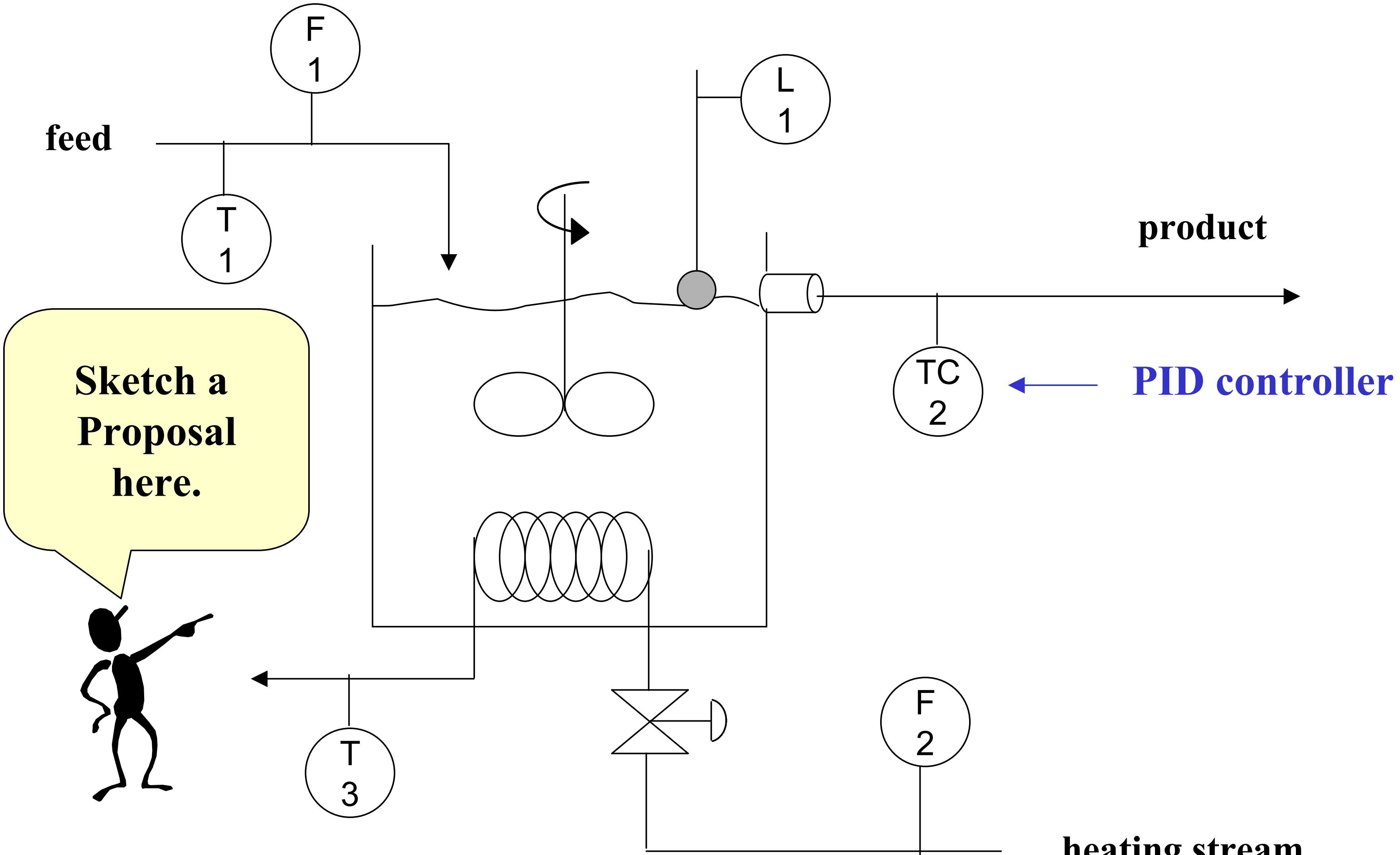
If we can maintain this variable approximately constant, can we reduce the effect of the disturbance?

v (valve) → ??? → Q → TC

↑

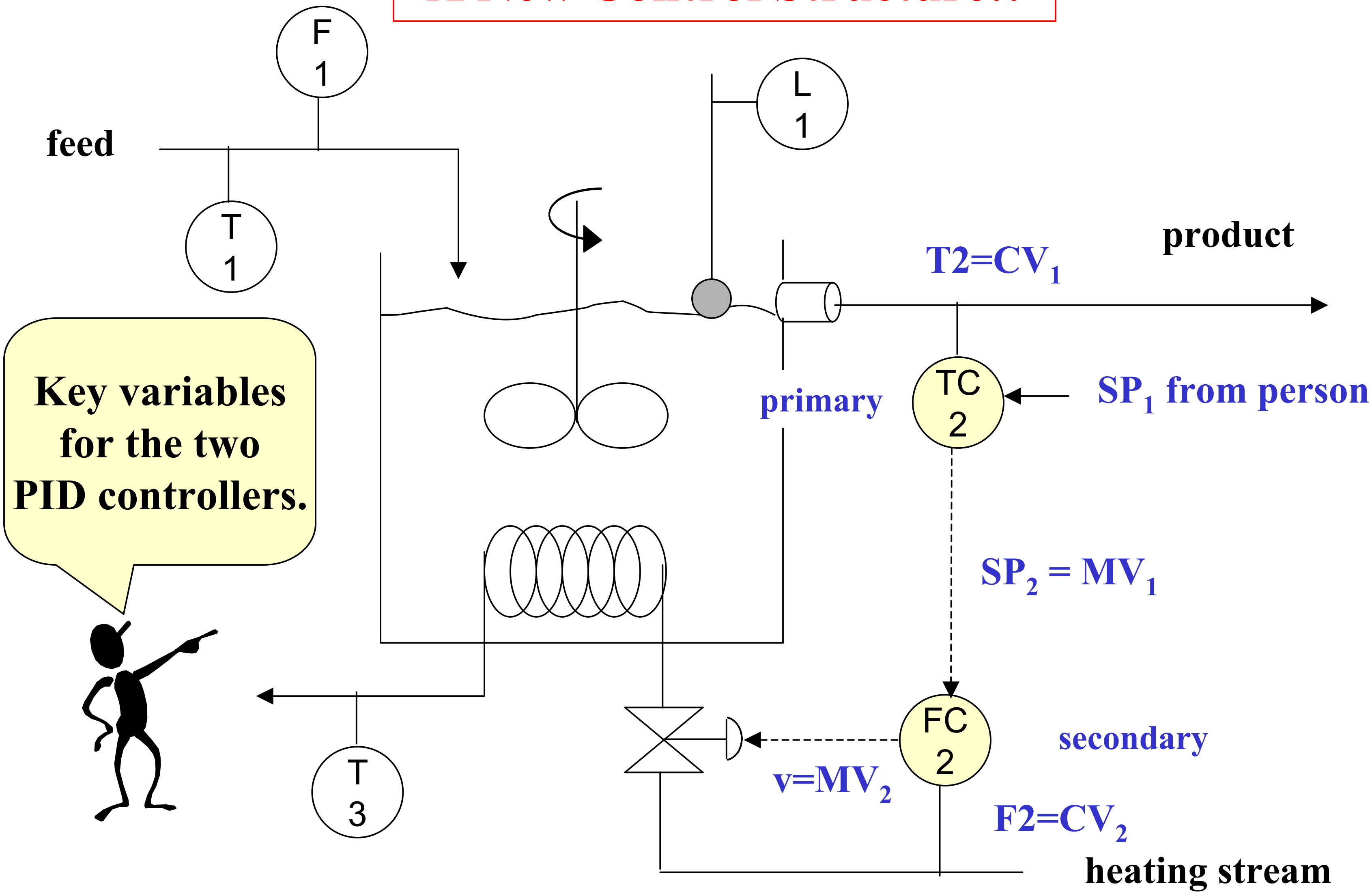
P
(heating oil)

CHAPTER 14: CASCADE CONTROL



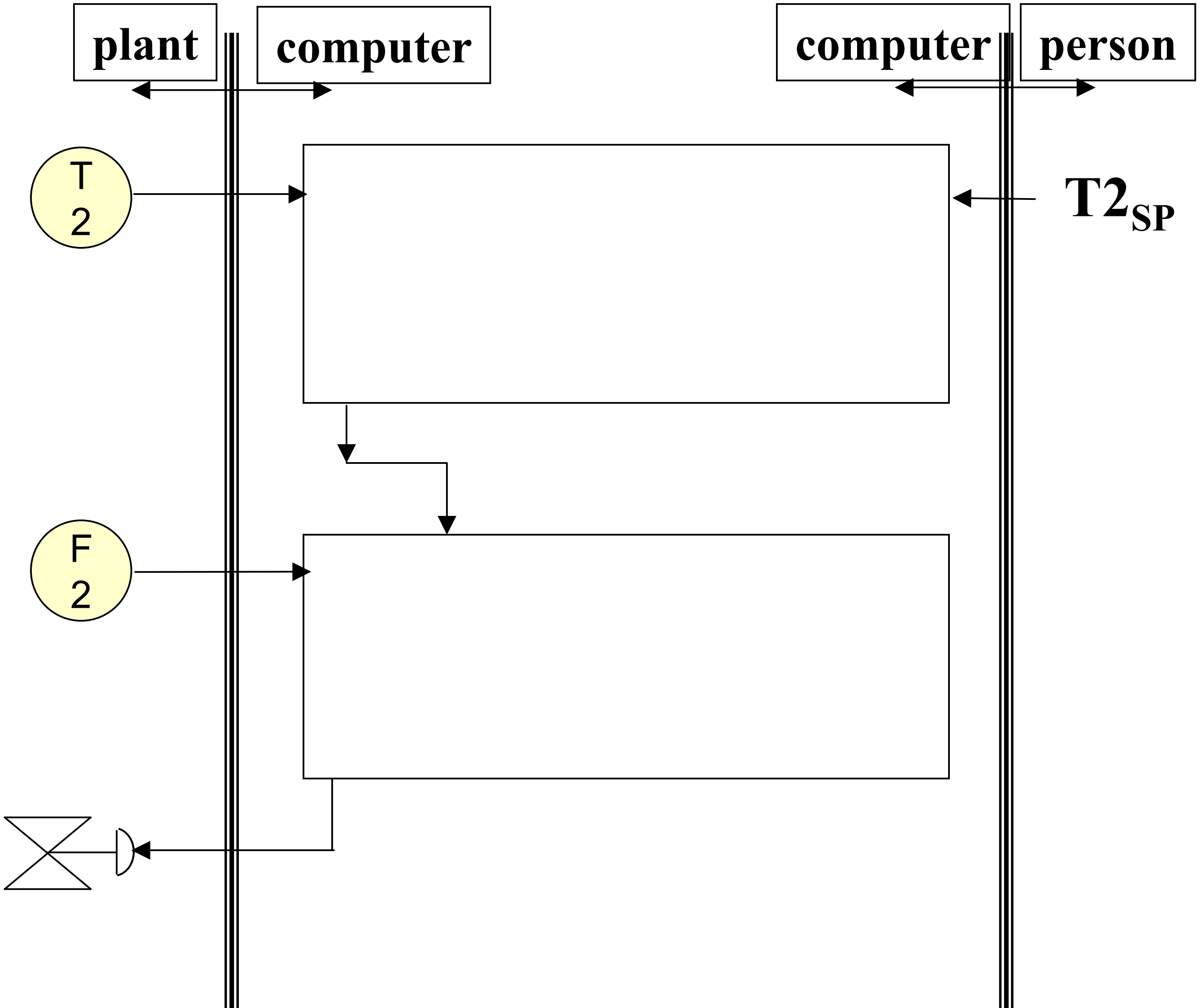
CHAPTER 14: CASCADE CONTROL

A New Control Structure!!

