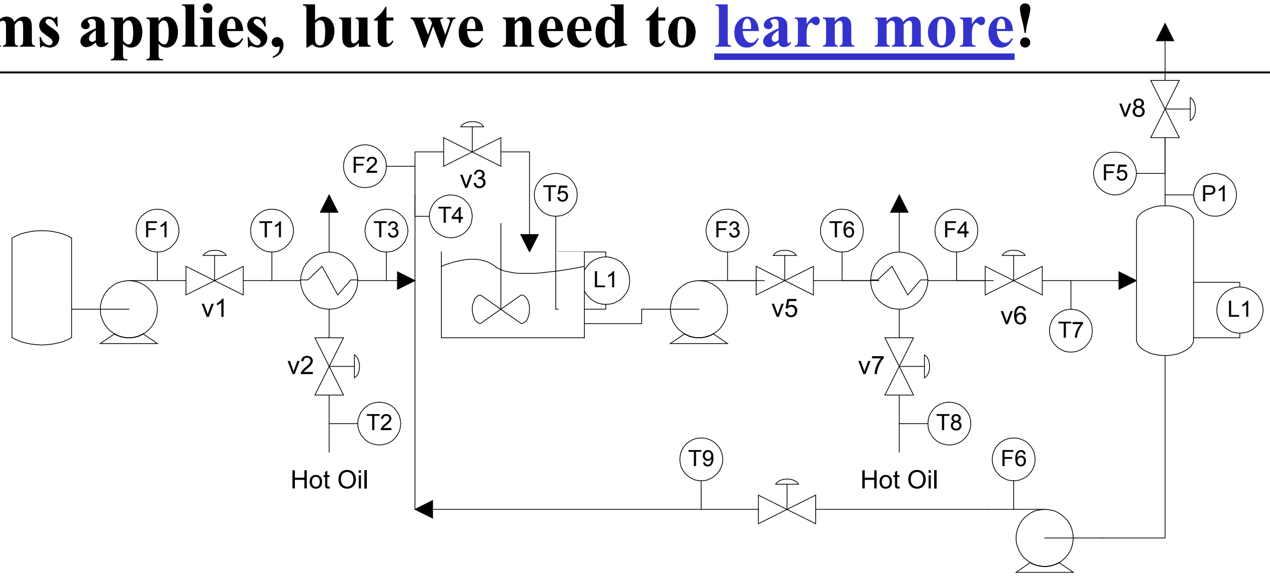
# CONTROL OF MULTIVARIABLE PROCESSES

**Process plants ( or complex experiments) have many variables that must be controlled. The engineer must**

1. **Provide the needed sensors**
2. **Provide adequate manipulated variables**
3. **Decide how the CVs and MVs are paired (linked via the control design)**

**Fortunately, most of what we learned about single-loop systems applies, but we need to learn more!**

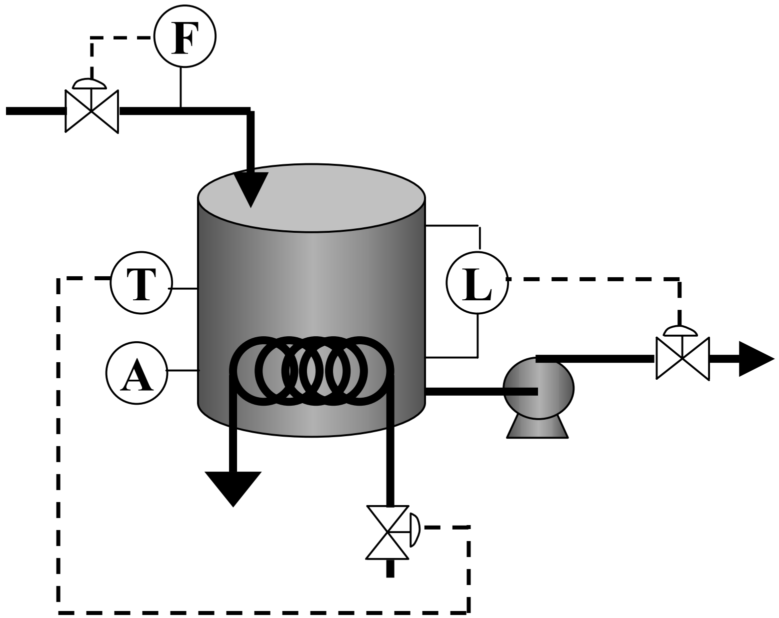


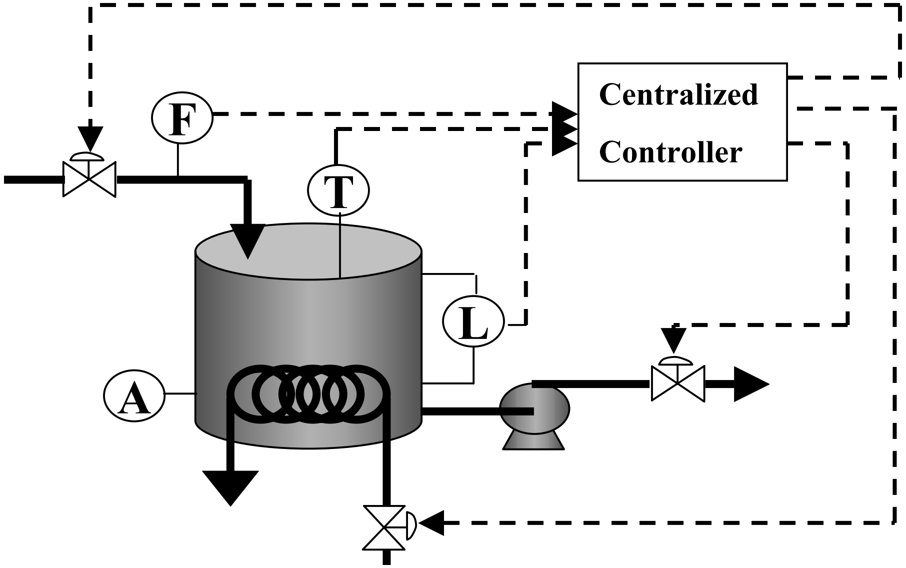
# CONTROL OF MULTIVARIABLE PROCESSES

**Two control approaches are possible**

**Multiloop: Many independent PID controllers**

**Centralized: Method covered in Chapter 23**



# CONTROL OF MULTIVARIABLE PROCESSES

**Two control approaches are possible**

**We will concentrate on <u>MULTILOOP</u>**

**<u>Multiloop</u>: Many independent PID controllers**

$$E(t) = SP(t) - CV(t)$$

$$MV(t) = K_c \left[ E(t) + \frac{1}{T_I} \int_0^t E(t')dt' - T_d \frac{d\,CV}{dt} \right] + I$$

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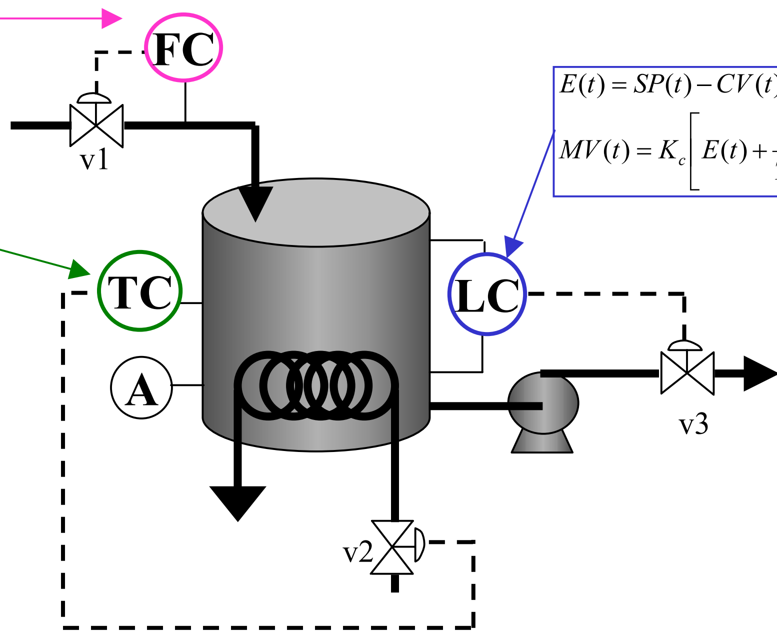


