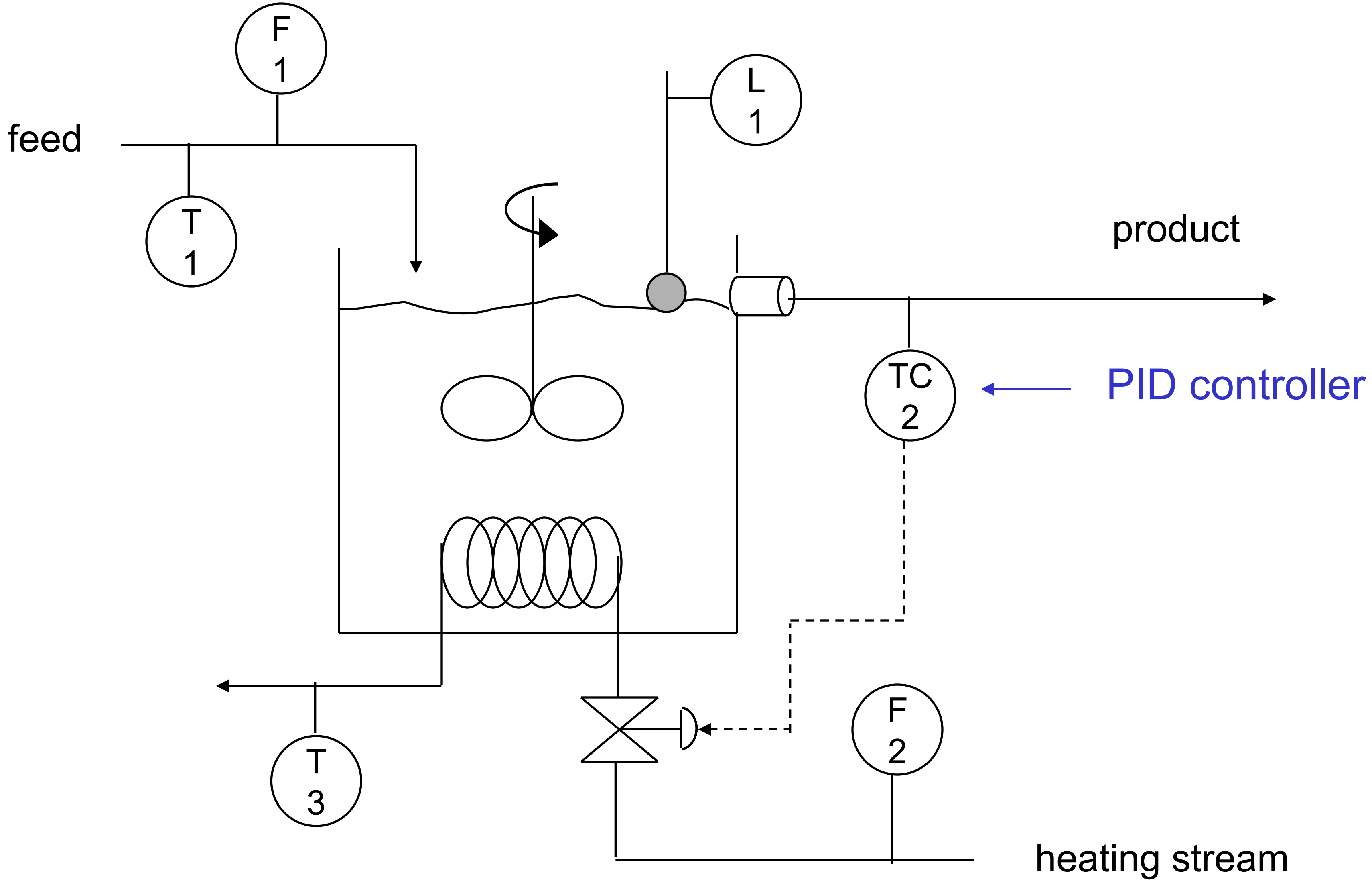
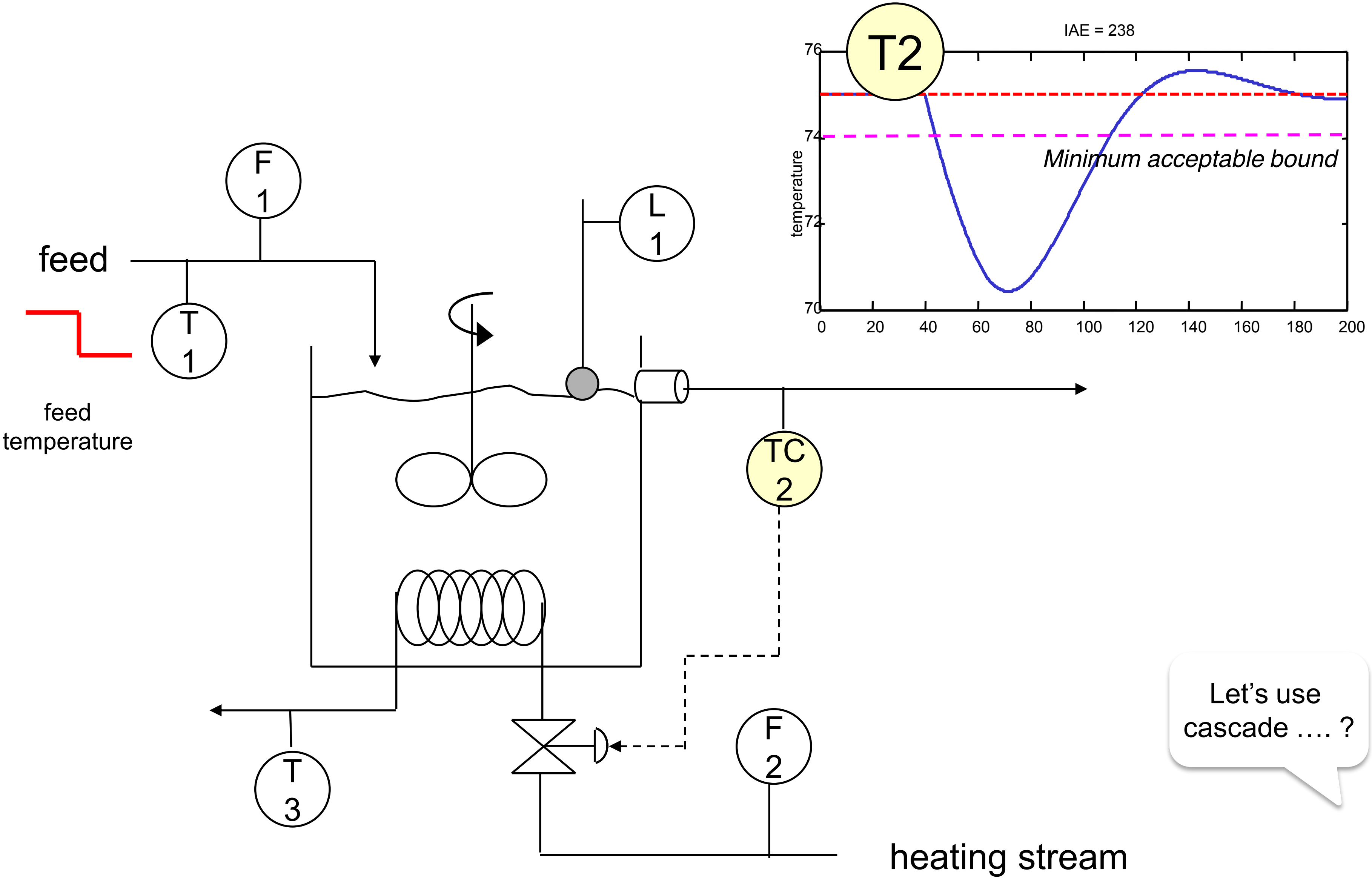
These slides are from Dr. Thomas Marlin


F
1
feed
T
1
L
1
product
TC
2
PID controller
F
2
T
3
heating stream



Let's use cascade …. ?