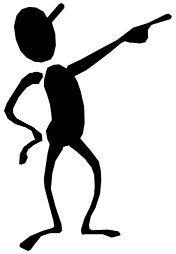


CHAPTER 14: CASCADE CONTROL

Class exercise

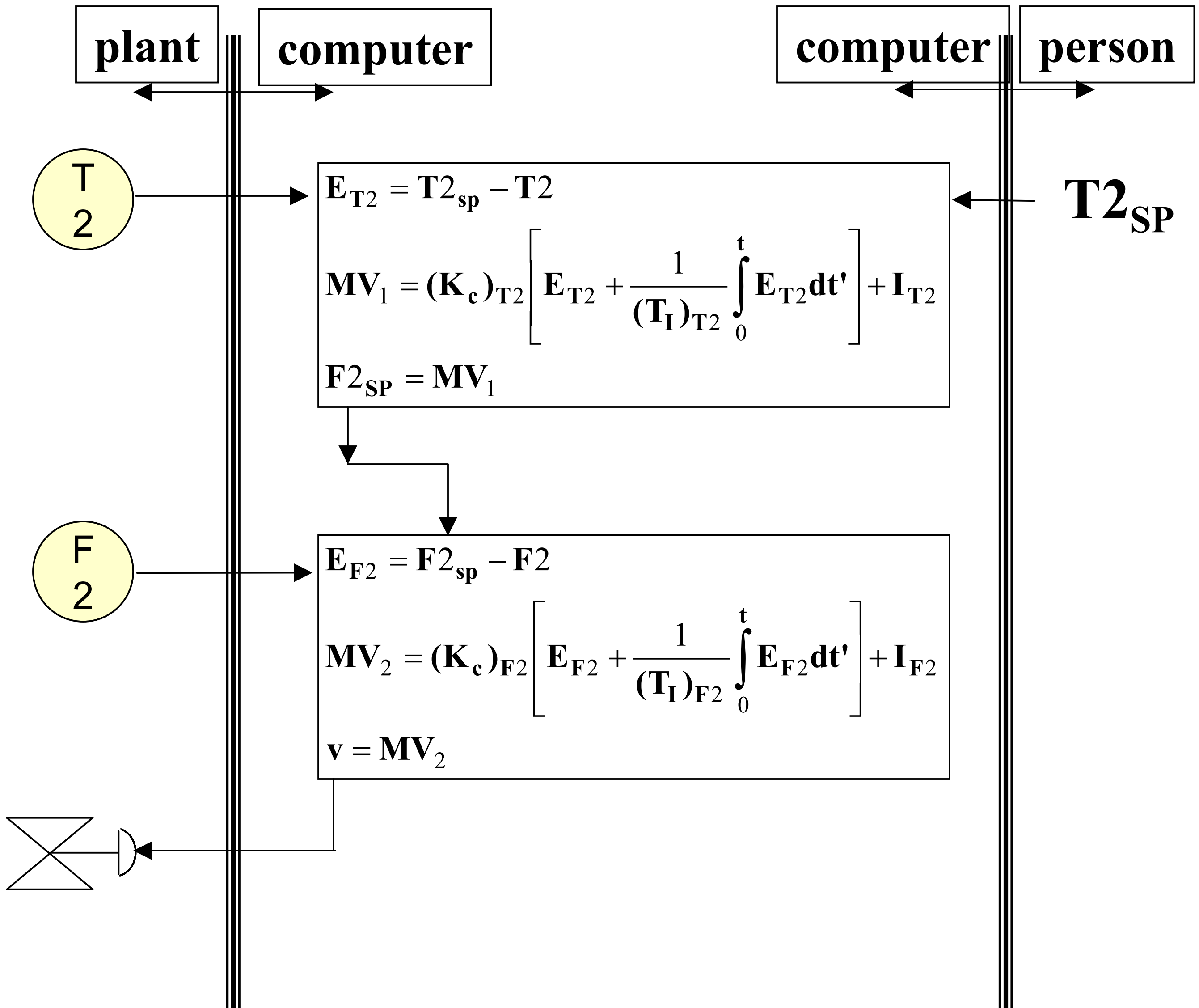


Define the calculations performed in the computer.



CHAPTER 14: CASCADE CONTROL

Class exercise



$$E_{T2} = T2_{sp} - T2$$

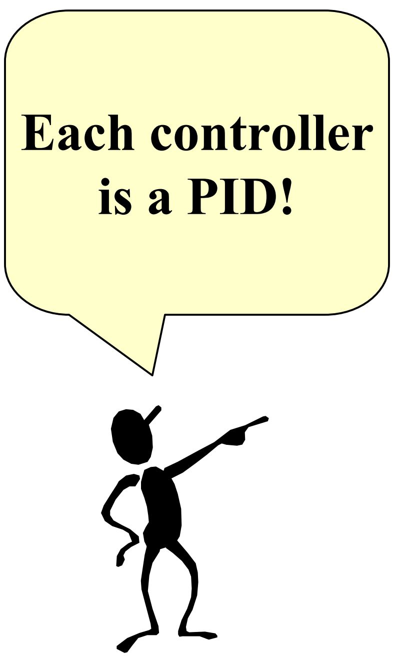
$$MV_1 = (K_c)_{T2}\left[E_{T2} + \frac{1}{(T_I)_{T2}}\int_0^t E_{T2}dt'\right] + I_{T2}$$

$$F2_{SP} = MV_1$$

$$E_{F2} = F2_{sp} - F2$$

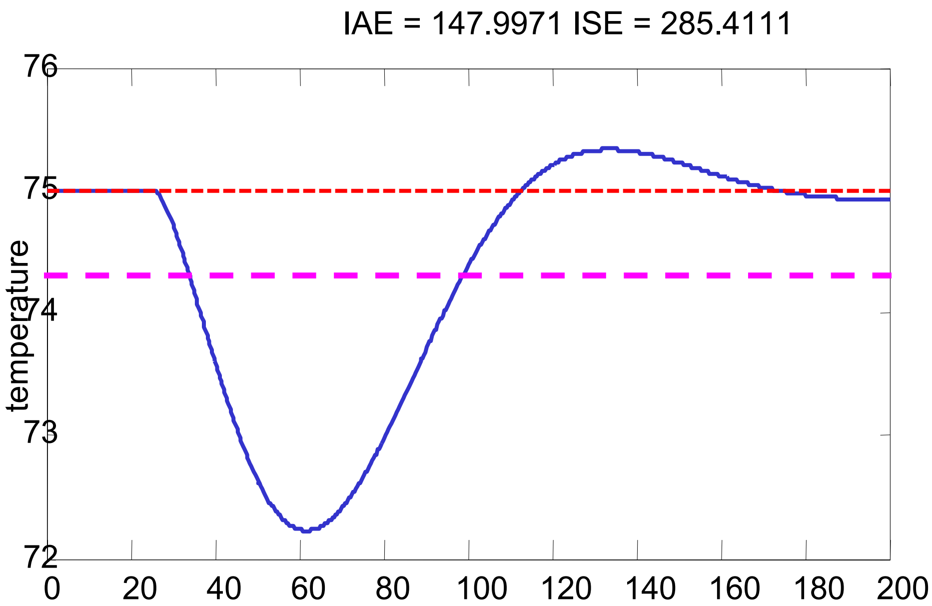
$$MV_2 = (K_c)_{F2}\left[E_{F2} + \frac{1}{(T_I)_{F2}}\int_0^t E_{F2}dt'\right] + I_{F2}$$