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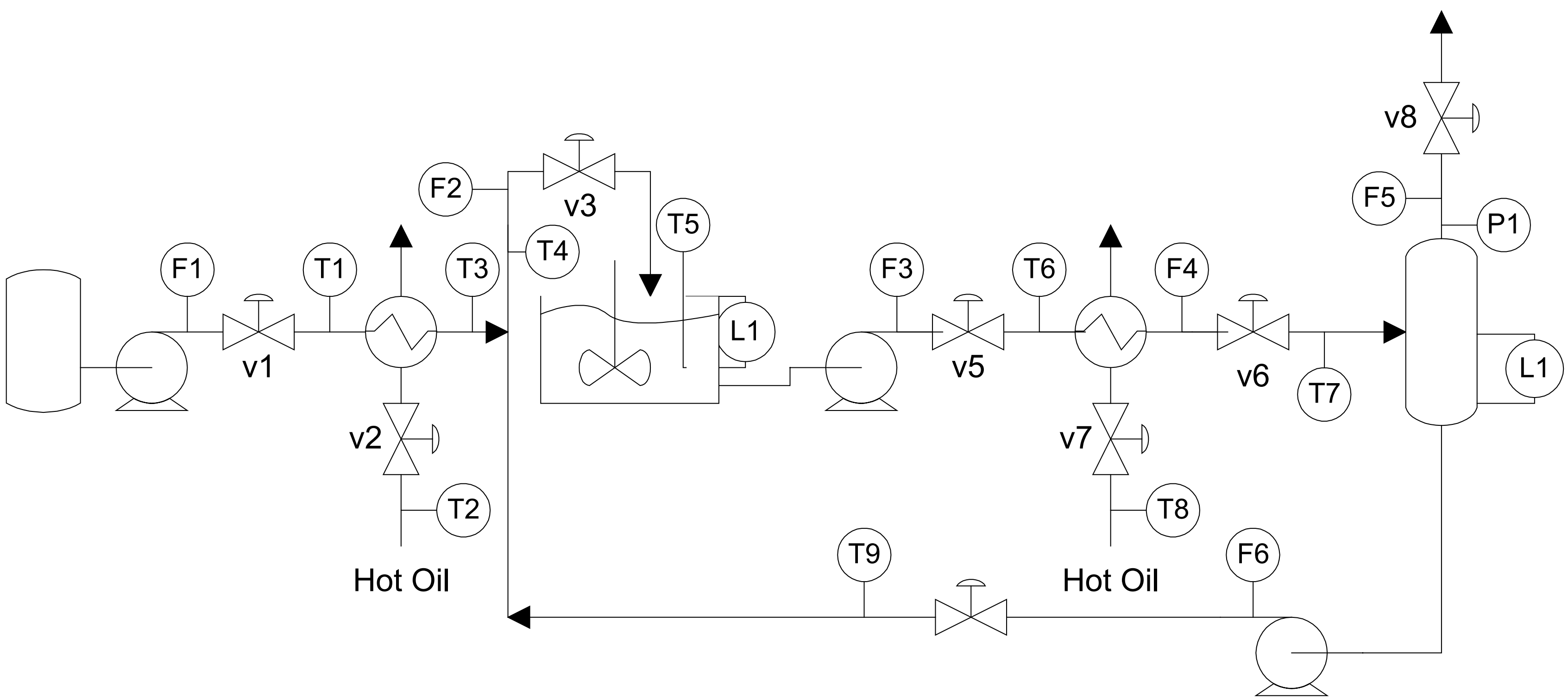
# CONTROL OF MULTIVARIABLE PROCESSES

**Let's assume (for now) that we have the sensors and valves.**

**How do we ask the right questions in the best order to have a systematic method for pairing multiloop control?**



# CONTROL OF MULTIVARIABLE PROCESSES

## Some key questions whose answers help us design a multiloop control system.

1. **IS INTERACTION PRESENT?**

   **- If no interaction $\Rightarrow$ All single-loop problems**


2. **IS CONTROL POSSIBLE?**

   **- Can we control the specified CVs with the available MVs?**

3. **WHAT IS S-S AND DYNAMIC BEHAVIOR?**

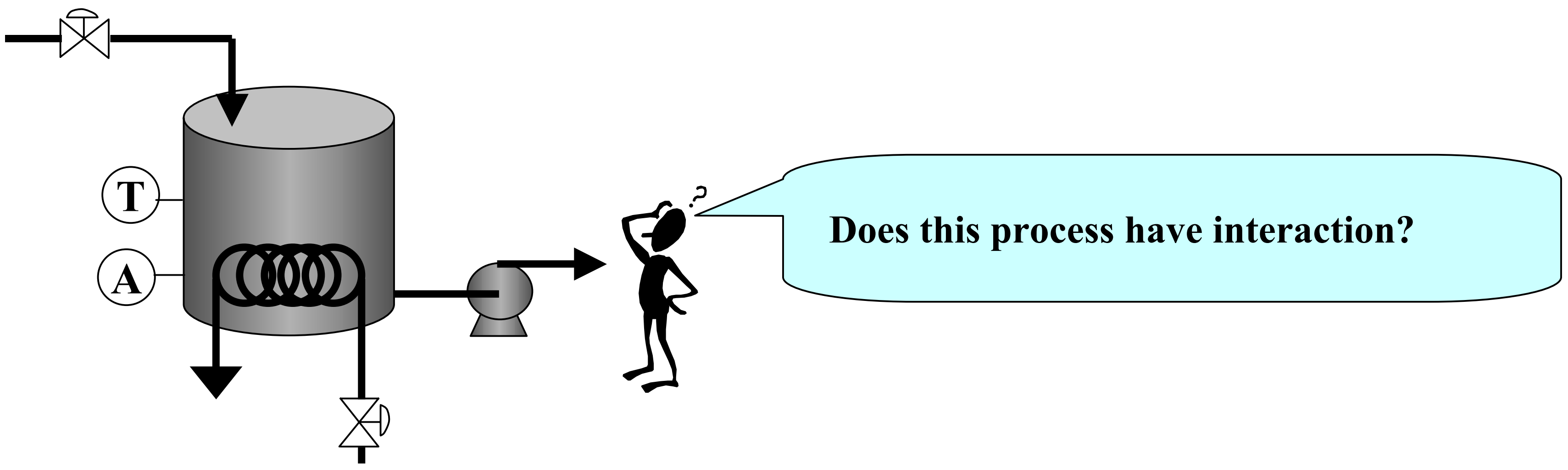
   **- Over what range can control keep CVs near the set points?**

# CONTROL OF MULTIVARIABLE PROCESSES

**What is different when we have multiple MVs and CVs?**

**INTERACTION!!**

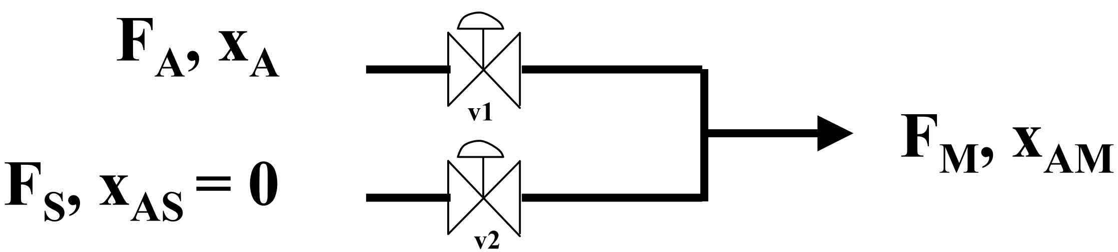
**Definition: A multivariable process has interaction when input (manipulated) variables affect more than one output (controlled) variable.**