Check the cascade control criteria for T1

Cascade is desired when

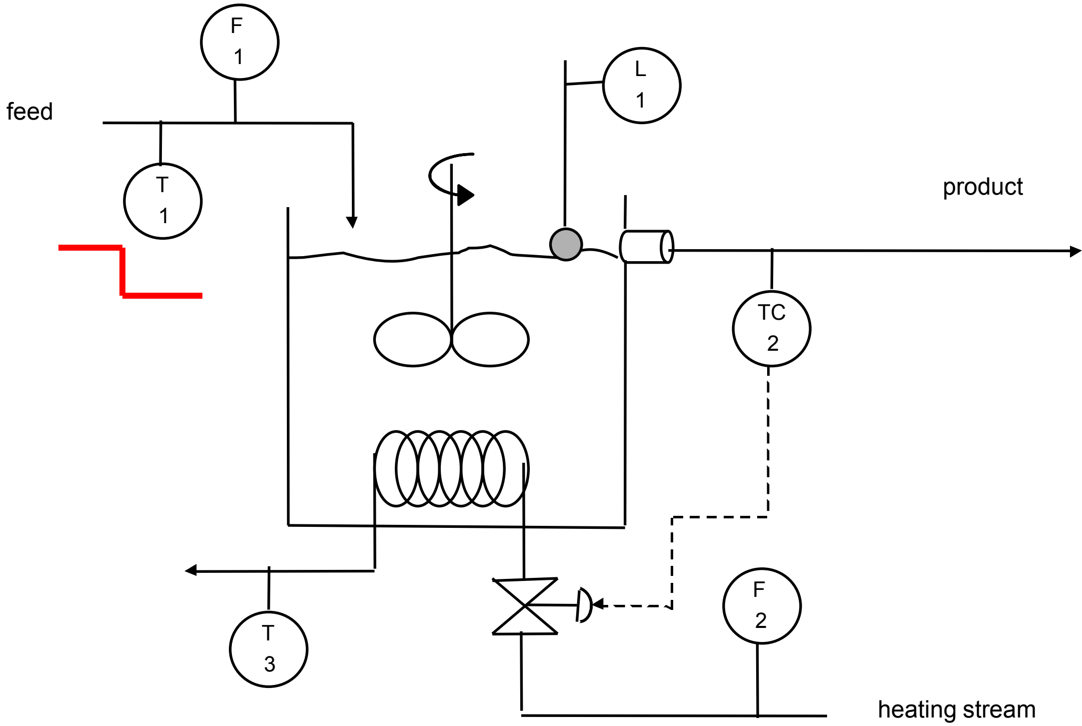
1. Single-loop performance unacceptable
2. A measured variable is available

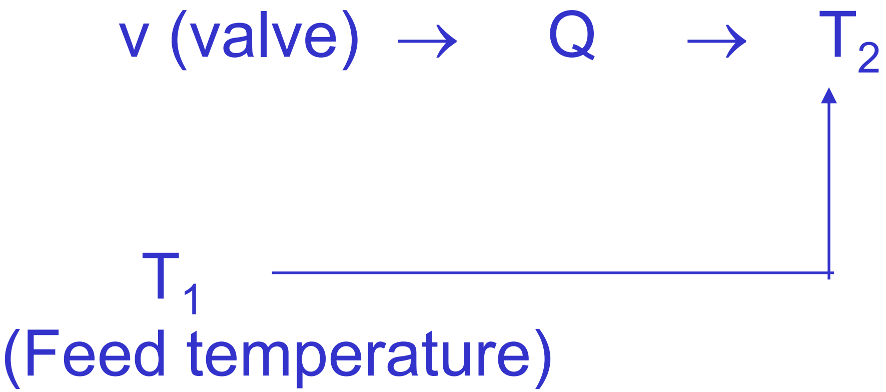
A secondary variable must

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’s response

Let’s think about the process behaviour.

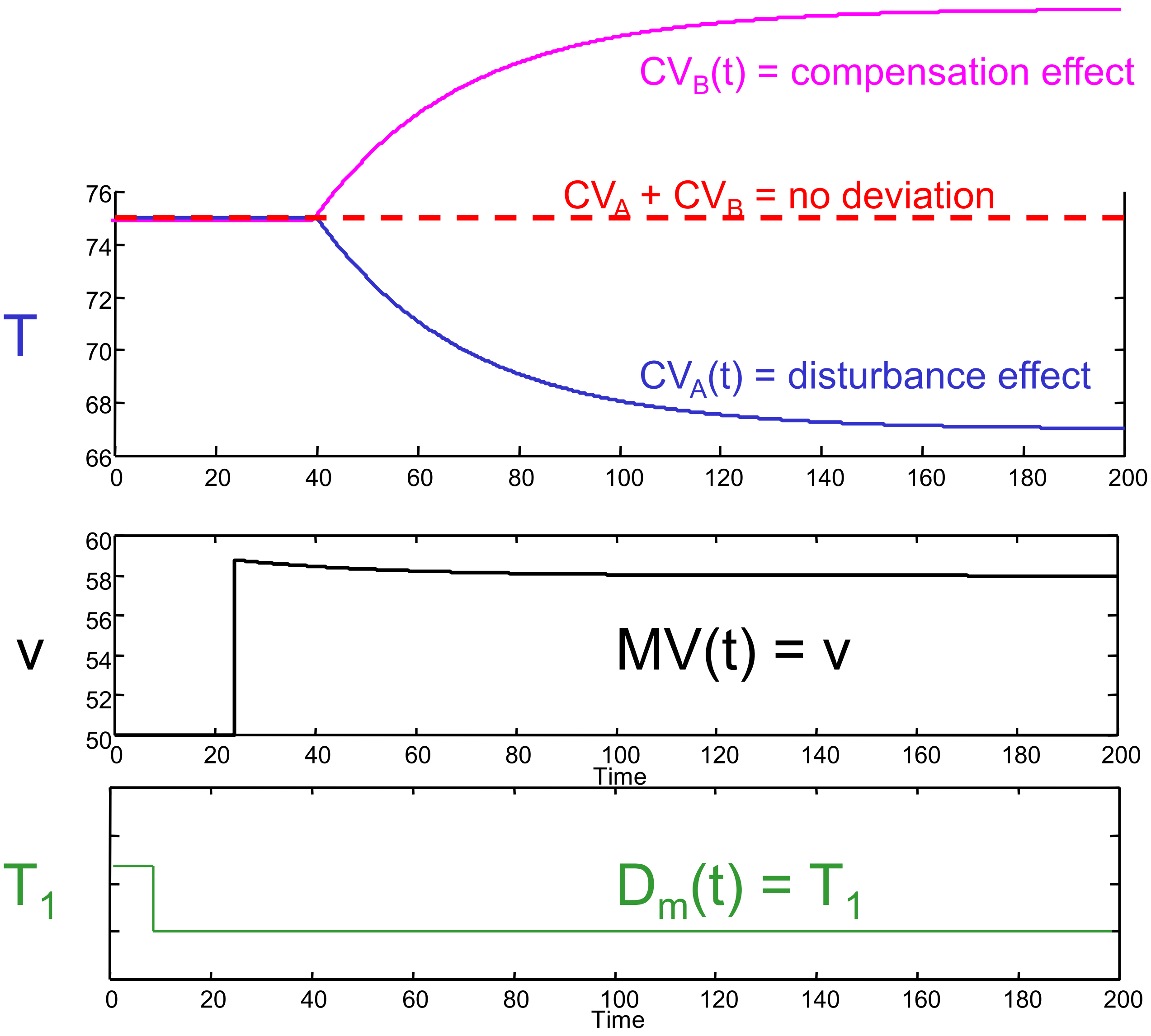
- Causal relationship from T_1 disturbance to T_2 (without control)
- How can we manipulate valve to compensate?