$$v = MV_2$$

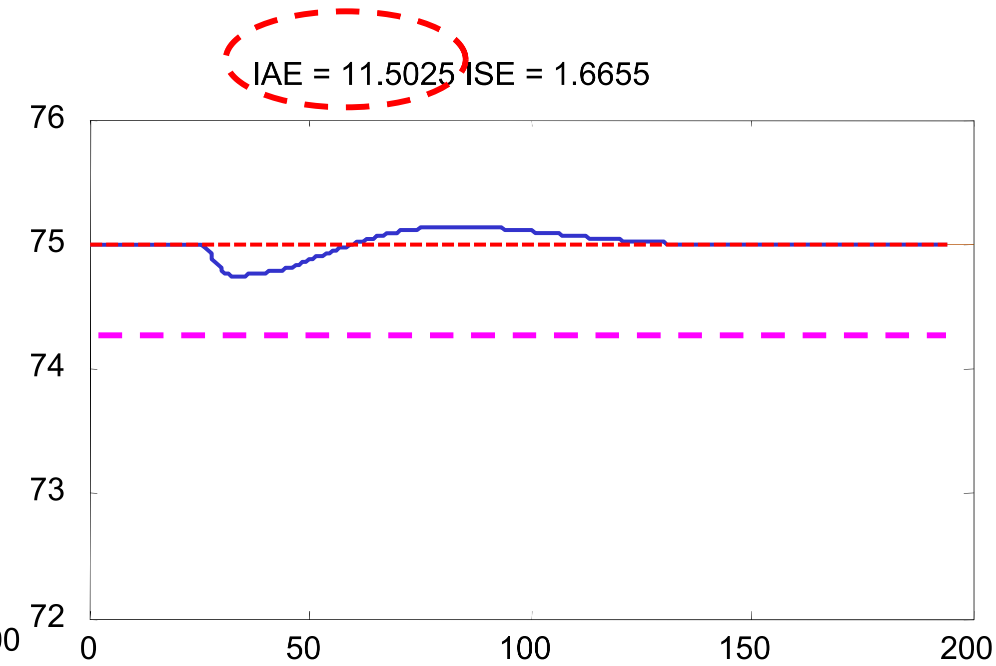


Control Performance Comparison for CST Heater

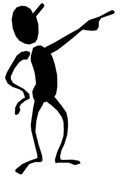
Single-Loop



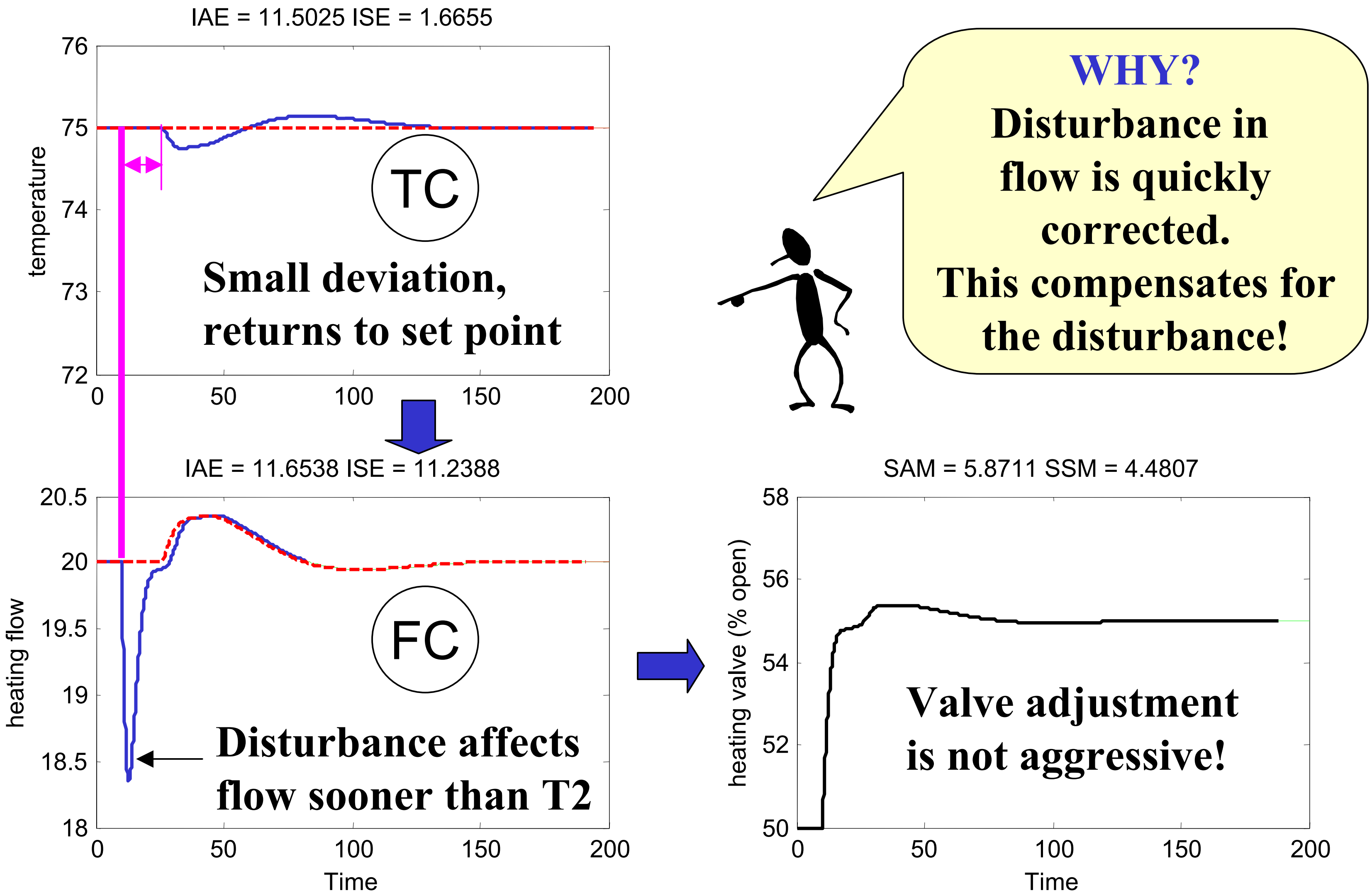
Cascade



Much better performance!
WHY?



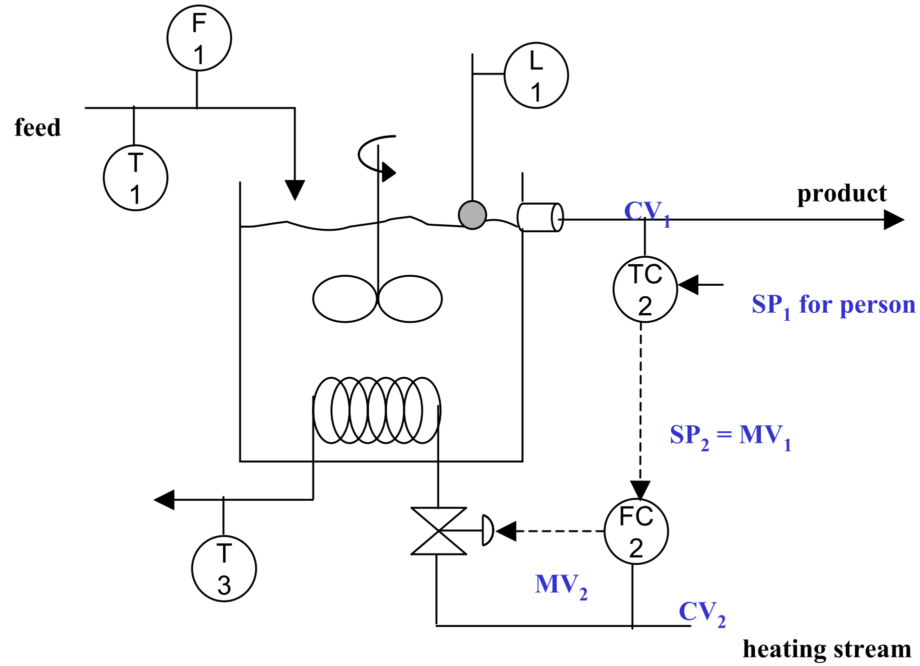
Cascade Control Performance for CST Heater



CHAPTER 14: CASCADE CONTROL

What have we gained and lost using cascade control?

For each case, is cascade better, same, worse than single-loop feedback (TC2 → v)?

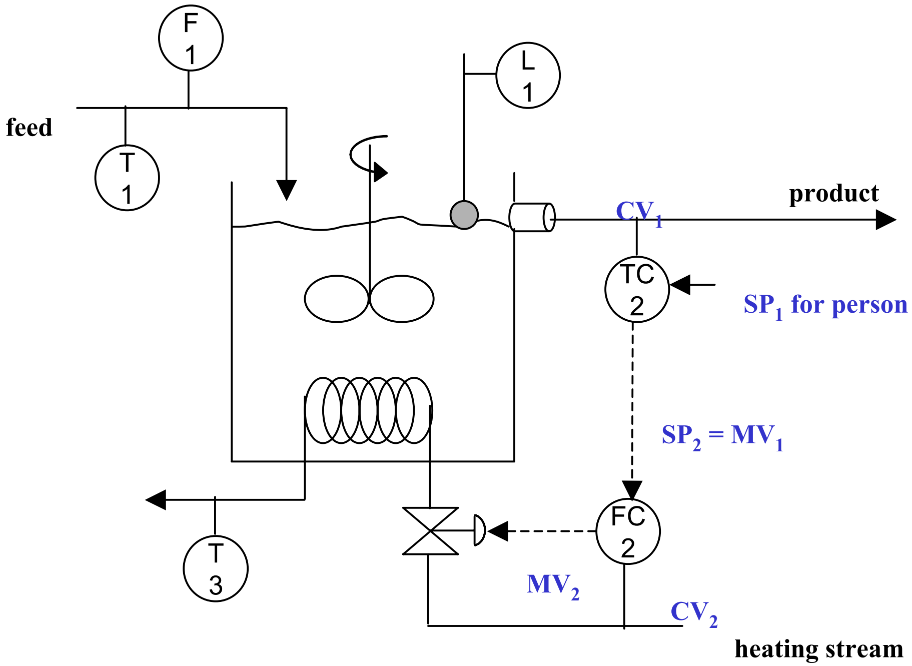


- **A disturbance in heating medium inlet pressure**
- **A disturbance in heating medium inlet temperature**
- **A disturbance in feed flow rate**
- **A change to the TC set point**

CHAPTER 14: CASCADE CONTROL

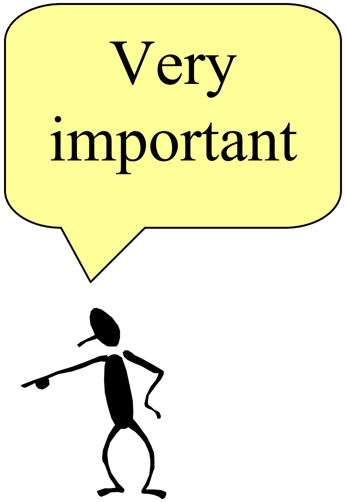
What have we gained and lost using cascade control?

For each case, is cascade better, same, worse than single-loop feedback (TC2 → v)?



- **A disturbance in heating medium inlet pressu** Cascade better
- **A disturbance in heating medium inlet tempe** Both the same
- **A disturbance in feed flow rate** Both the same
- **A change to the TC set point** Both the same

CHAPTER 14: CASCADE CONTROL



CASCADE DESIGN CRITERIA

Cascade is desired when

1. **Single-loop performance unacceptable**
2. **A measured variable is available**

A secondary variable must

3. **Indicate the occurrence of an important disturbance**
4. **Have a causal relationship from valve to secondary (cause → effect)**
5. **Have a faster response than the primary**

CHAPTER 14: CASCADE CONTROL

ADVANTAGES OF CASCADE CONTROL

- **Large improvement in performance when the secondary is much faster than primary**
- **Simple technology with PID algorithms**
- **Use of feedback at all levels. Primary has zero offset for "step-like" disturbances.**
- **Plant operating personnel find cascades easy to operate. Open a cascade at one level, and all controllers above are inactive.**