# CONTROL OF MULTIVARIABLE PROCESSES

**How can we determine how much interaction exists?**

**One way - Fundamental modelling**




**Fundamental (n-l)**

$$F_A + F_S = F_M$$

$$F_A x_A + \cancel{F_S x_{AS}} = F_M x_{AM}$$

**Fundamental linearized**

$$\mathbf{F'_M = F'_A + F'_S}$$

$$\mathbf{x'_{AM}} = \left[\frac{\mathbf{F_S}}{(\mathbf{F_s} + \mathbf{F_A})^2}\right]_{ss} \mathbf{F'_A} + \left[\frac{-\mathbf{F_A}}{(\mathbf{F_s} + \mathbf{F_A})^2}\right]_{ss} \mathbf{F'_S}$$

# CONTROL OF MULTIVARIABLE PROCESSES

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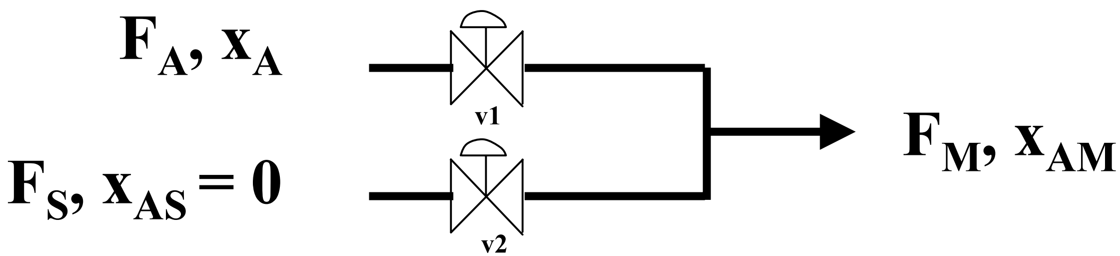


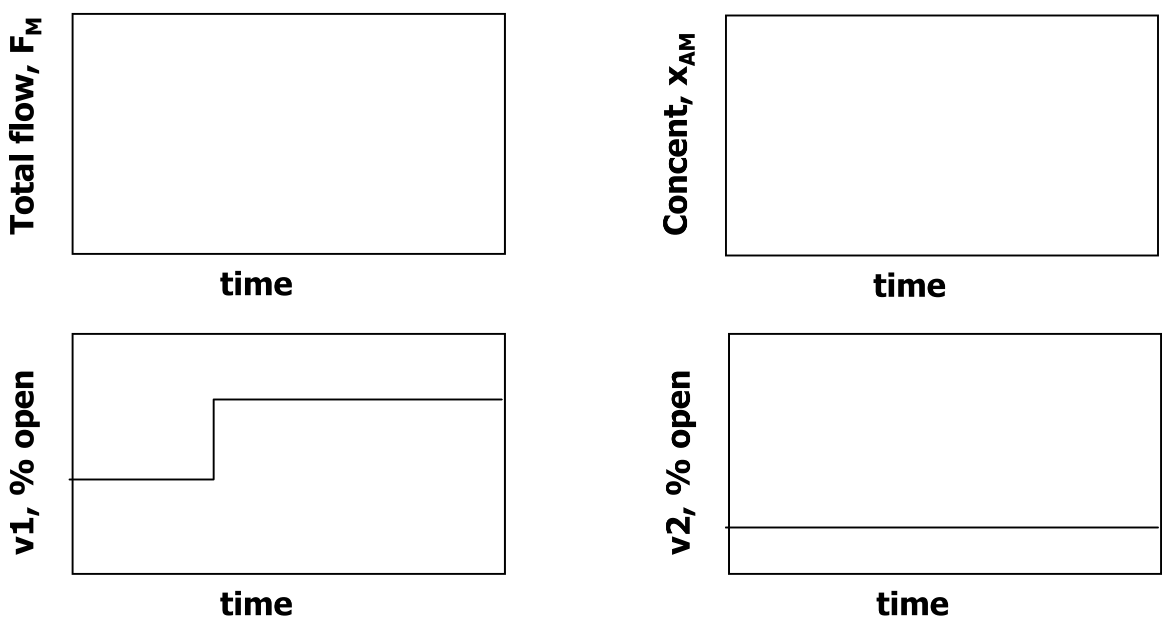


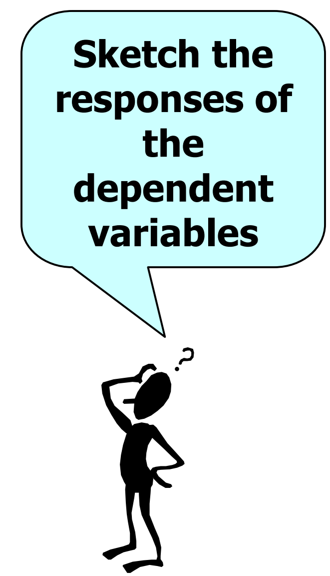

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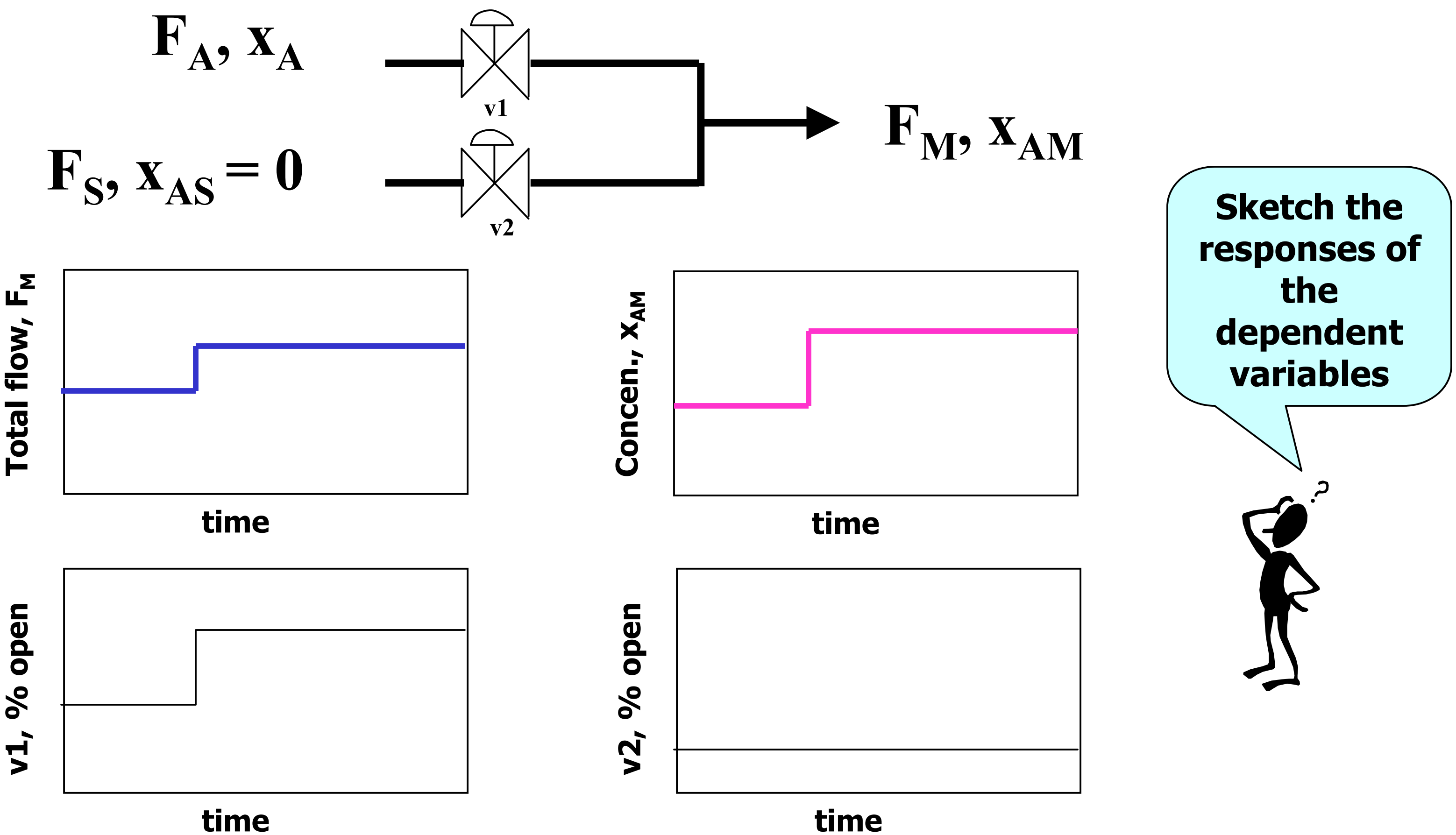
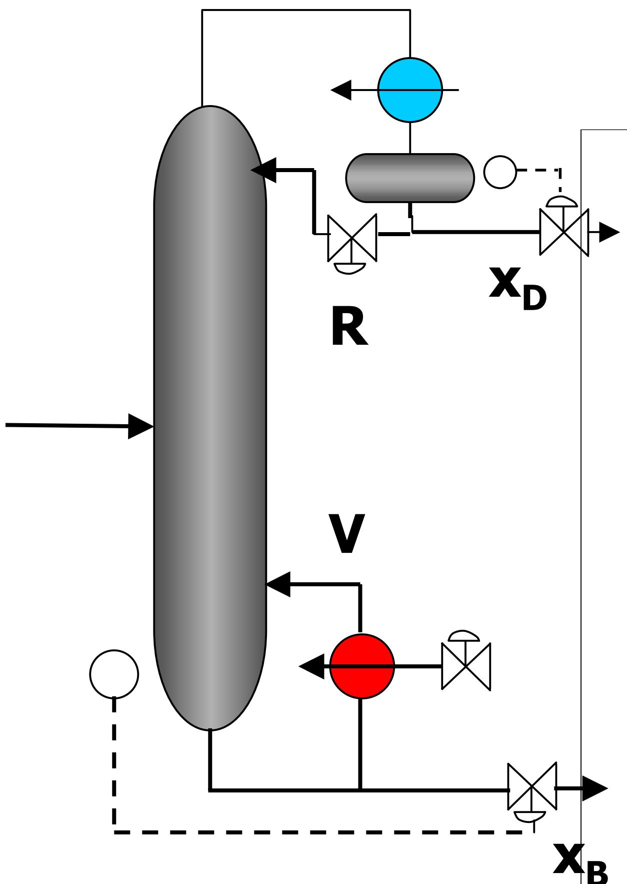