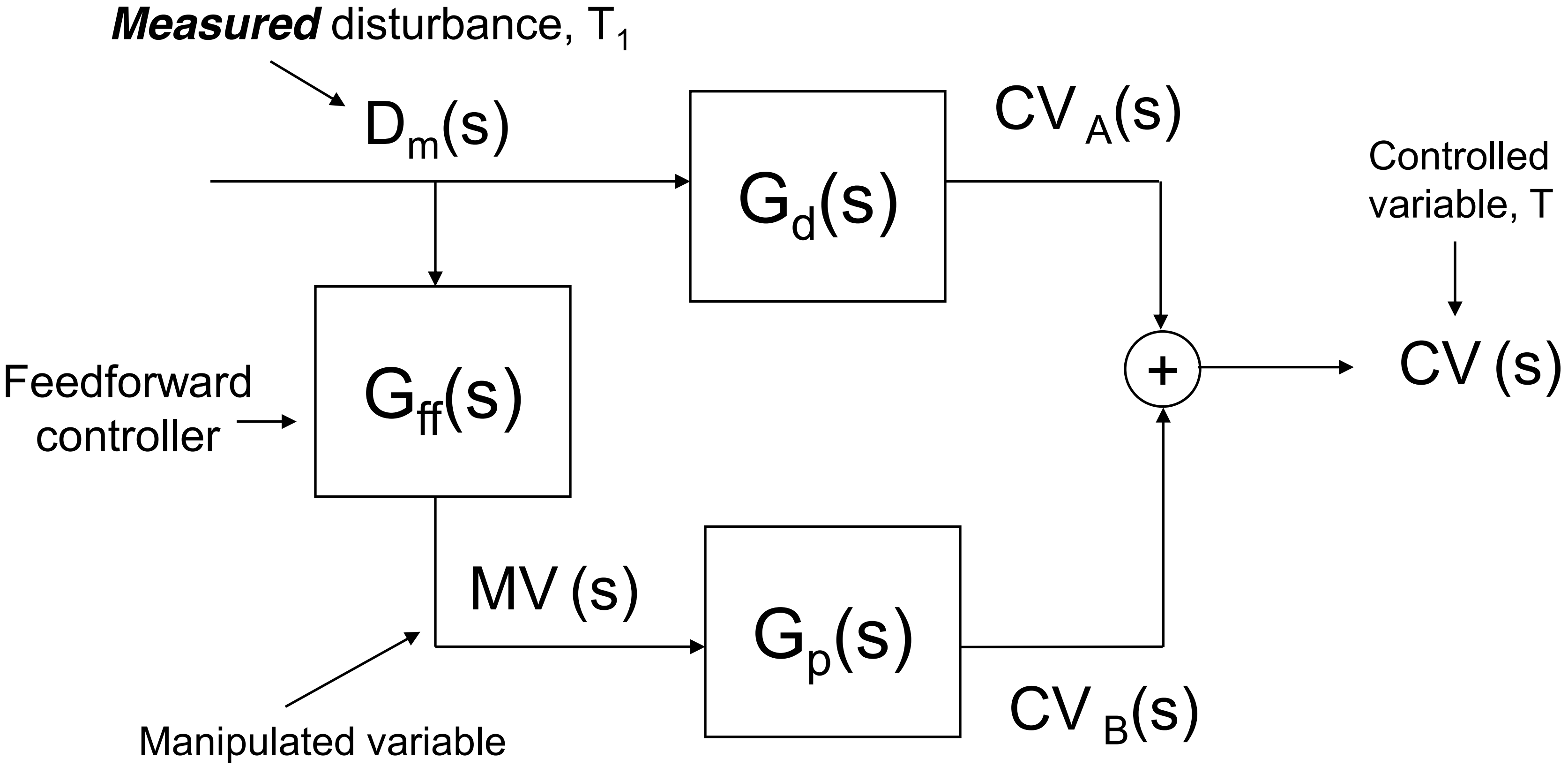

v (valve) → Q → T_2

T_1
(Feed temperature)

We want to adjust the valve to cancel the effect of the disturbance



We use block diagram algebra to determine the form of the calculation [$G_{ff}(s)$] to achieve the desired performance.


Measured disturbance, T_1

$D_m(s)$

$G_d(s)$

$CV_A(s)$

Controlled variable, T

Feedforward controller

$G_{ff}(s)$

+

$CV(s)$

$MV(s)$

$G_p(s)$

$CV_B(s)$

Manipulated variable

How do we measure CV_A?

$$\text{CV}(s) = \text{CV}_A(s) + \text{CV}_B(s) = 0$$

$$\text{CV}(s) = \left[G_d(s) + G_{ff}(s)G_p(s)\right]D_m(s) = 0$$

$$\boxed{G_{ff}(s) = \frac{\text{output}(s)}{\text{input}(s)} = \frac{MV(s)}{D_m(s)} = -\frac{G_d(s)}{G_p(s)}}$$

This is the general form for feedforward control.
It is **not** a PI(D) controller.

$$G_{ff}(s)=\frac{\text{output}(s)}{\text{input}(s)}=\frac{MV(s)}{D_m(s)}=-\frac{G_d(s)}{G_p(s)}$$

Special case of $G_p(s)$ and $G_d(s)$ being first order with dead time

$$\boxed{G_{ff}(s)=\frac{MV(s)}{D_m(s)}=\underbrace{K_{ff}}_{\text{Gain}}\ \underbrace{\frac{T_{ld}s+1}{T_{lag}s+1}}_{\text{Lead-lag}}\ \underbrace{e^{-\theta_{ff}s}}_{\text{Dead time}}}$$

$$\boxed{G_{ff}(s) = K_{ff} \; \frac{T_{ld}s+1}{T_{lag}s+1} \; e^{-\theta_{ff}s}}$$