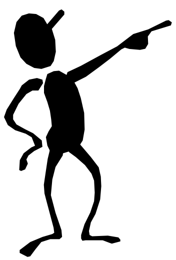
CHAPTER 14: CASCADE CONTROL

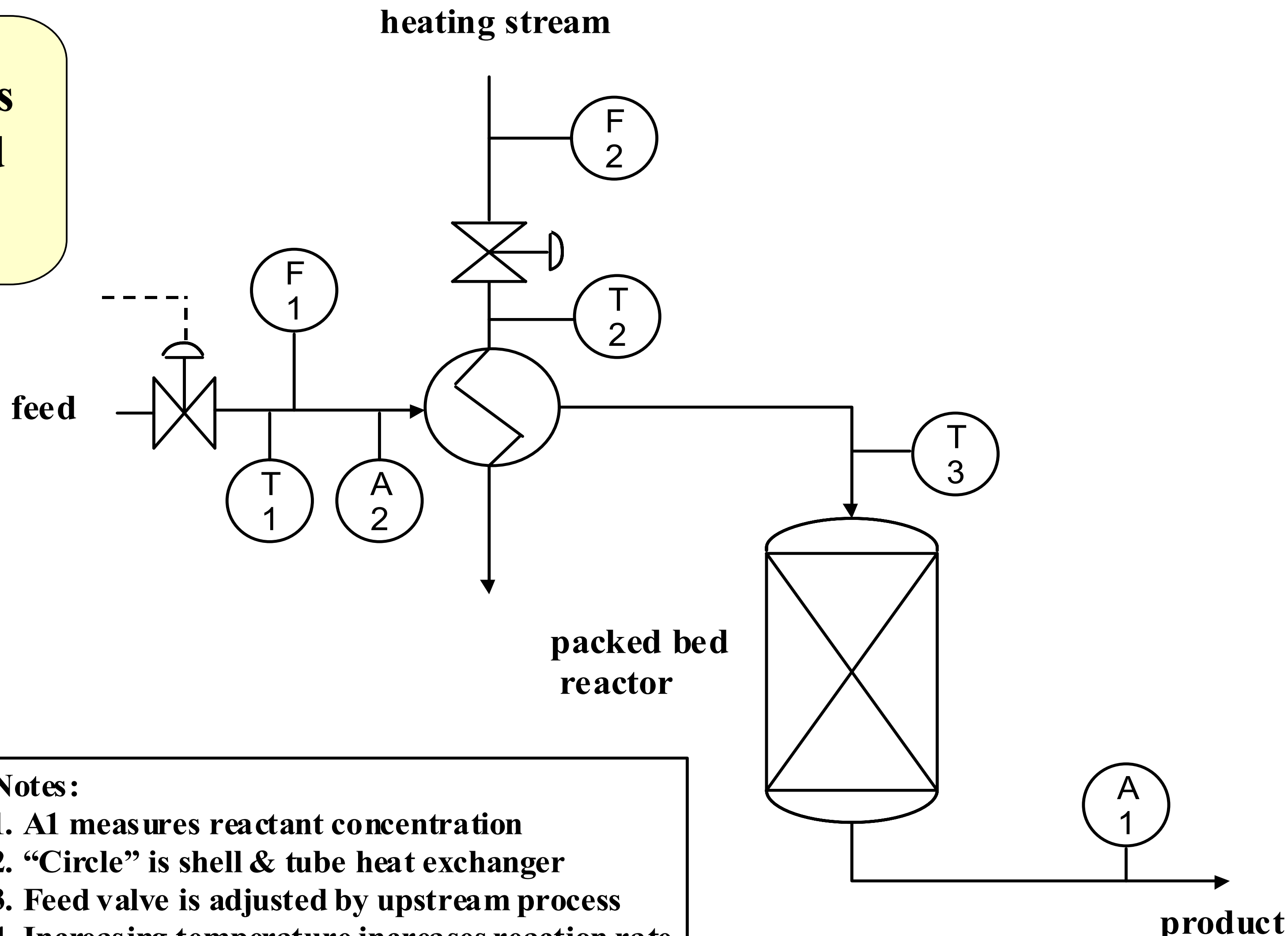
CLASS EXERCISE: SOME QUESTIONS ABOUT CASCADE CONTROL

- **Why do we retain the primary controller?**
- **Which modes are required for zero steady-state offset?**
- **Which modes are recommended?**
- **What is the additional cost for cascade control?**
- **Normally, each PID controller represents one independent controlled variable. Is anything different in a cascade structure?**
- **What procedure is used for tuning cascade control?**

CHAPTER 14: CASCADE CONTROL

Discuss this packed bed reactor.

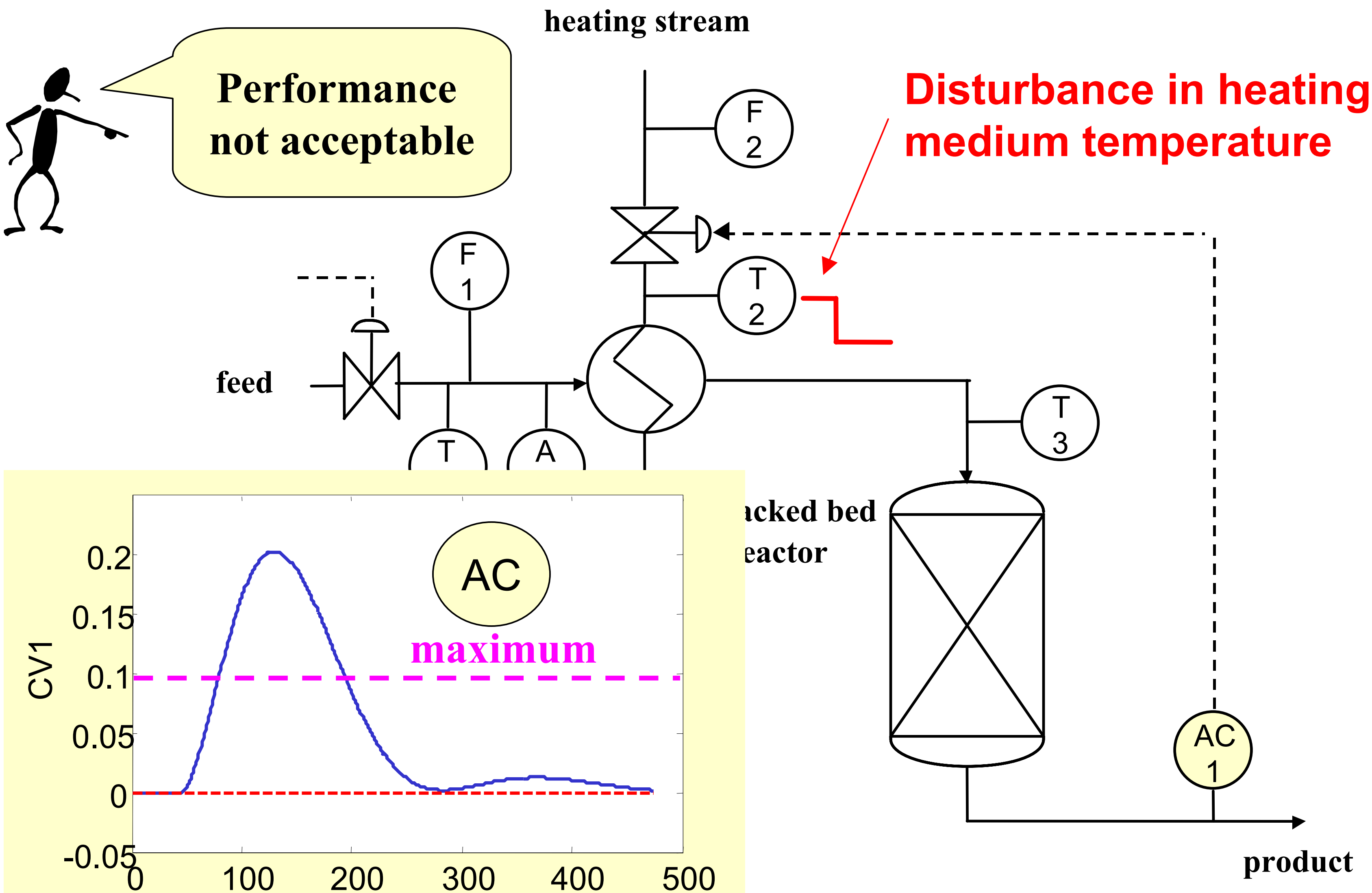




Notes:
1. A1 measures reactant concentration
2. "Circle" is shell & tube heat exchanger
3. Feed valve is adjusted by upstream process
4. Increasing temperature increases reaction rate

CHAPTER 14: CASCADE CONTROL

Class exercise: **Design a cascade control structure to improve performance.**

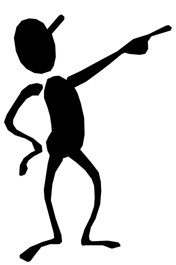


CHAPTER 14: CASCADE CONTROL

Class exercise: Design a cascade control structure to improve performance.

Cascade design criteria	A2	F1	F2	T1	T2	T3
1. Single-loop not acceptable						
2. Secondary variable is measured						
3. Indicates a key disturbance						
4. Causal relationship, valve → secondary						
5. Secondary dynamics faster than primary						

Let's use the cascade design rules!



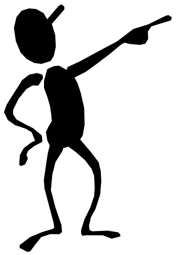
Remember: The disturbance is the heating medium inlet temperature and the primary is AC-1.

CHAPTER 14: CASCADE CONTROL

Class exercise: Design a cascade control structure to improve performance.

Cascade design criteria	A2	F1	F2	T1	T2	T3
1. Single-loop not acceptable	Y	Y	Y	Y	Y	Y
2. Secondary variable is measured	Y	Y	Y	Y	Y	Y
3. Indicates a key disturbance	N	N	N	N	Y	Y
4. Causal relationship, valve → secondary	N	N	Y	N	N	Y
5. Secondary dynamics faster than primary	N/A	N/A	N/A	N/A	N/A	Y

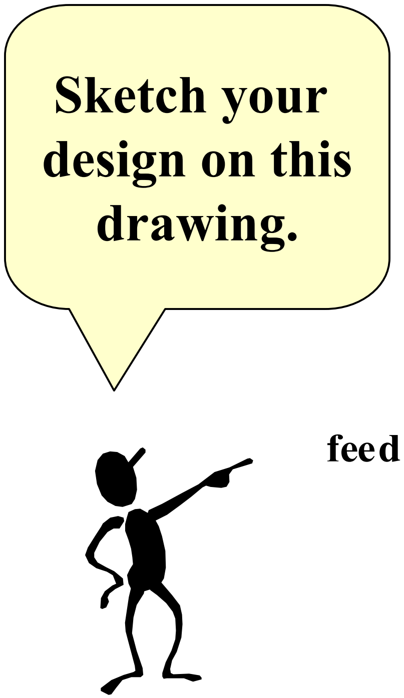
Let's use the cascade design rules!