# CONTROL OF MULTIVARIABLE PROCESSES

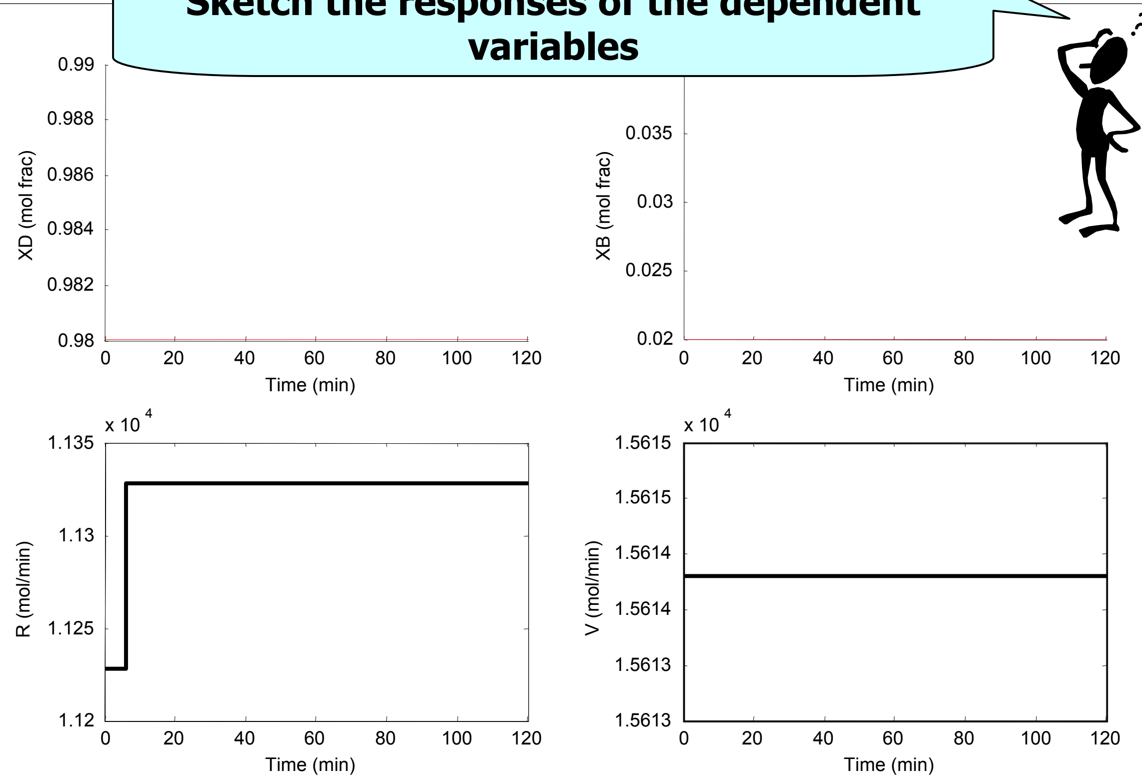
## How can we determine how much interaction exists?

## Second way - Empirical modelling (process reaction curve)




Step change to reflux with constant reboiler

**Sketch the responses of the dependent variables**



# CONTROL OF MULTIVARIABLE PROCESSES

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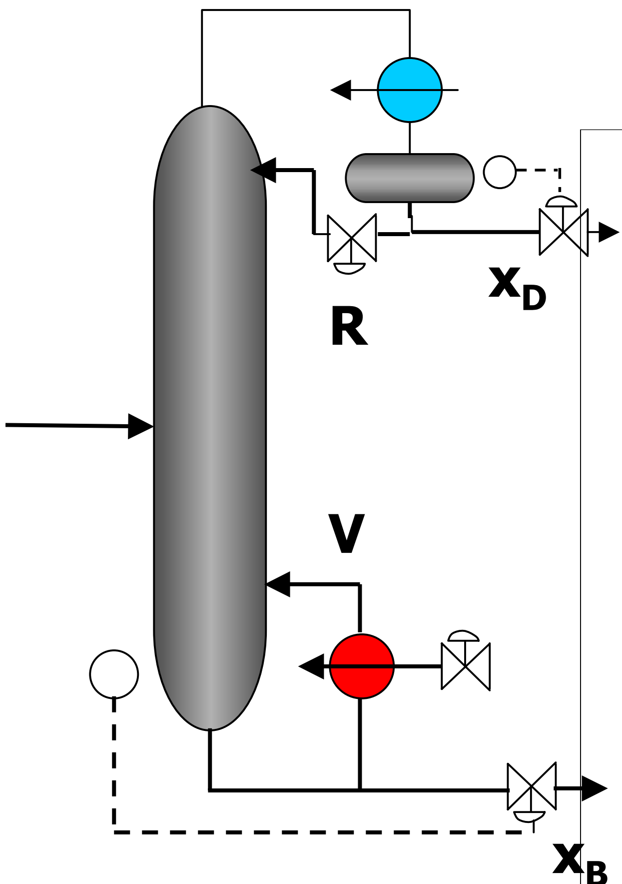
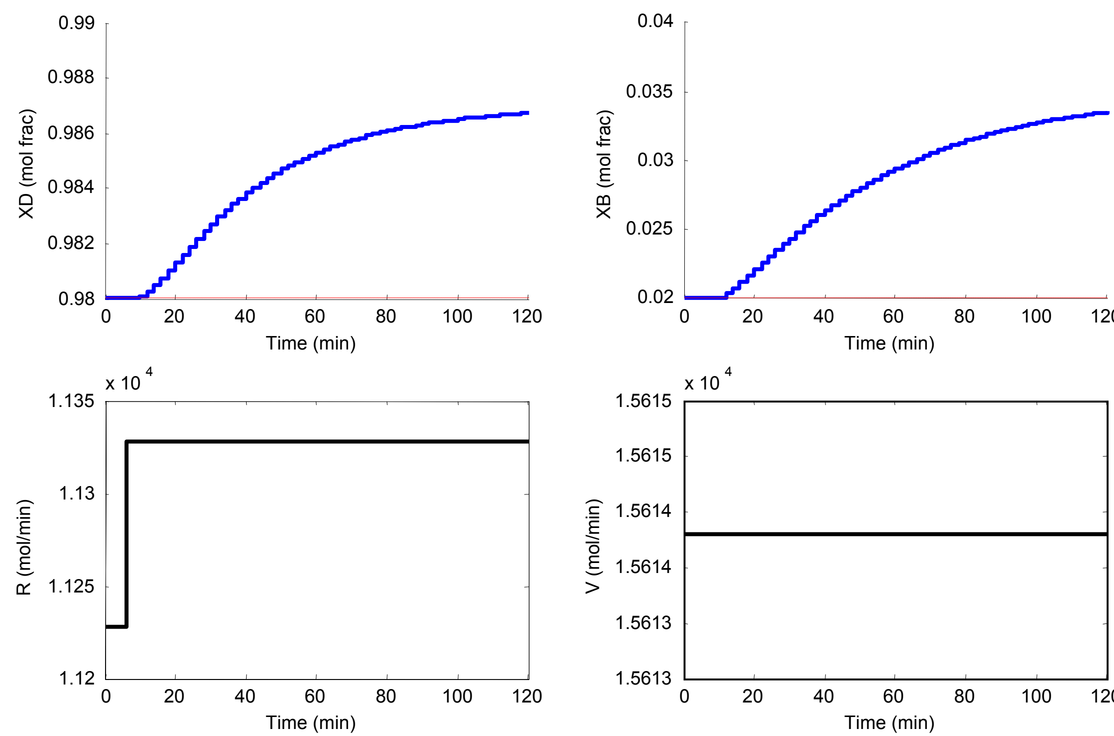