Lead-lag = $(T_{ld}s+1)/(T_{lag}s+1)$

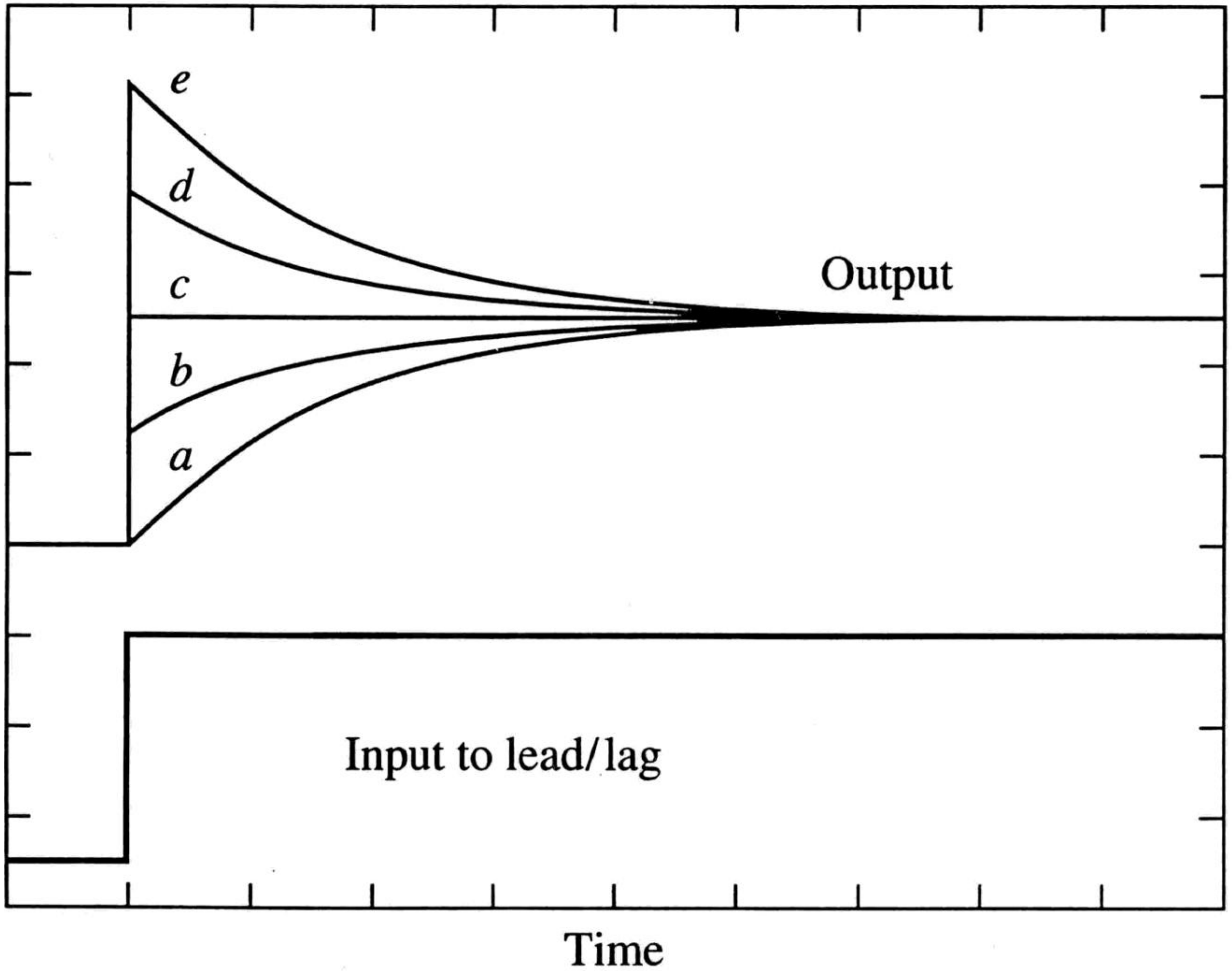
FF controller gain = $K_{ff} = - K_d / K_p$

controller dead time = $\theta_{ff} = \theta_d - \theta_p \geq 0$

Lead time = $T_{ld} = \tau_p$

Lag time = $T_{lag} = \tau_d$

Typical dynamic responses from the lead-lag element in the feedforward controller. It synchronizes the compensation and disturbance effects.



Results for several cases of T_{ld} / T_{lag} :