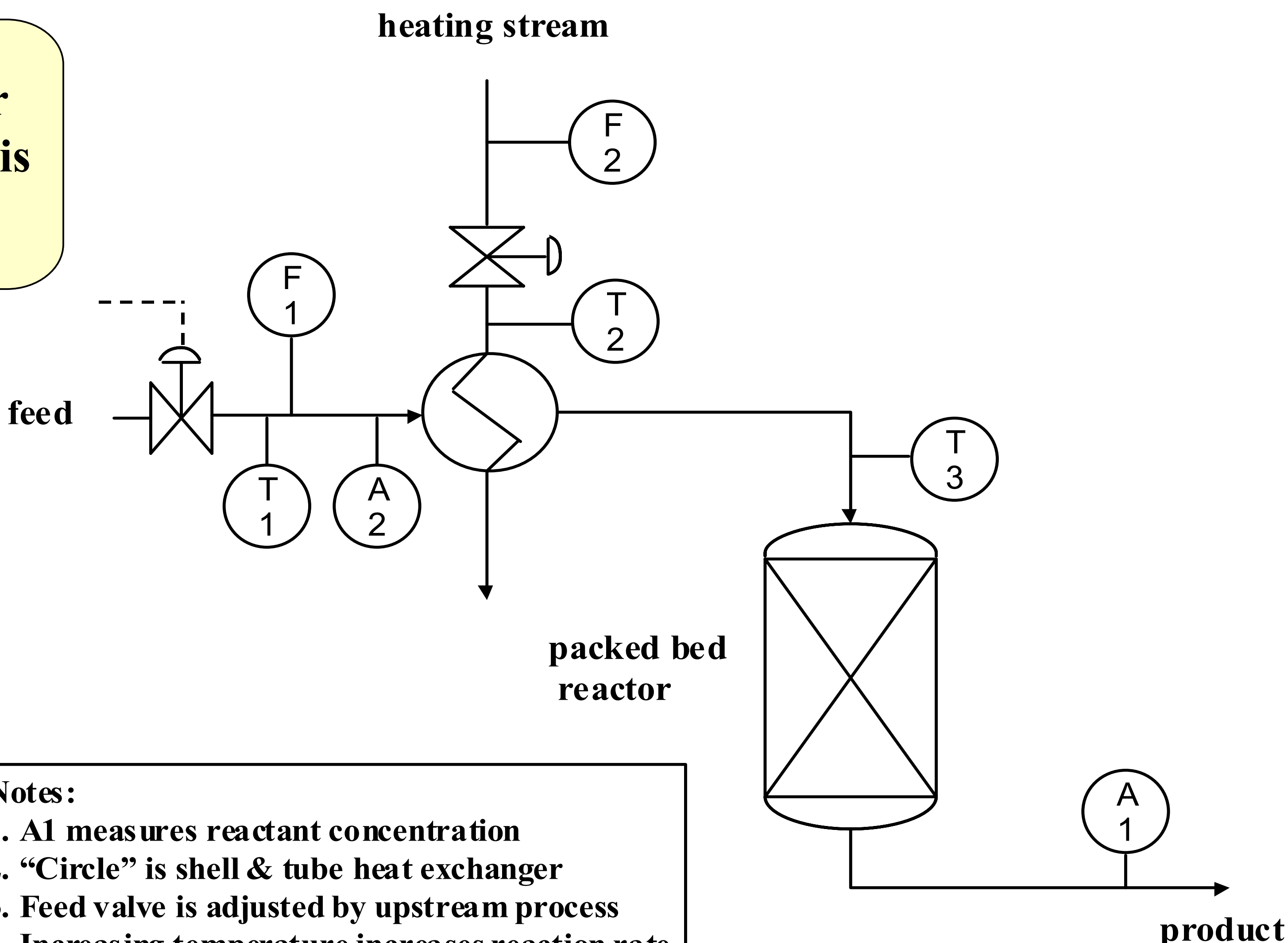


T2 is the disturbance but cannot be used in cascade!

T3 satisfies all of the rules and can be used as a secondary in a cascade.

CHAPTER 14: CASCADE CONTROL





Notes:
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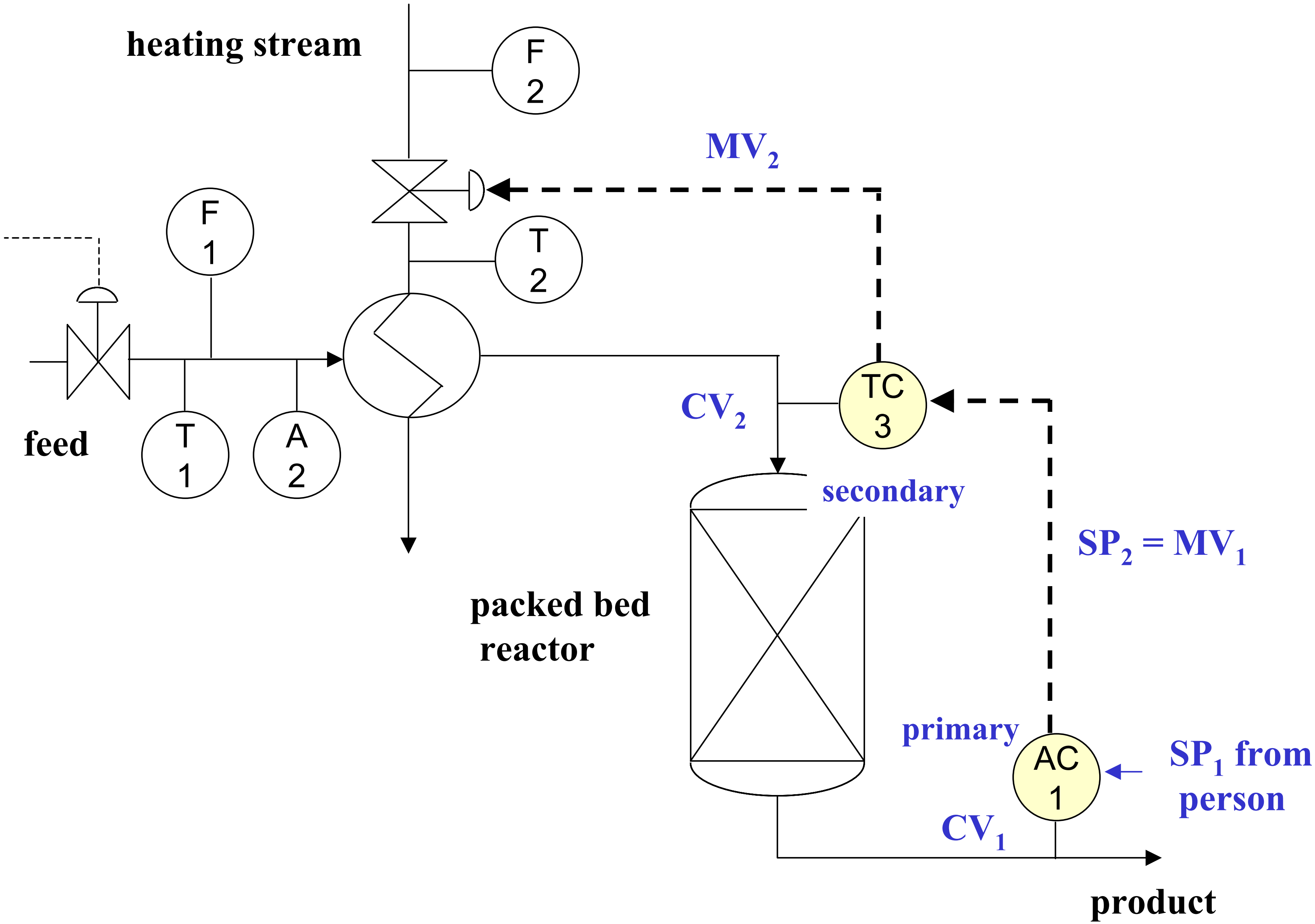
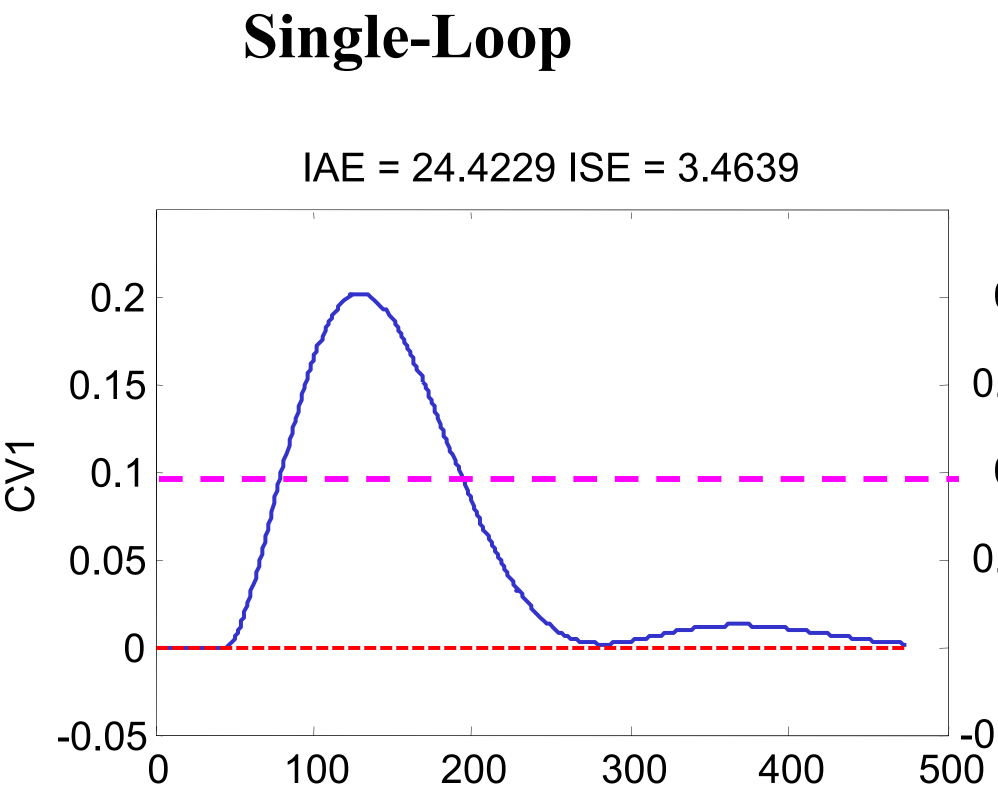
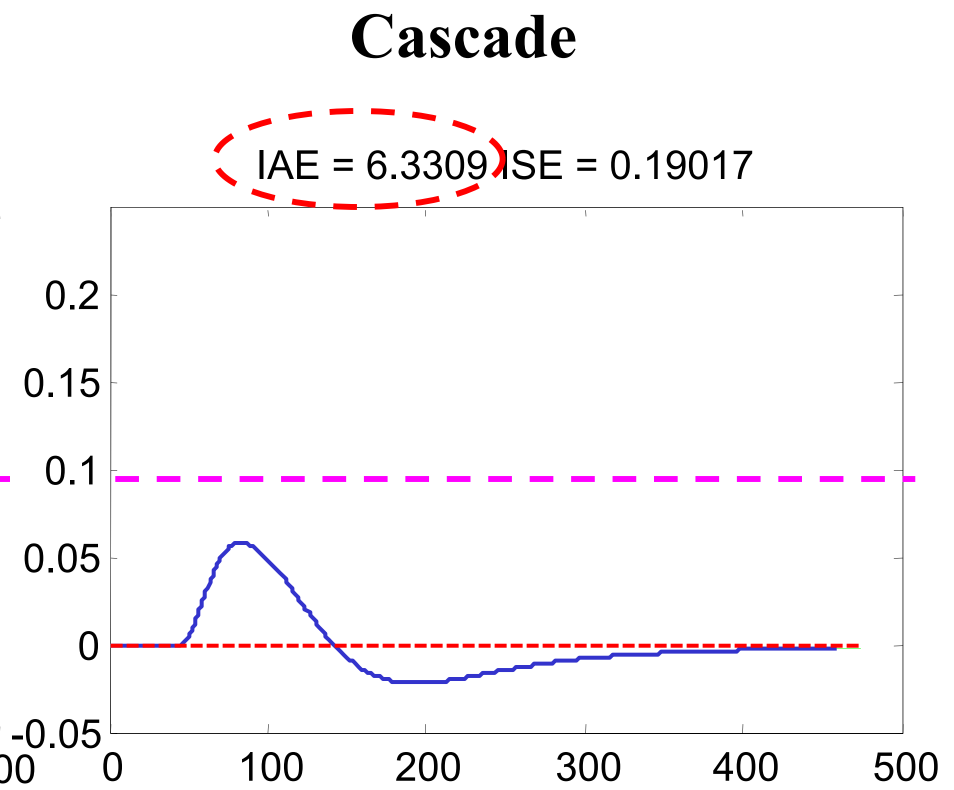
CHAPTER 14: CASCADE CONTROL