**Step change to reflux with constant reboiler**



# CONTROL OF MULTIVARIABLE PROCESSES

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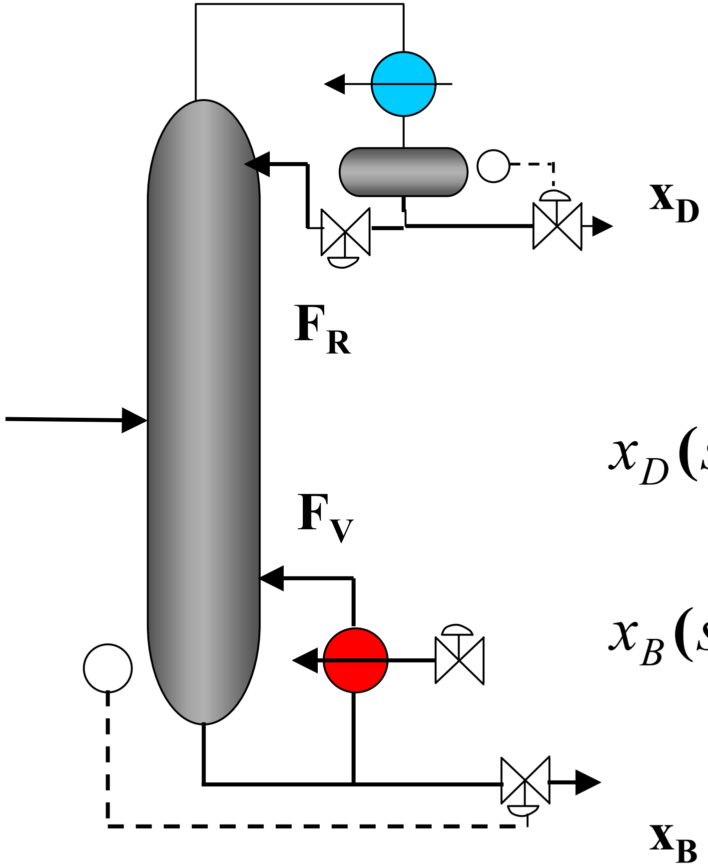
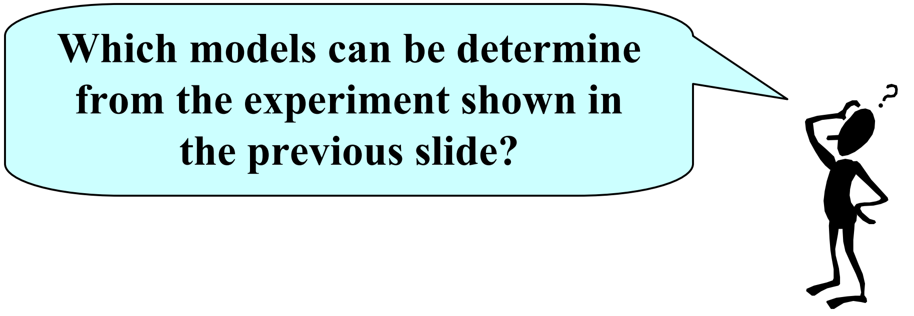



$$x_D(s) = \frac{0.0747e^{-3s}}{12s+1}F_R(s) - \frac{0.0667e^{-2s}}{15s+1}F_V(s)$$

$$x_B(s) = \frac{0.1173e^{-3.3s}}{11.7s+1}F_R(s) - \frac{0.1253e^{-2s}}{10.2s+1}F_V(s)$$

# CONTROL OF MULTIVARIABLE PROCESSES

**How can we determine how much interaction exists?**

**Use the model; if model can be arranged so that it has a "diagonal" form, no interaction exists.**

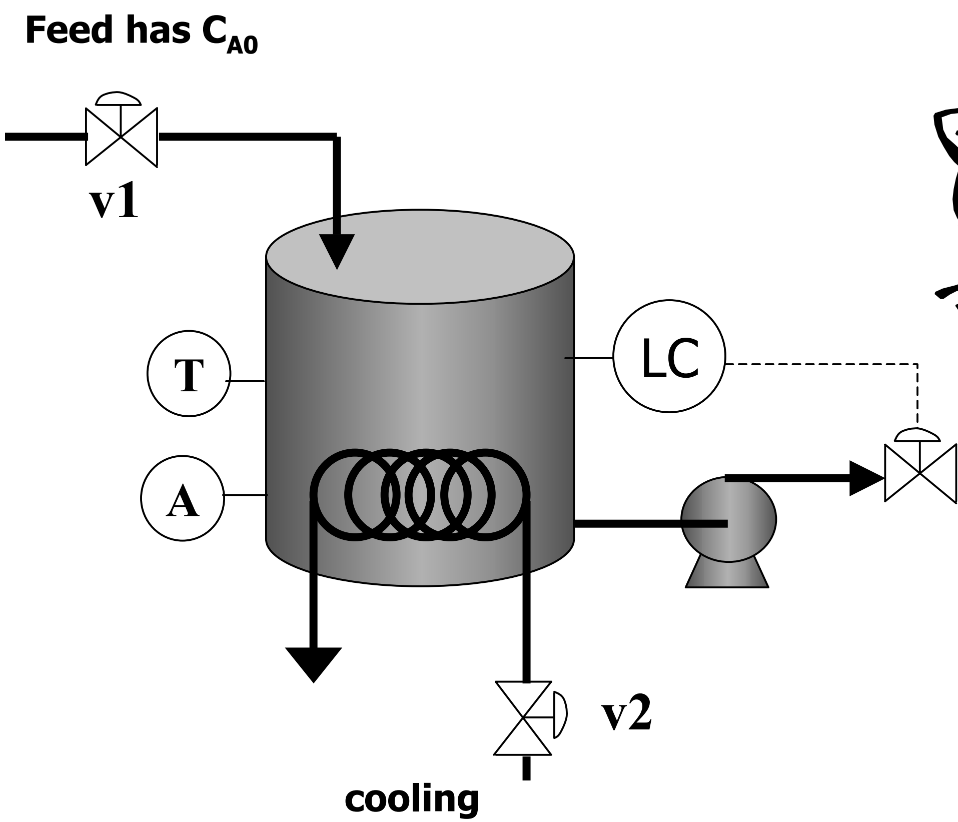
$$\begin{bmatrix} CV_1 \\ \cdots \\ CV_n \end{bmatrix} = \begin{bmatrix} K_{11} & 0 & 0 \\ 0 & K_{22} & 0 \\ 0 & 0 & K_{nn} \end{bmatrix} \begin{bmatrix} MV_1 \\ MV_2 \\ MV_3 \end{bmatrix}$$