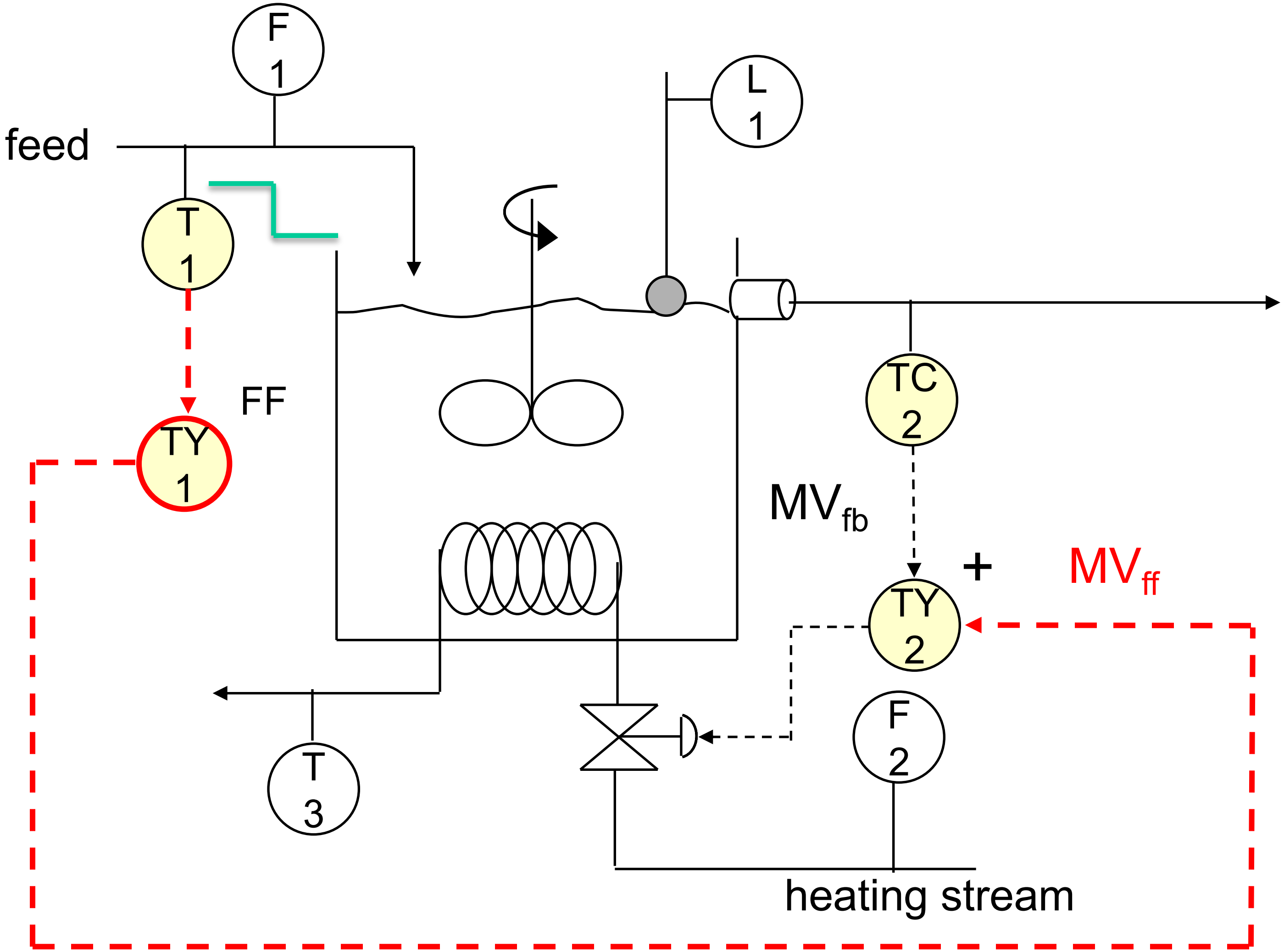
a. 0.0

b. 0.5

c. 1.0

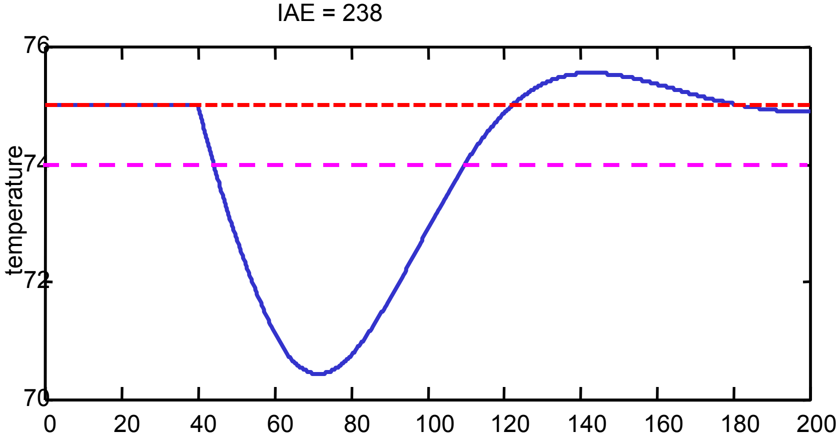
d. 1.5

e. 2.0

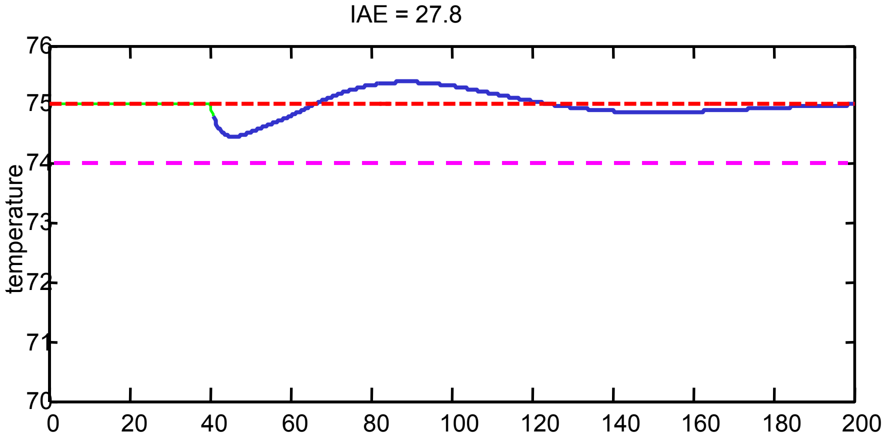

F 1
feed
L 1
T 1
FF
TY 1
TC 2
MVfb
+
MVff
TY 2
F 2
T 3
heating stream

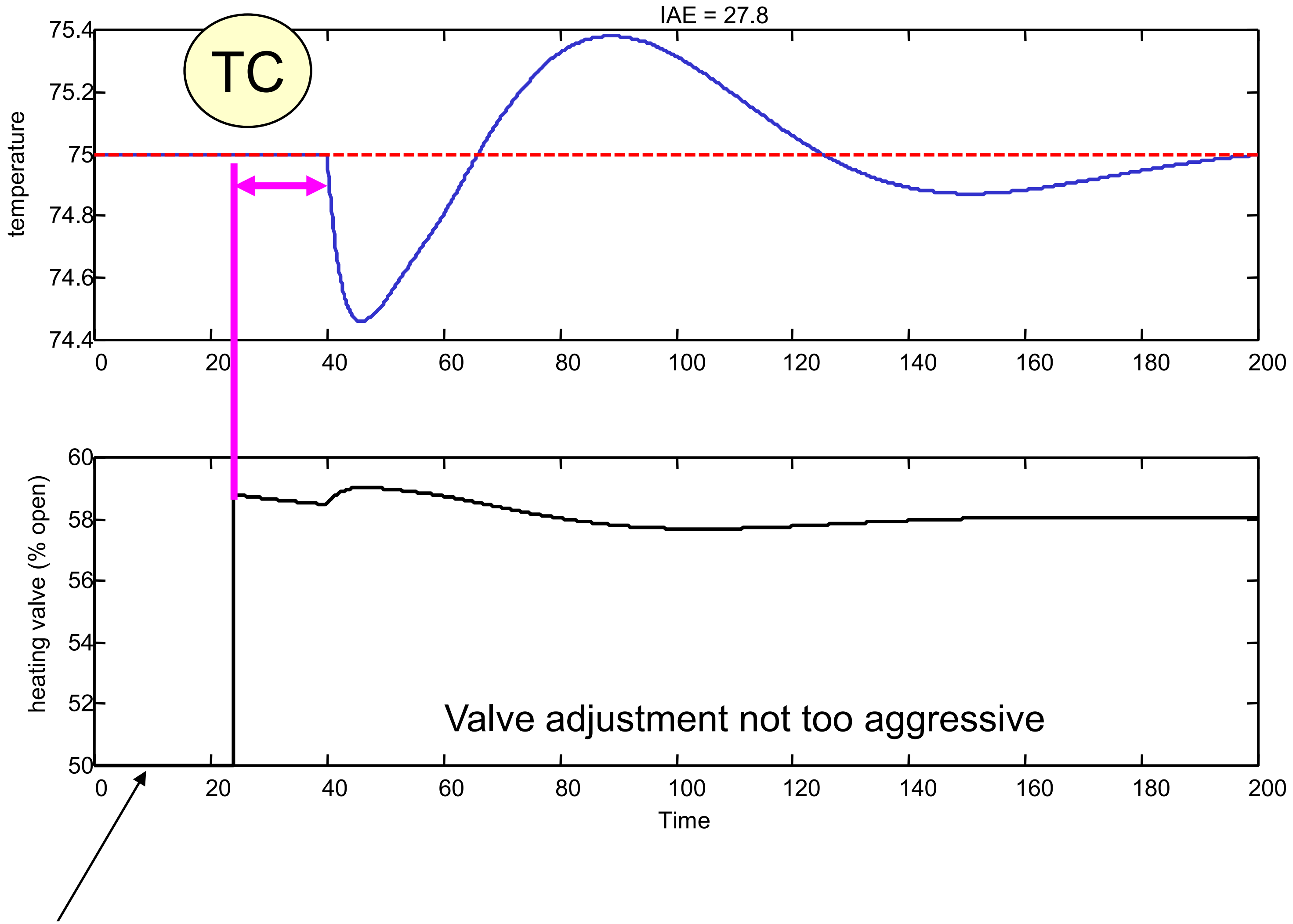
Control Performance Comparison for tank example

Single-Loop



Feedforward with feedback



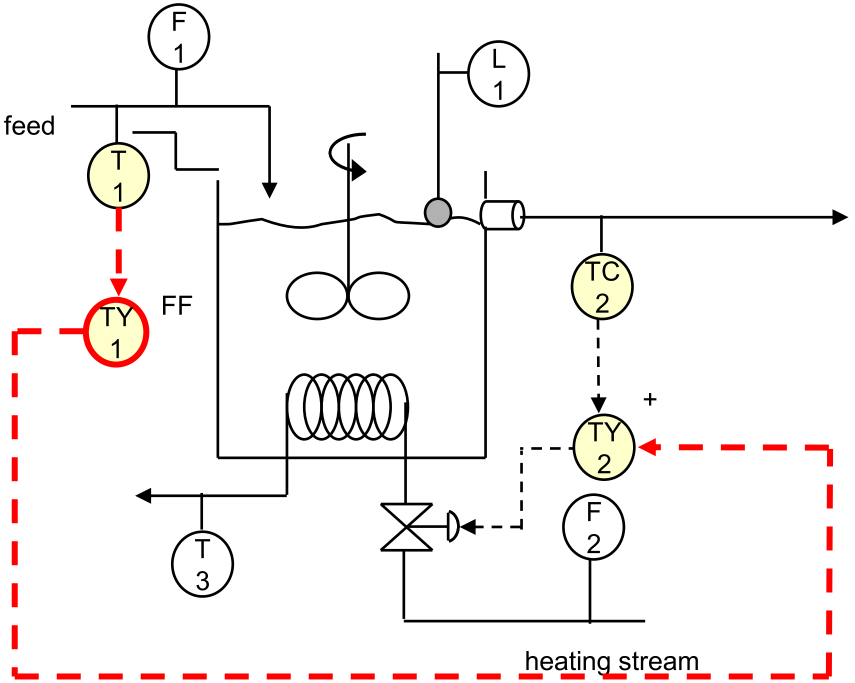


Valve adjustment not too aggressive

Disturbance occurred at this time

What have we gained and lost using feedforward and feedback?