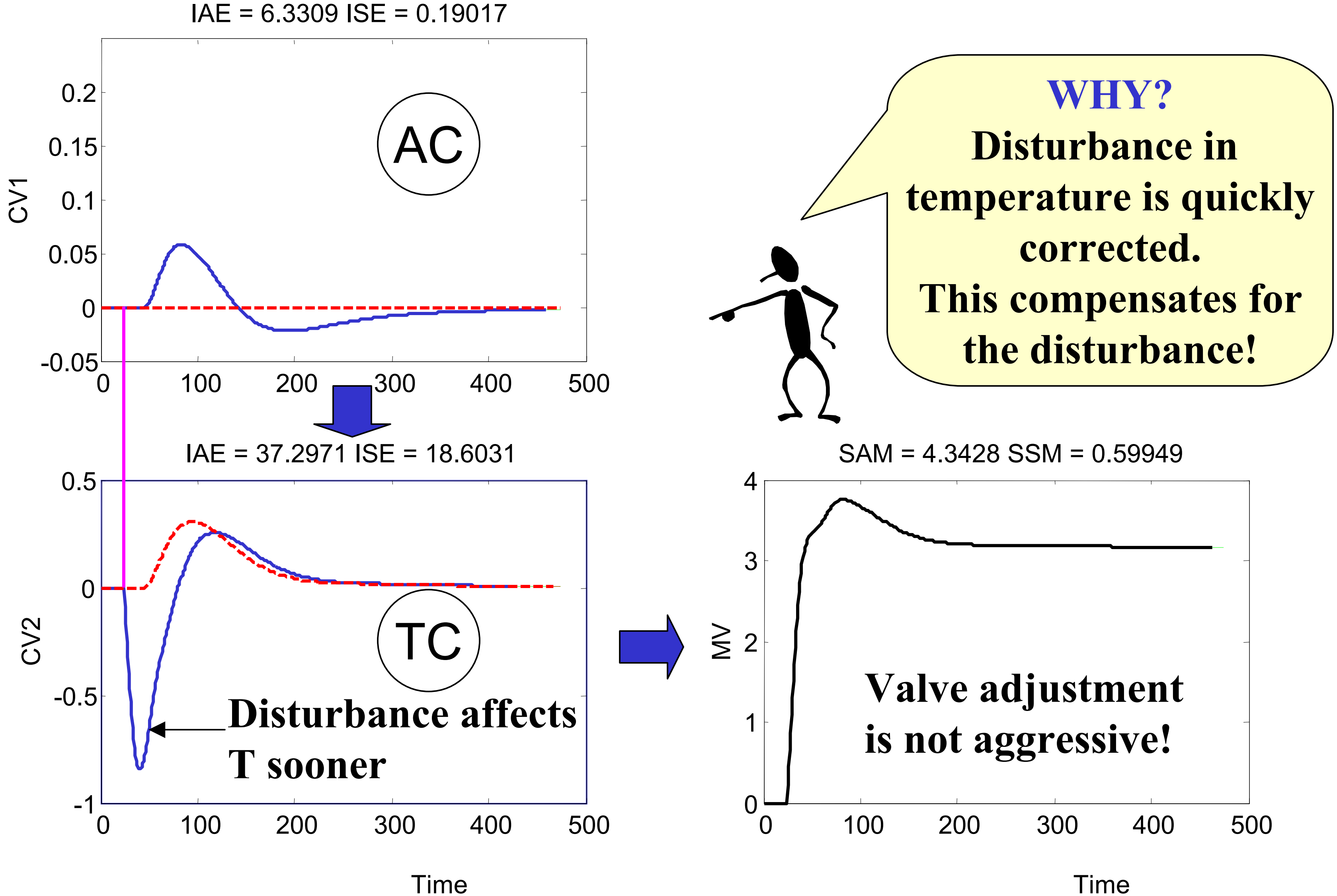


Control Performance Comparison for Packed Bed Reactor





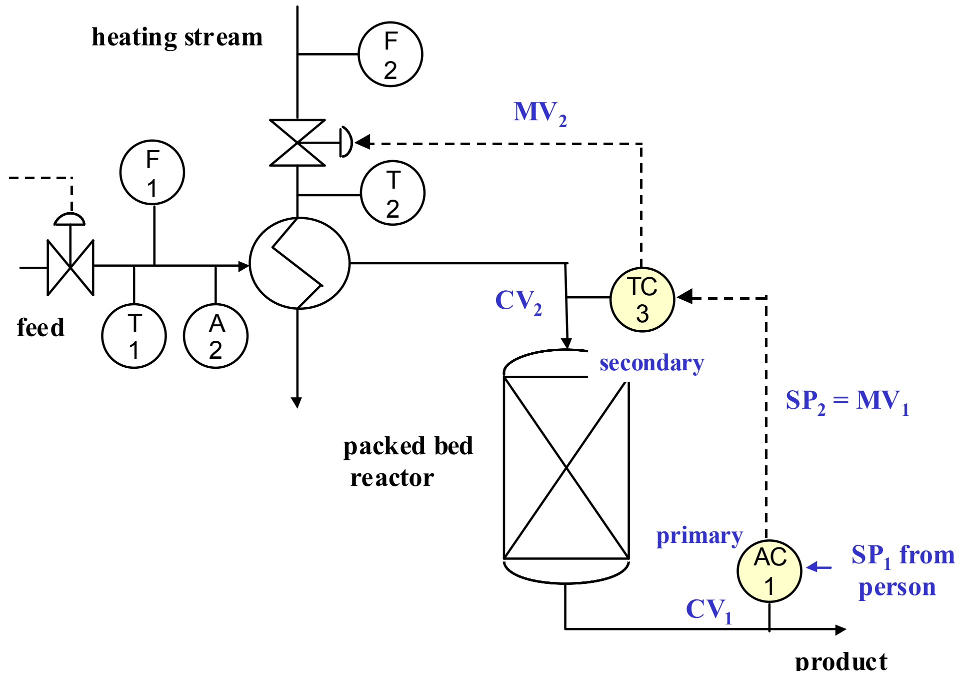
Cascade Control Performance for Packed Bed Reactor



CHAPTER 14: CASCADE CONTROL

What have we gained and lost using cascade control?

How does the system respond to the following?



- A disturbance in T1
- A disturbance in heating medium inlet pressure
- A disturbance in feed pressure
- A disturbance to feed composition, A2
- A change to the AC-1 set point

CHAPTER 14: CASCADE CONTROL

What have we **gained and lost** using cascade control?

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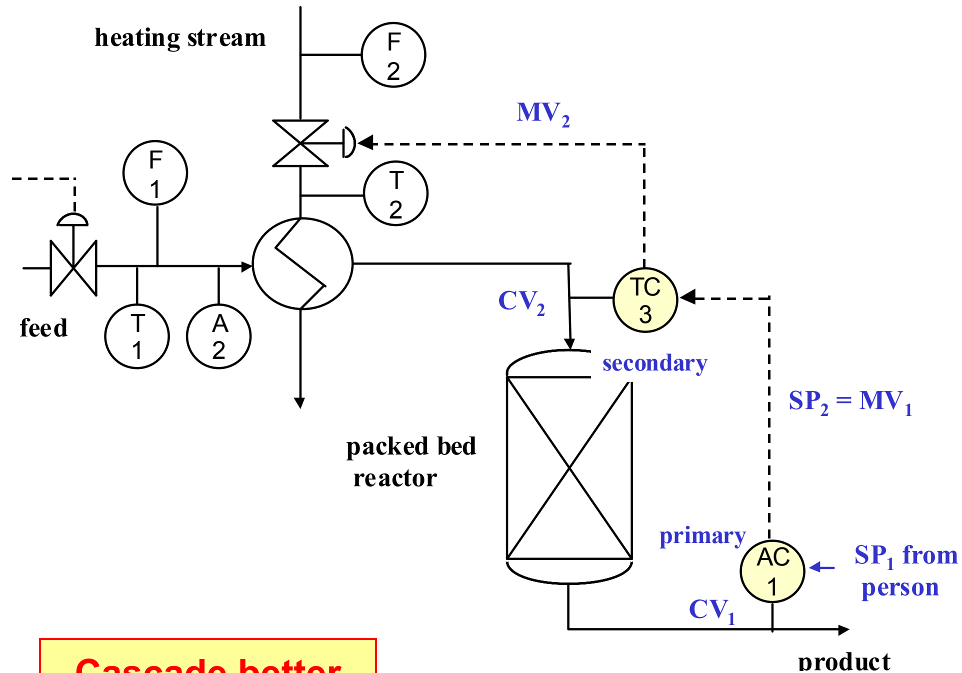
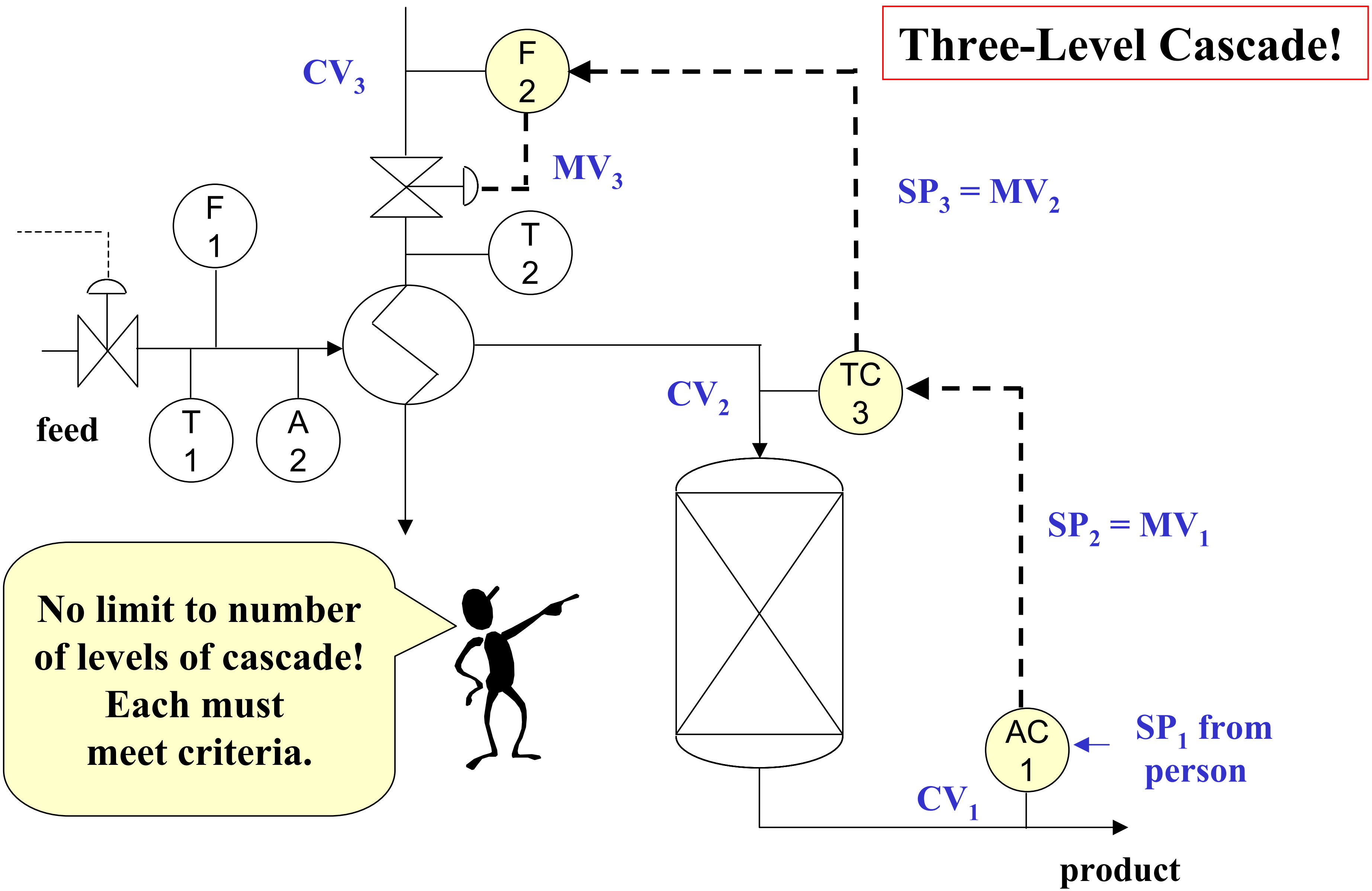