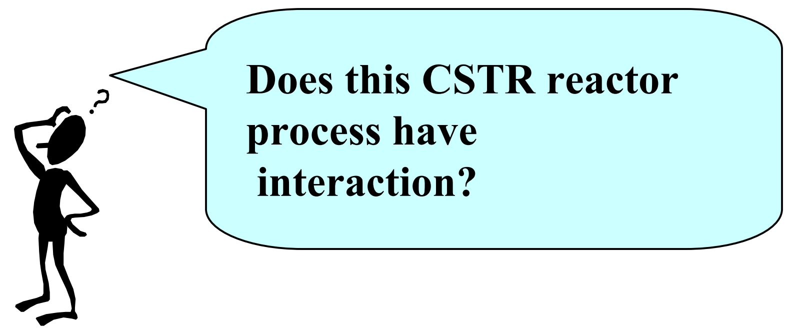
**If any off-diagonal are non-zero, interaction exists.**

# CONTROL OF MULTIVARIABLE PROCESSES

**How can we determine how much interaction exists?**

**Let's use qualitative understanding to answer the question.**



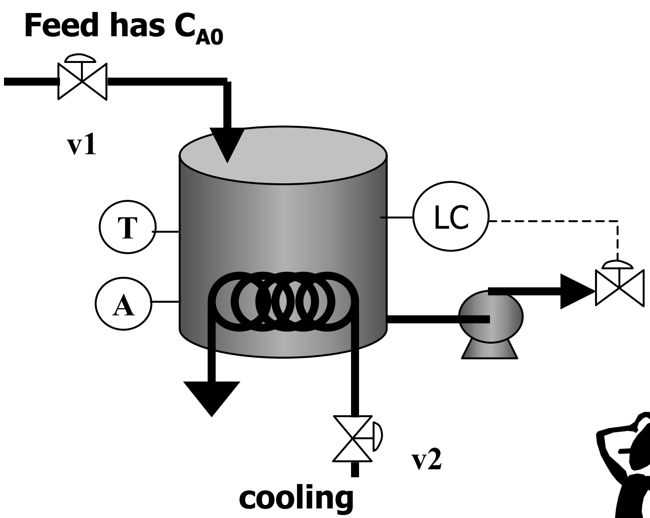

**Information:**

1. **Exothermic reaction**
2. $-r_A = k_0\, e^{-E/RT}\, C_A$

# CONTROL OF MULTIVARIABLE PROCESSES

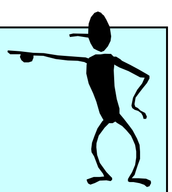
**How can we determine how much interaction exists?**

**Let's use qualitative understanding to answer the question.**




**From the cause-effect analysis, v1 affects both sensors; interaction exists!**

**What about v2?**



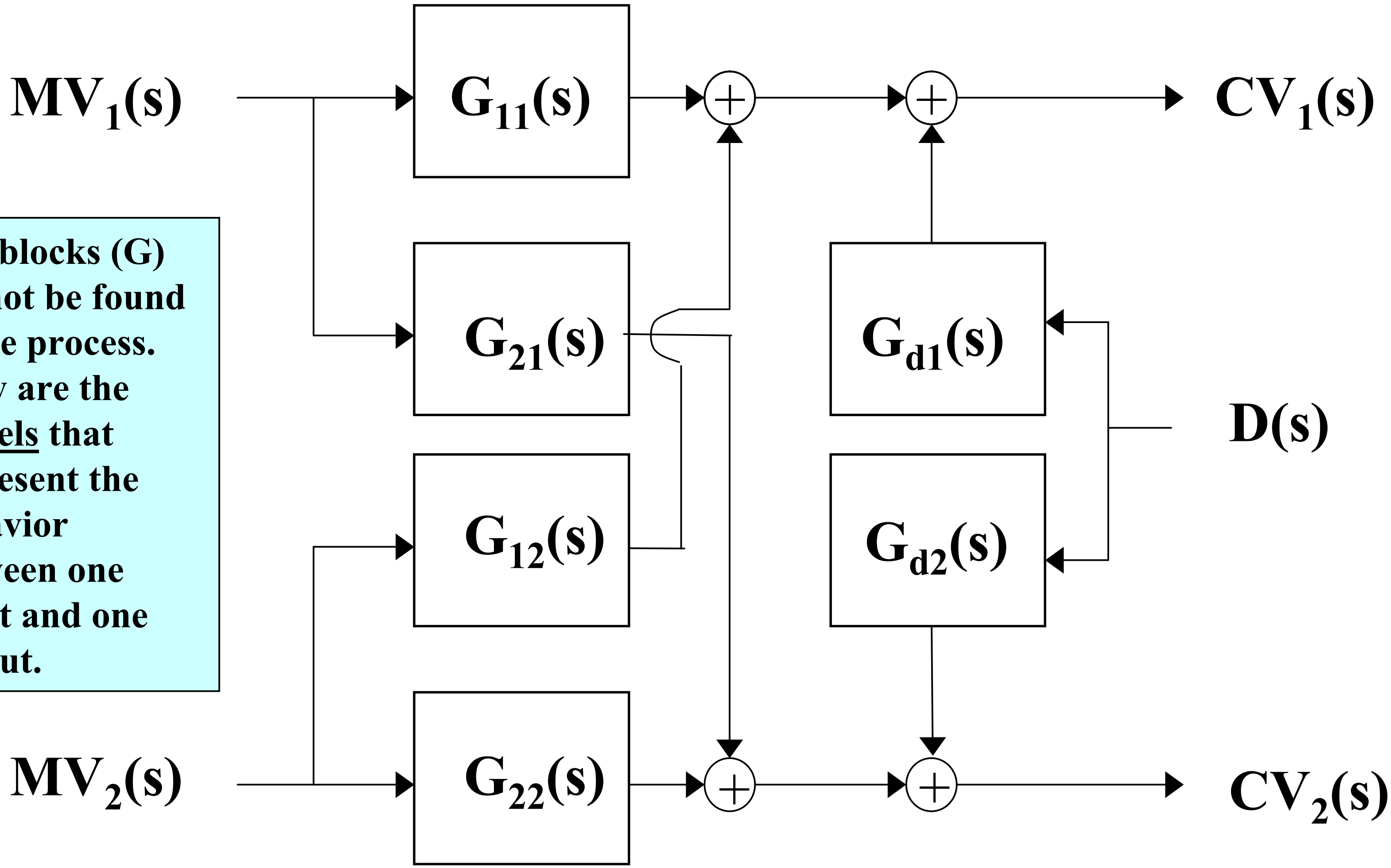
**v1 → feed flow rate → residence time → conversion → "heat generated" → T**