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



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

Feedforward Design Criteria

Feedforward is desired when

1. Single-loop performance unacceptable
2. Measured variable is available

A measured disturbance variable must

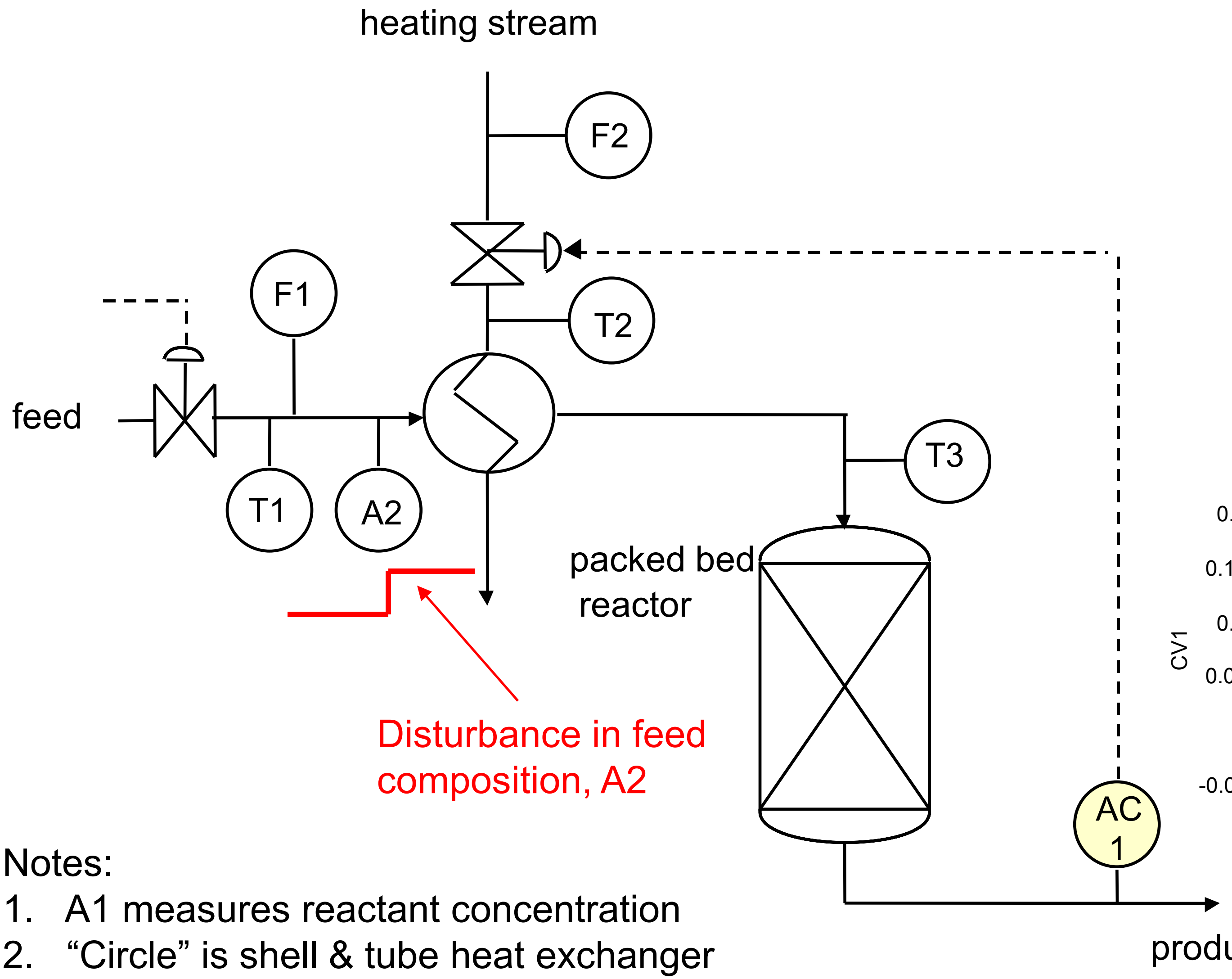
3. Indicate the occurrence of an important disturbance
4. NOT have a causal relationship from valve to measured disturbance sensor
5. Not have a much faster effect on the CV than the MV (when combined with feedback)

Feedforward and Feedback are complementary

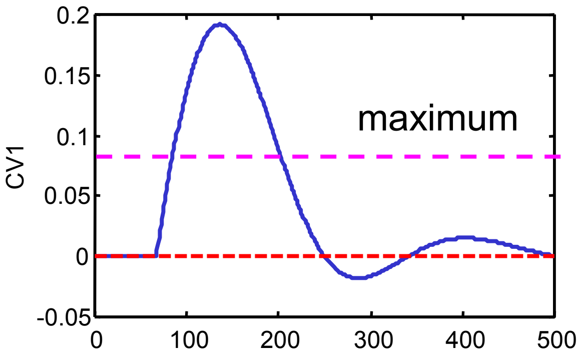
	Feedforward	Feedback
Advantages	• Compensates for disturbance before CV is affected • Does not affect the stability of the control sysytem (if $G_{ff}(s)$ stable)	• Provides zero steady-state offset • Effective for all disturbances
Disadvantages	• Cannot eliminate steady-state offset • Requires a sensor and model for each disturbance	• Does not take control action until the CV deviates from its set point • Affects the stability of the control system

Improve the performance for feed composition disturbances by adding feedforward control

What about cascade?