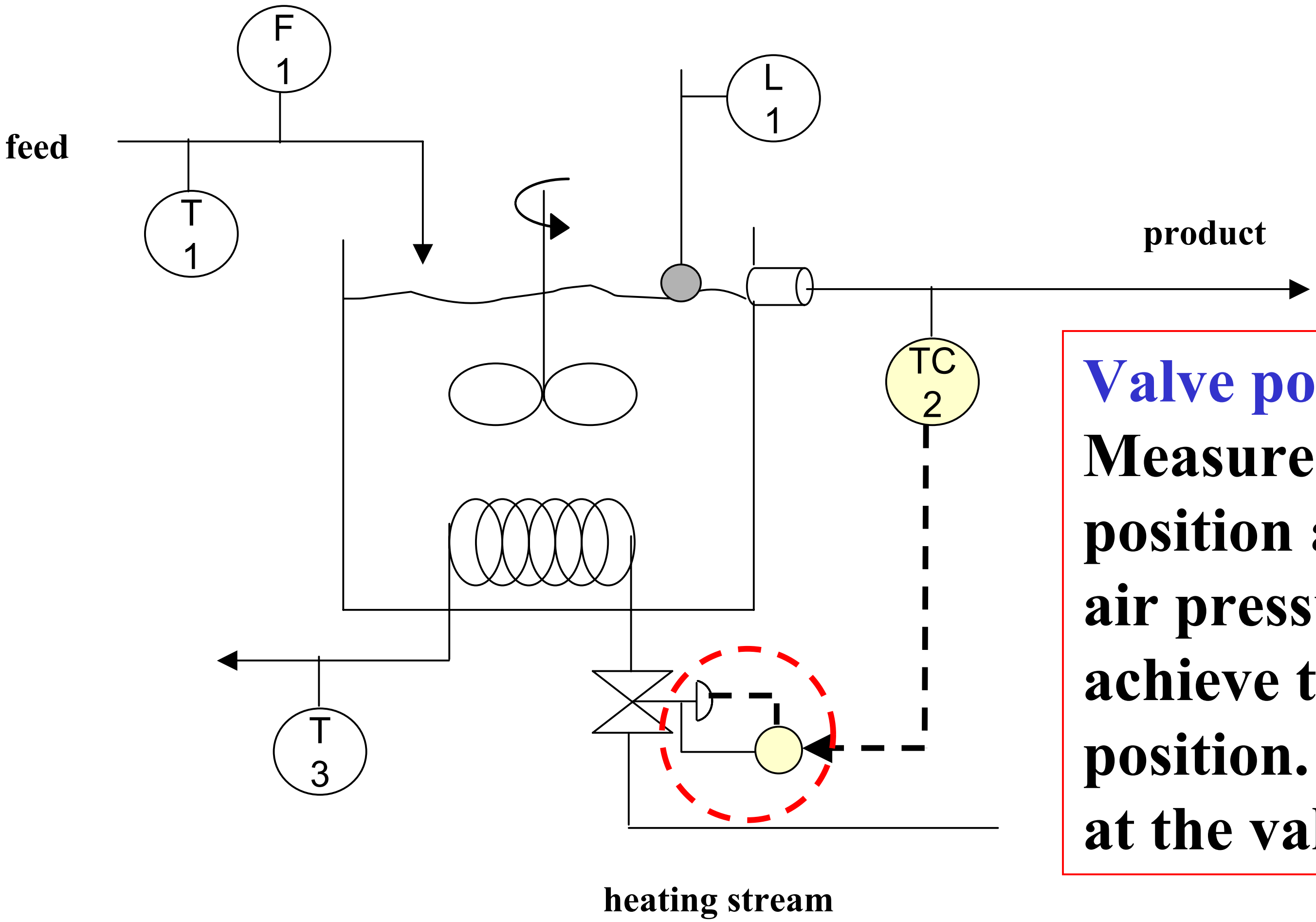
- A disturbance in T1 — Cascade better
- A disturbance in heating medium inlet pressure — Cascade better
- A disturbance in feed pressure — Cascade better, but not “perfect”
- A disturbance to feed composition, A2 — Both the same
- A change to the AC-1 set point — Both the same

CHAPTER 14: CASCADE CONTROL



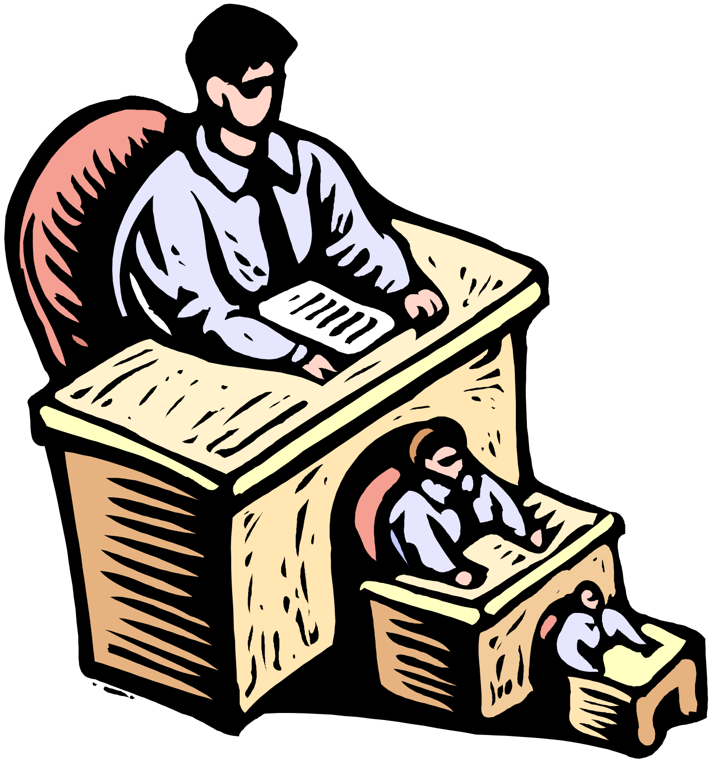
CHAPTER 14: CASCADE CONTROL

Does cascade apply to instrumentation? Yes, a valve positioner is a secondary that reduces effects of friction!!



Valve positioner: Measures the stem position and adjusts the air pressure to (closely) achieve the desired position. This is located at the valve.

CHAPTER 14: CASCADE CONTROL



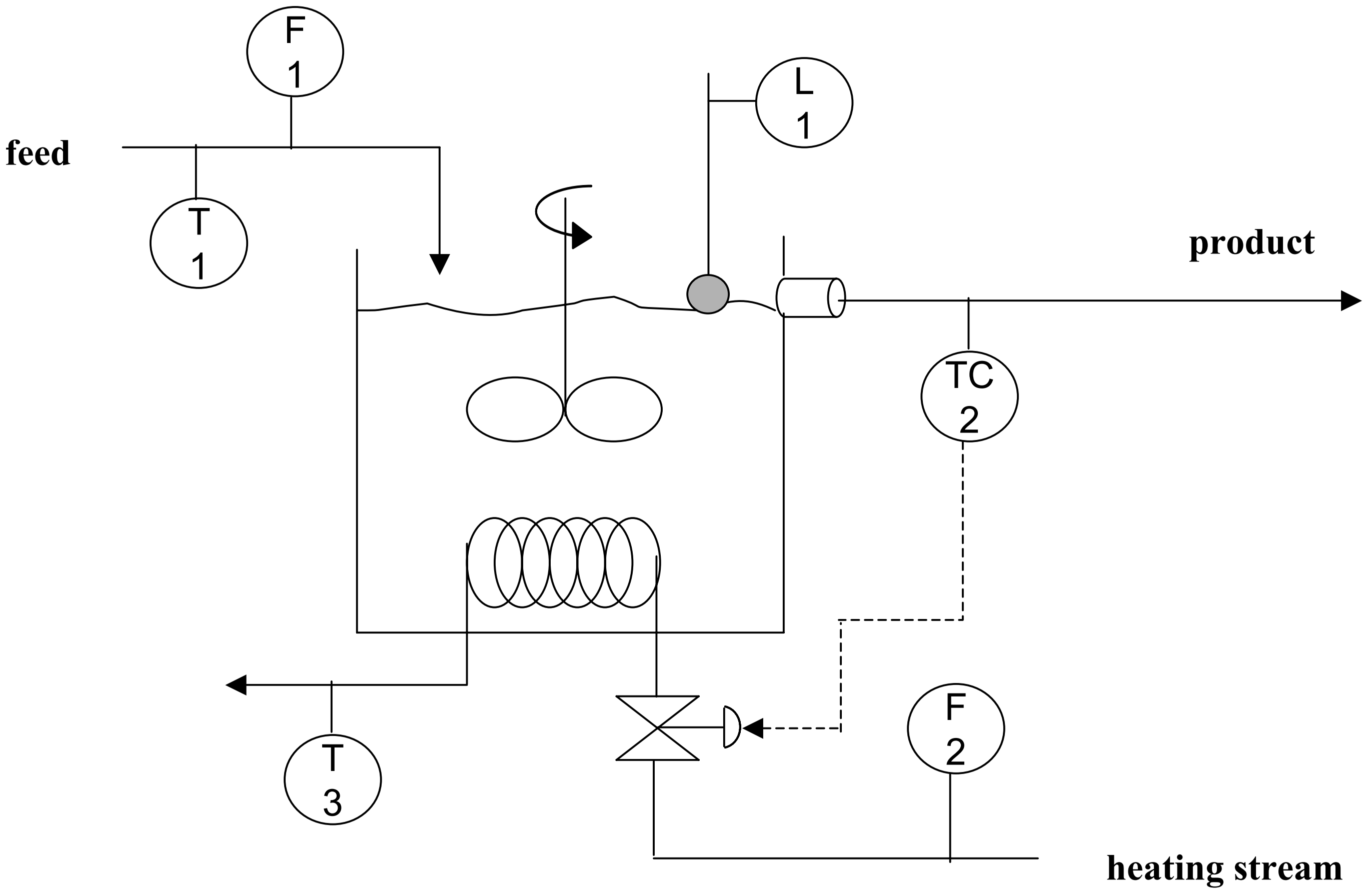
A cascade is a hierarchy, with decisions transmitted from upper to lower levels.