**→ $Q/(F\rho C_P)$ → → T**

**v2 → coolant flow → heat transfer → conversion → Analyzer**

# CONTROL OF MULTIVARIABLE PROCESSES

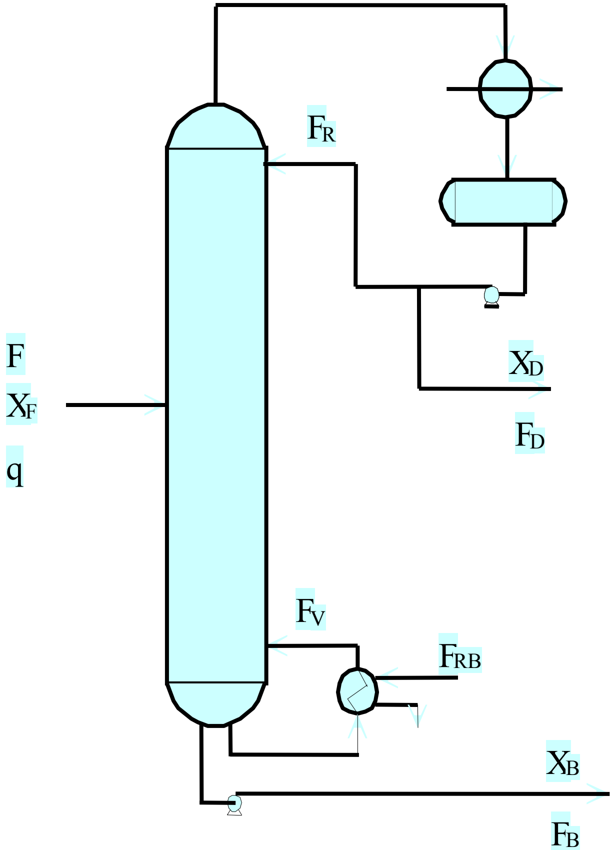
**We will use a block diagram to represent the dynamics of a 2x2 process, which involves multivariable control.**

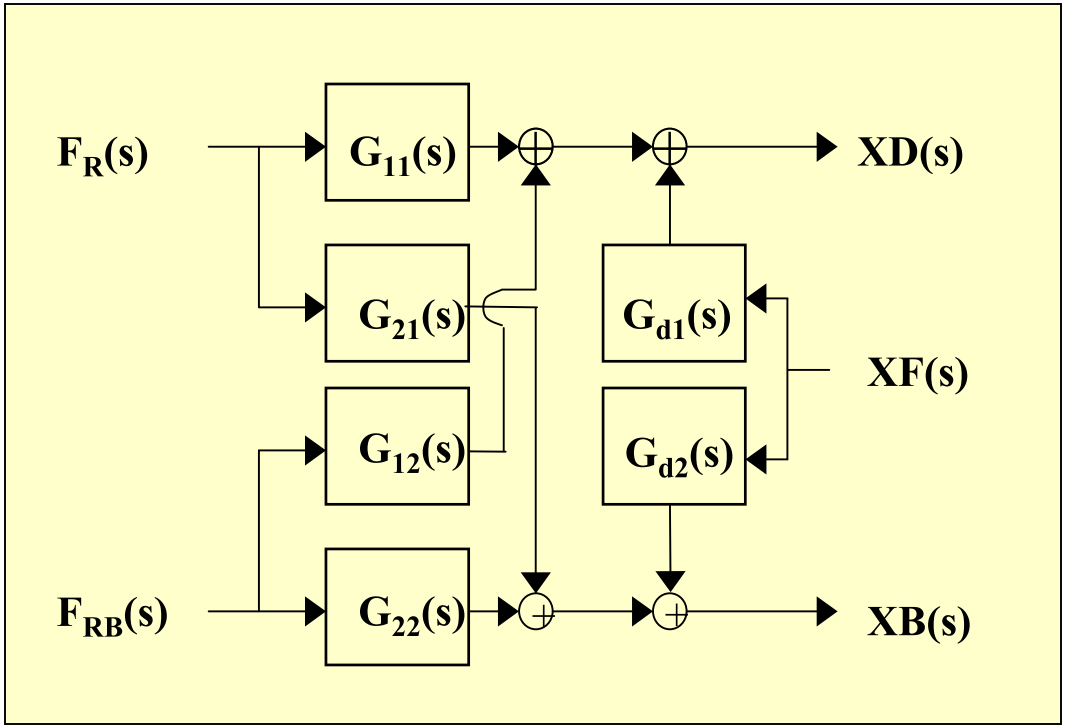



The blocks (G) cannot be found in the process. They are the <u>models</u> that represent the behavior between one input and one output.

# CONTROL OF MULTIVARIABLE PROCESSES

**Let's relate the block diagram to a typical physical process. What are the MVs, CVs, and a disturbance, D?**



# CONTROL OF MULTIVARIABLE PROCESSES

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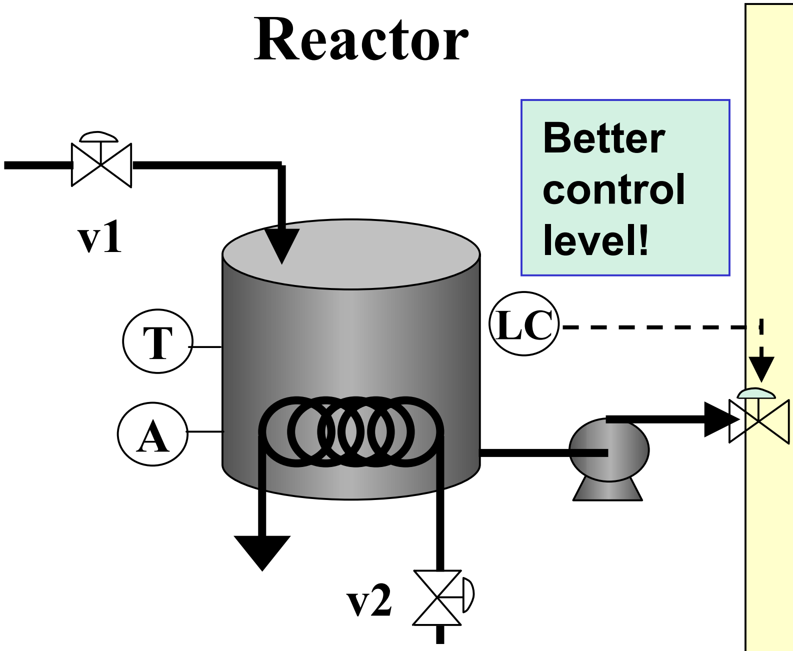
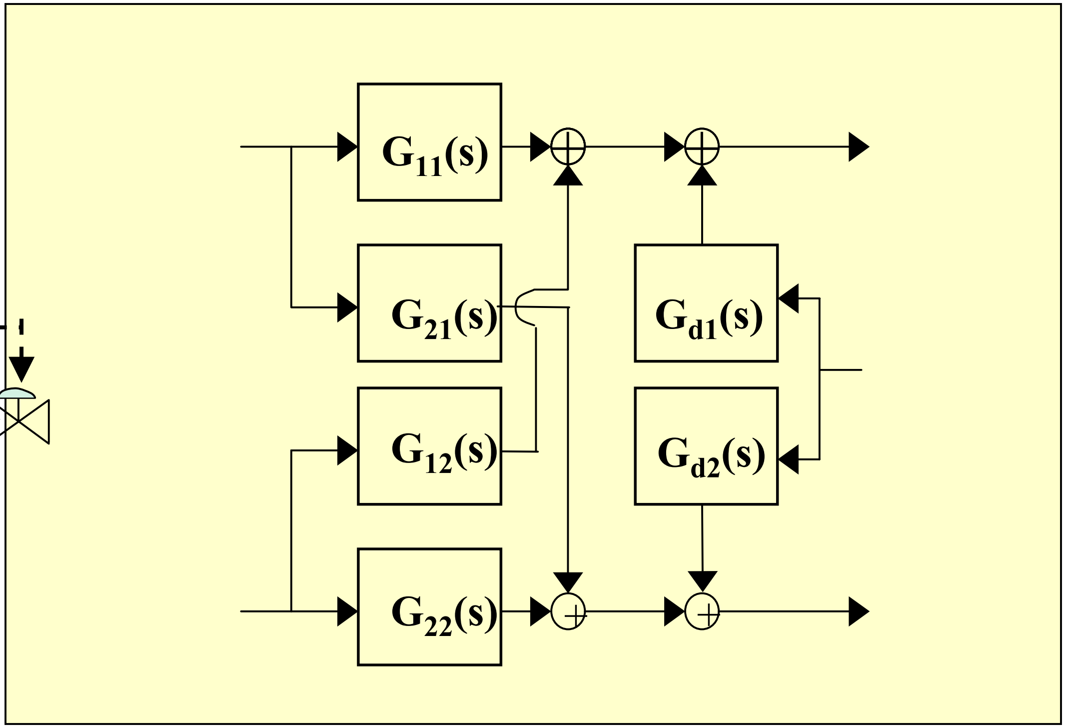
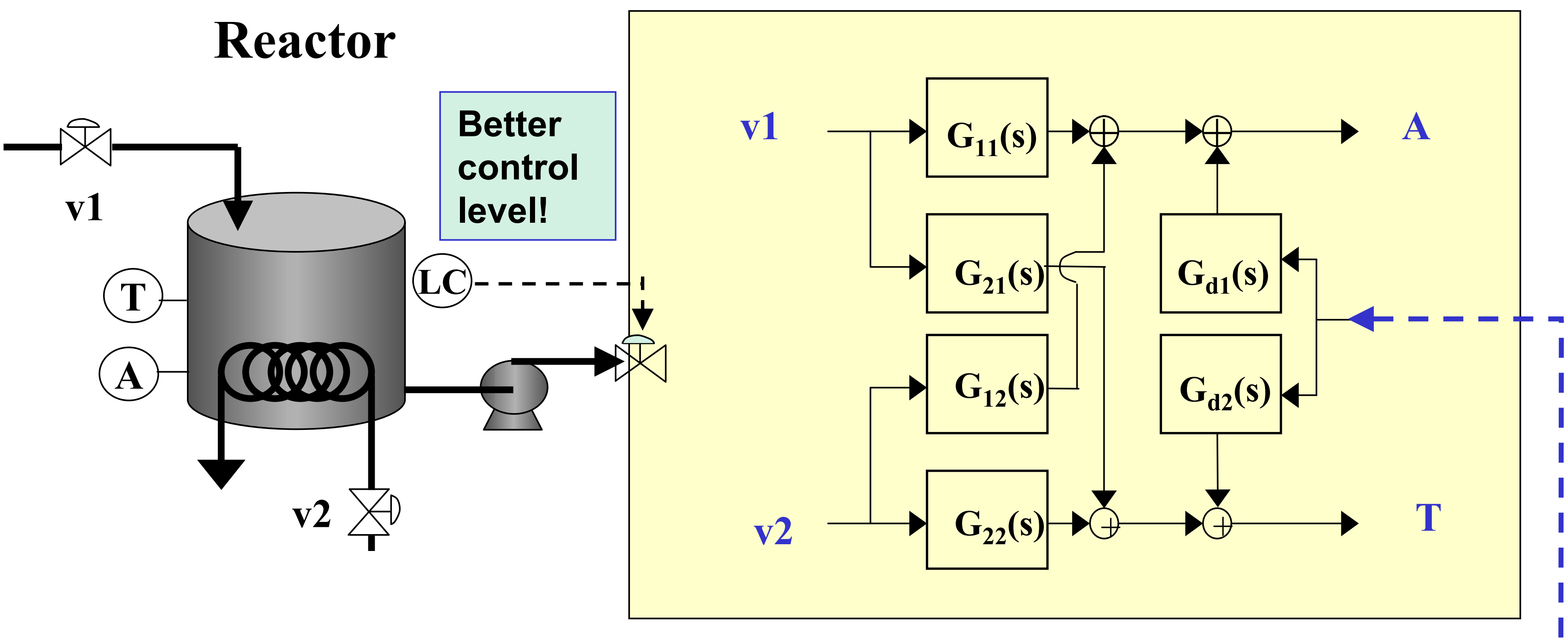