Disturbance in feed composition, A2

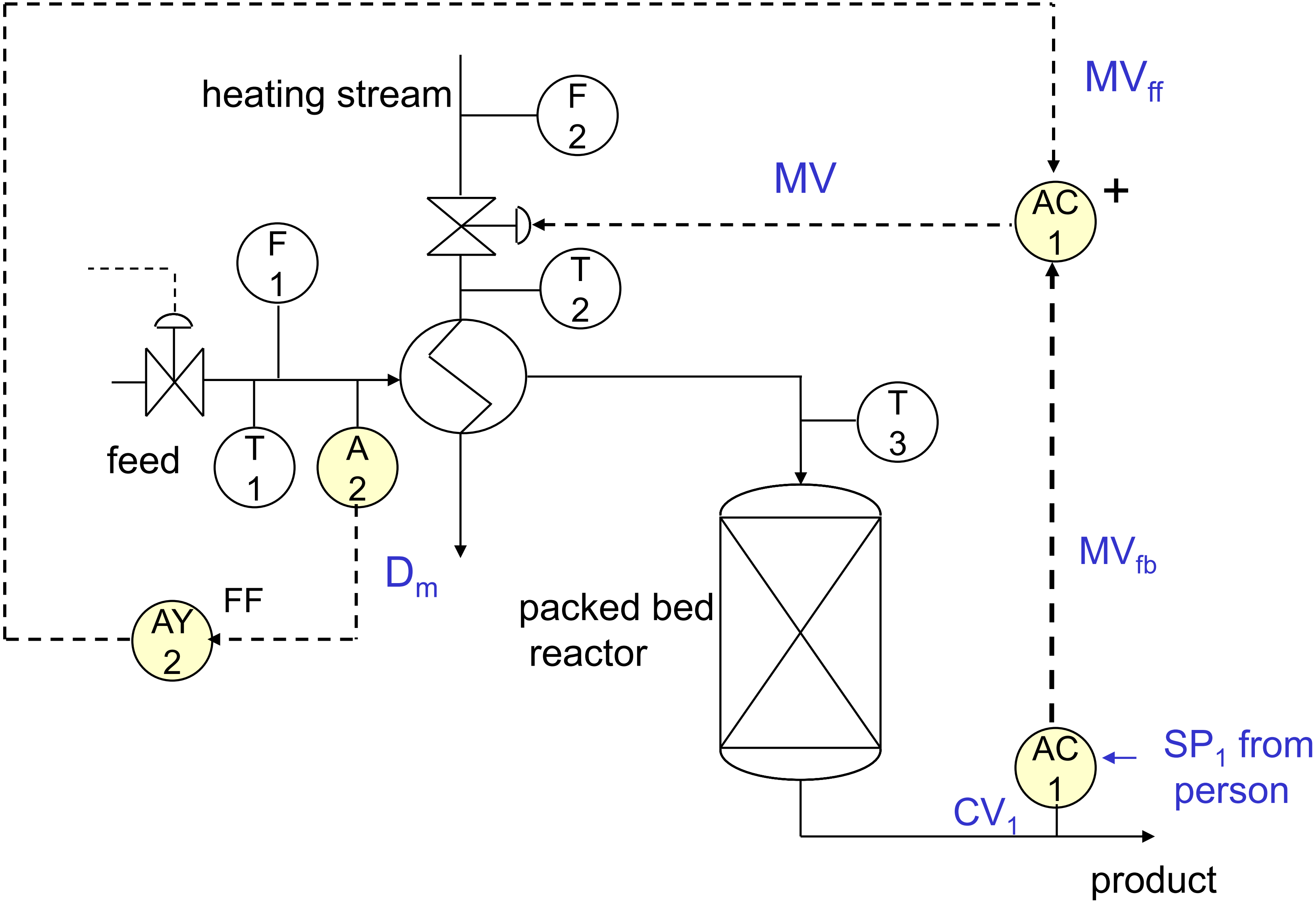


Notes:

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

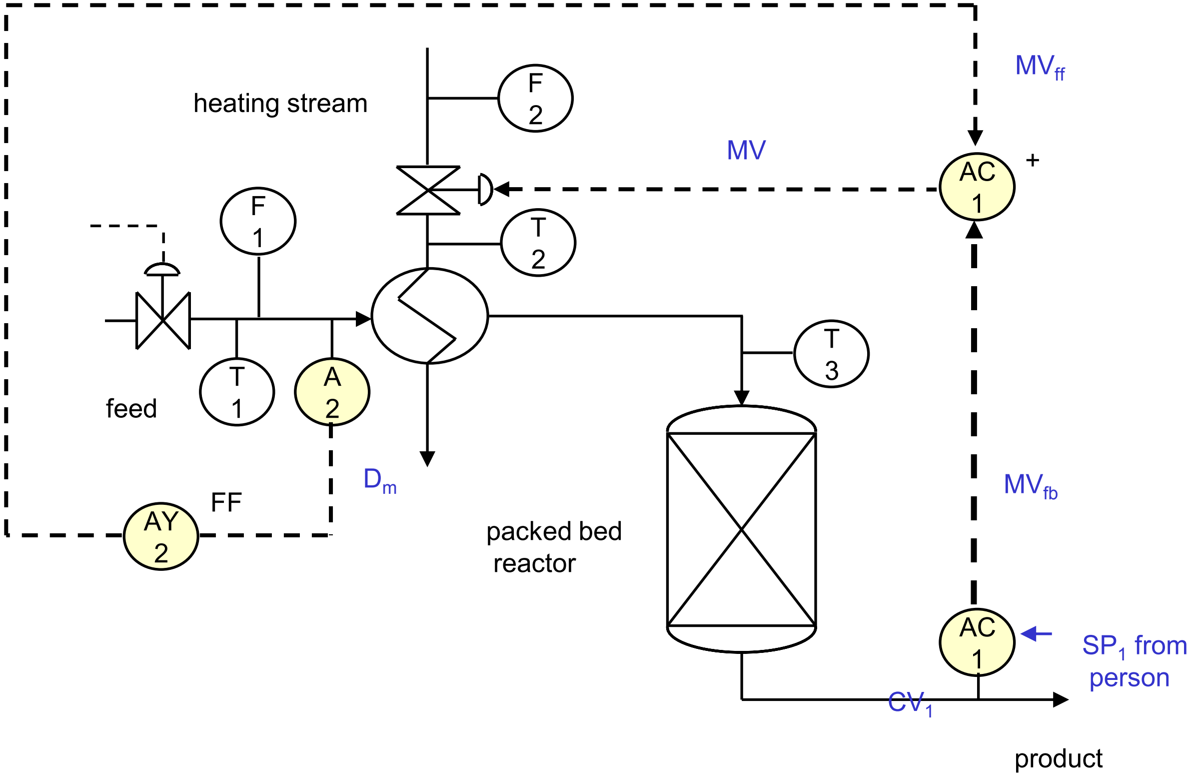
Exercise: Design feedforward control to improve the performance when the disturbance is the feed composition.

Feedforward design criteria	A2	F1	F2	T1	T2	T3
1. Single-loop not acceptable						
2. Disturbance variable is measured						
3. Indicates a key disturbance						
4. No causal relationship from the valve to D_m						
5. Disturbance dynamics not much faster than compensation						


MV$_{ff}$
heating stream
F 2
MV
AC 1
+
F 1
T 2
feed
T 1
A 2
T 3
D_m
MV$_{fb}$
FF
AY 2
packed bed reactor
AC 1
SP$_1$ from person
CV$_1$
product