No communication flows up the hierarchy.

- **What are advantages of a hierarchy?**
- **What information should be transmitted up the hierarchy?**
- **What information should flow from secondary to primary in a cascade?**

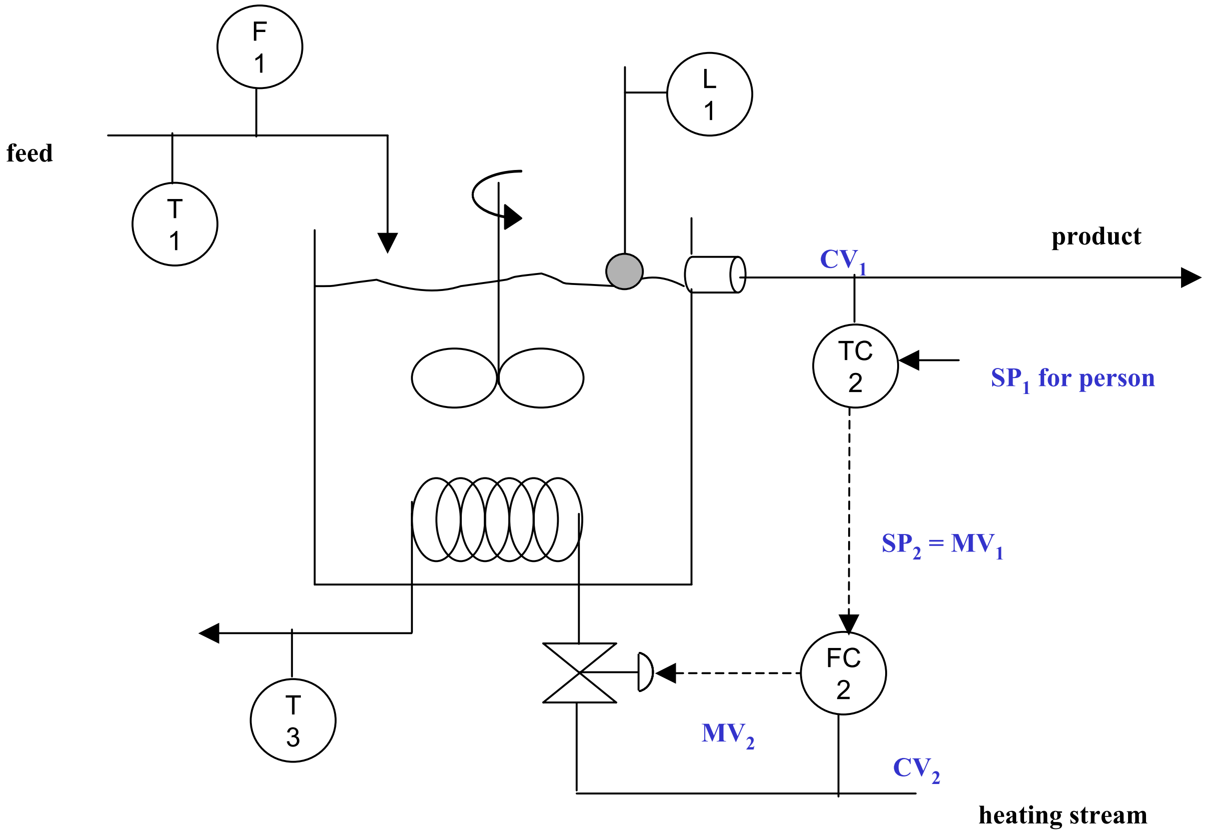
CHAPTER 14: CASCADE CONTROL WORKSHOP 1

Evaluate cascade control for a disturbance in the heating medium inlet temperature. You may add a sensor but make no other changes to the equipment.



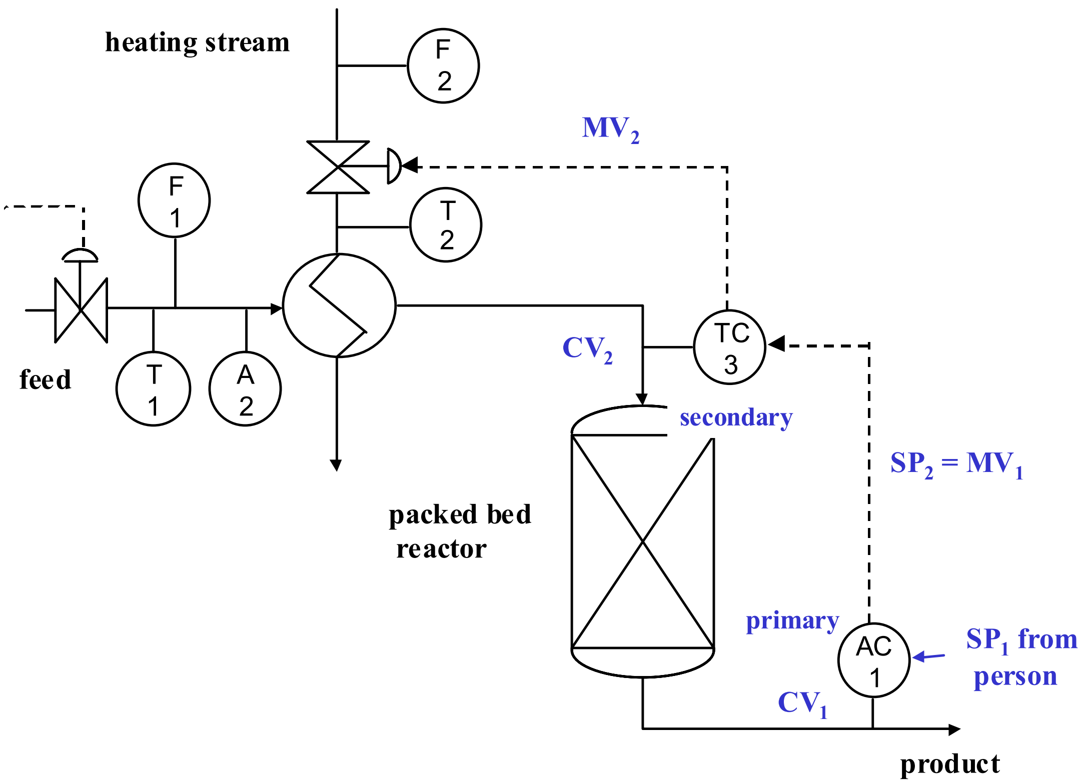
CHAPTER 14: CASCADE CONTROL WORKSHOP 2

Prepare a detailed plan for tuning the two cascade controllers shown in the following sketch.



CHAPTER 14: CASCADE CONTROL WORKSHOP 3

Prepare a flowchart for the calculations performed by the packed bed cascade controllers. Show every calculation and use process variable symbols (e.g., A1), not generic symbols (CV_1).



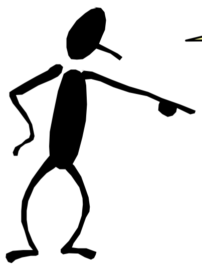
CHAPTER 14: CASCADE CONTROL WORKSHOP 4

Identify process examples in which a valve positioner will improve performance and not improve performance.

Draw a sketch of each process and discuss your recommendation of whether or not to use a positioner.

Note: **Modern positioners provide diagnosis of the valve behavior that can be transmitted digitally for later evaluation. This can be very useful in maintenance and trouble shooting.**

CHAPTER 14: CASCADE CONTROL



When I complete this chapter, I want to be able to do the following.

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- **Design cascade control using the five design rules**
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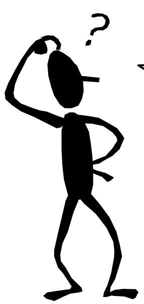

Lot's of improvement, but we need some more study!

- **Read the textbook**
- **Review the notes, especially learning goals and workshop**
- **Try out the self-study suggestions**
- **Naturally, we'll have an assignment!**

CHAPTER 14: LEARNING RESOURCES

- **SITE PC-EDUCATION WEB**
  - Instrumentation Notes
  - Interactive Learning Module (Chapter 14)
  - Tutorials (Chapter 14)

- **S_LOOP**
  - Dynamic simulation of linear system

- **The Textbook, naturally, for many more examples**

CHAPTER 14: SUGGESTIONS FOR SELF-STUDY

1. **Prove that an integral mode is required for zero steady-state offset of the primary.**

   Do we achieve zero offset for the secondary. Why or why not?

   Is there any advantage for achieving zero offset for the secondary?

2. **Program a cascade control for one of the processes modelled in Chapters 3-5.**

3. **Determine a guideline for how much faster the secondary must be than the primary for cascade to function well.**

CHAPTER 14: SUGGESTIONS FOR SELF-STUDY

4. **Using block diagram algebra, derive the transfer functions in textbook equations (14.6) to (14.8).**

5. **Review the following publication to find other advantages for cascade control.**

   Verhaegen, S., When to use cascade control, *Intech*, 38-40 (Oct. 1991).

6. **Discuss applications of cascade control (hierarchical decision systems) in business, government, and university. Explain advantages and disadvantages of these systems.**