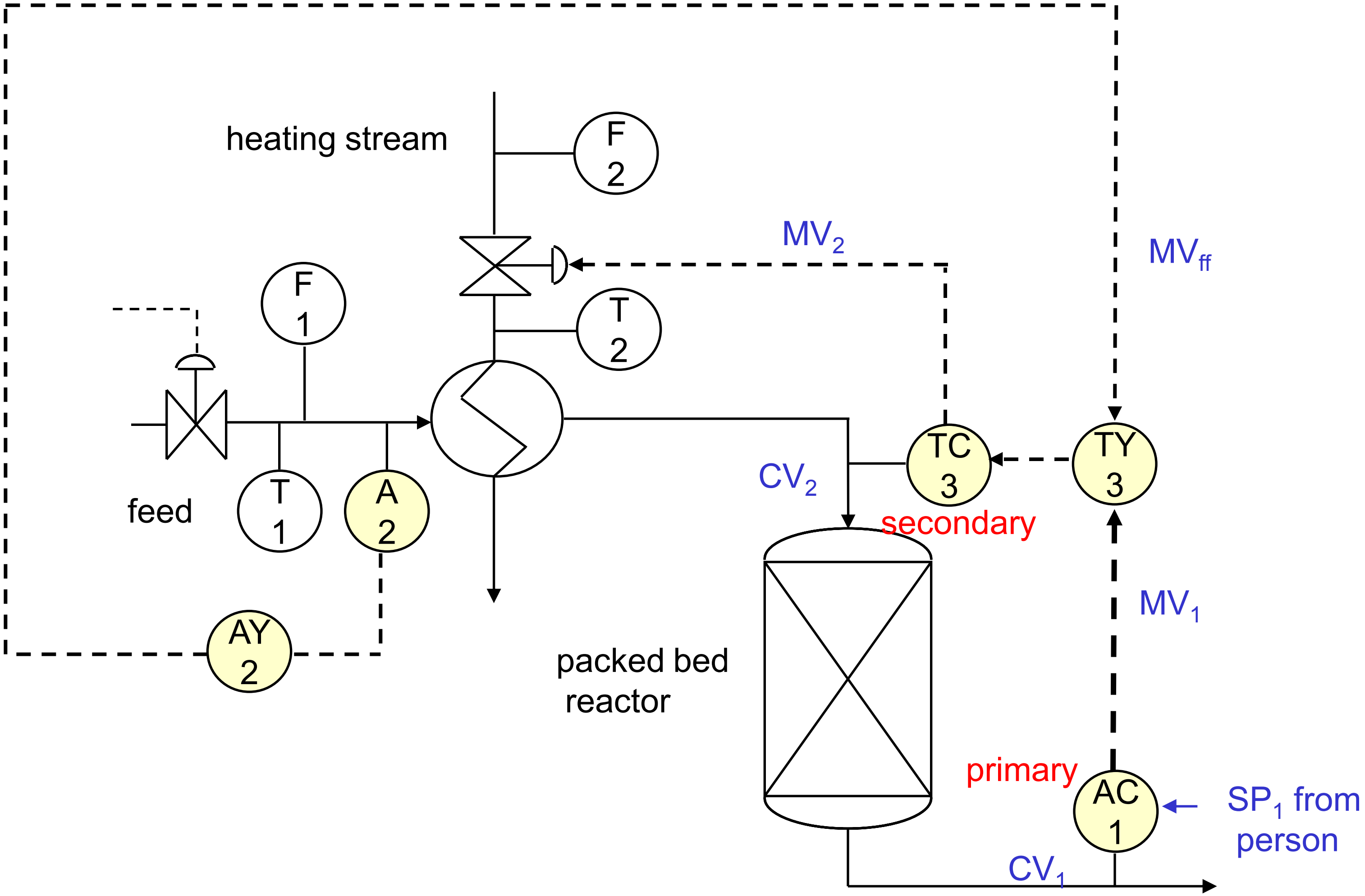
What have we gained and lost using feedforward and feedback?

Compare against just regular feedback control from AC1 to the MV.

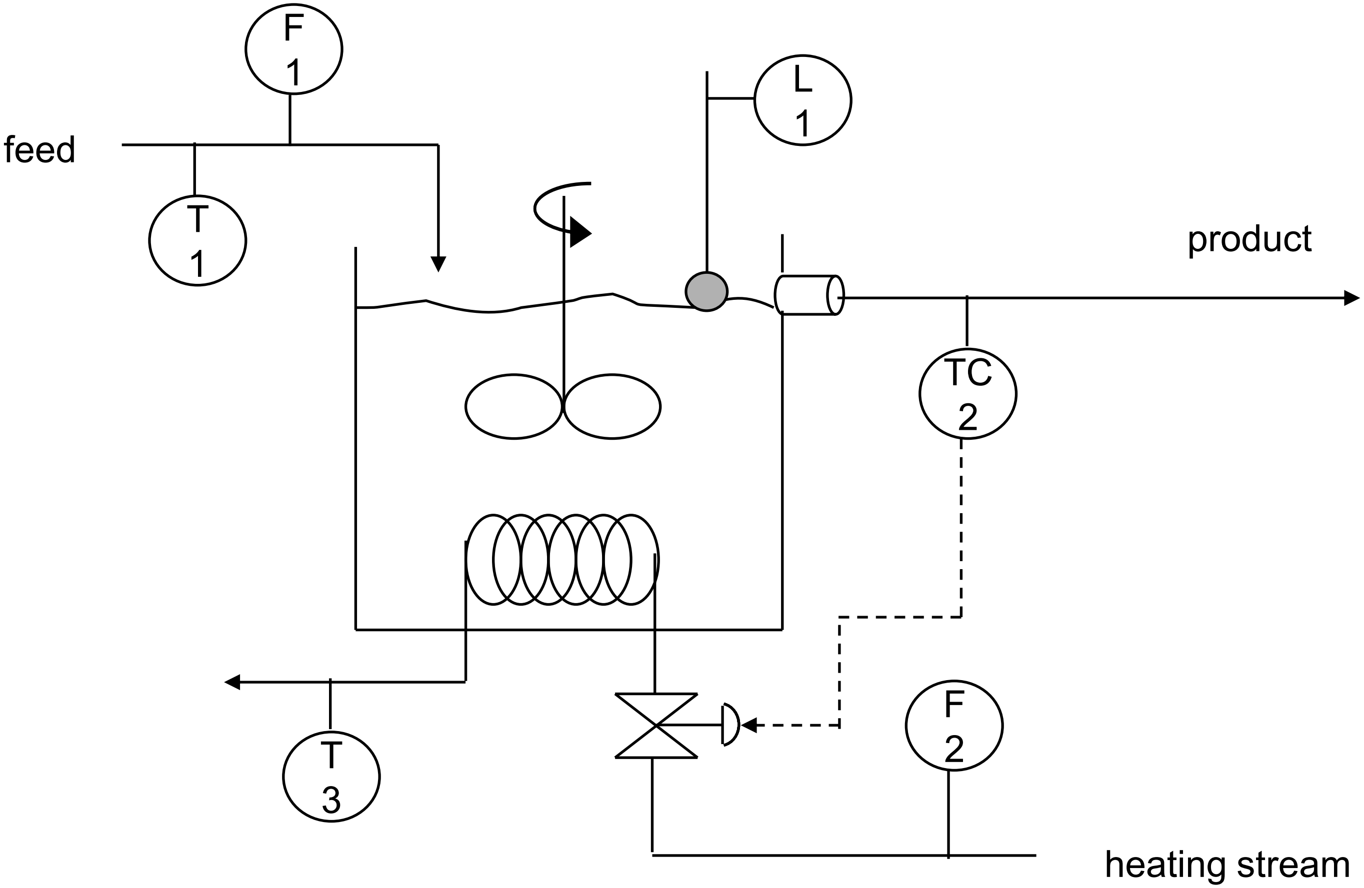


- A disturbance in T2
- A disturbance in heating medium inlet pressure
- A disturbance in T1
- A disturbance to feed composition, A2
- A change to the AC1 set point

We can combine cascade and feedforward to gain the advantages of both.



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



Answer each of the following questions **true** or **false**

1. The feedback controller tuning does not change when combined with feedforward compensation.
2. The feedforward controller has no tuning parameter.
3. The feedforward controller should react immediately when the measured disturbance is measured.
4. Feedforward could be applied for a set point change.

Some questions about feedforward control

- Why do we retain the feedback controller?
- When would feedforward give zero steady-state offset?
- Why does the feedforward controller sometimes delay its compensation? Don’t we always want fast control?
- What is the additional cost for feedforward control?
- How can we design a strategy that has two controllers both adjusting the same valve?
- What procedure is used for tuning feedforward control?