# CONTROL OF MULTIVARIABLE PROCESSES

**Let's relate the block diagram to a typical physical process. What are the MVs, CVs, and a disturbance, D?**




Disturbances = feed composition, feed temperature, coolant temperature, …

# CONTROL OF MULTIVARIABLE PROCESSES

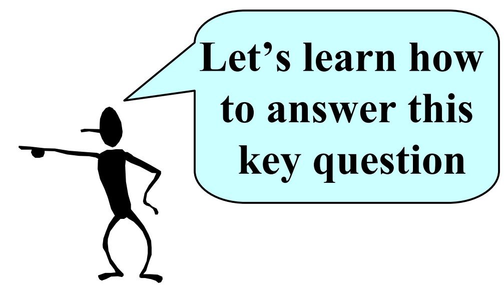
## Some key questions whose answers help us design a multiloop control system.

**IS INTERACTION PRESENT?**

- If no interaction $\Rightarrow$ All single-loop problems

2. **IS CONTROL POSSIBLE?**

- How many degrees of freedom exist?
- Can we control CVs with MVs?



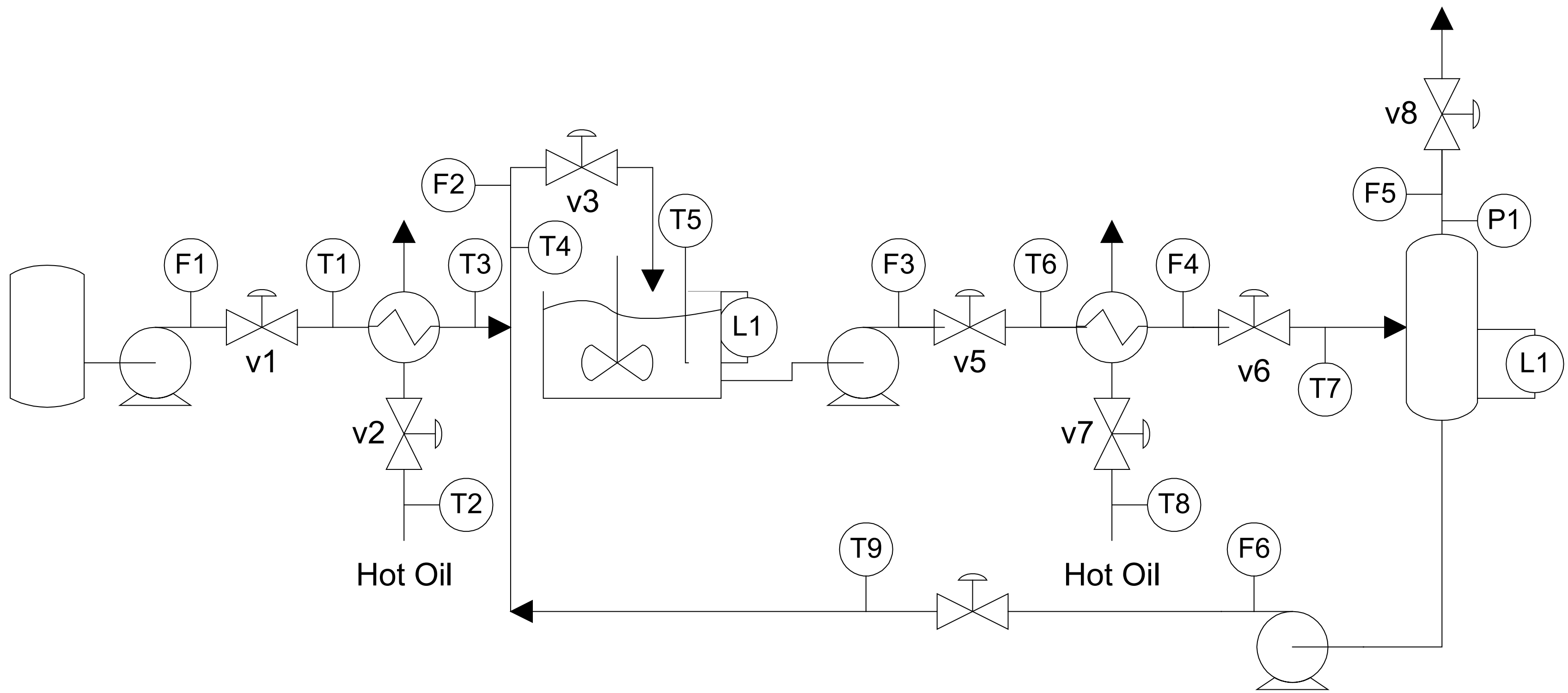

3. **WHAT IS S-S AND DYNAMIC BEHAVIOR?**

- Over what range can control keep CVs near the set points?

# CONTROL OF MULTIVARIABLE PROCESSES

## DEGREES OF FREEDOM

**How do we determine the maximum # variables that be controlled in a process?**

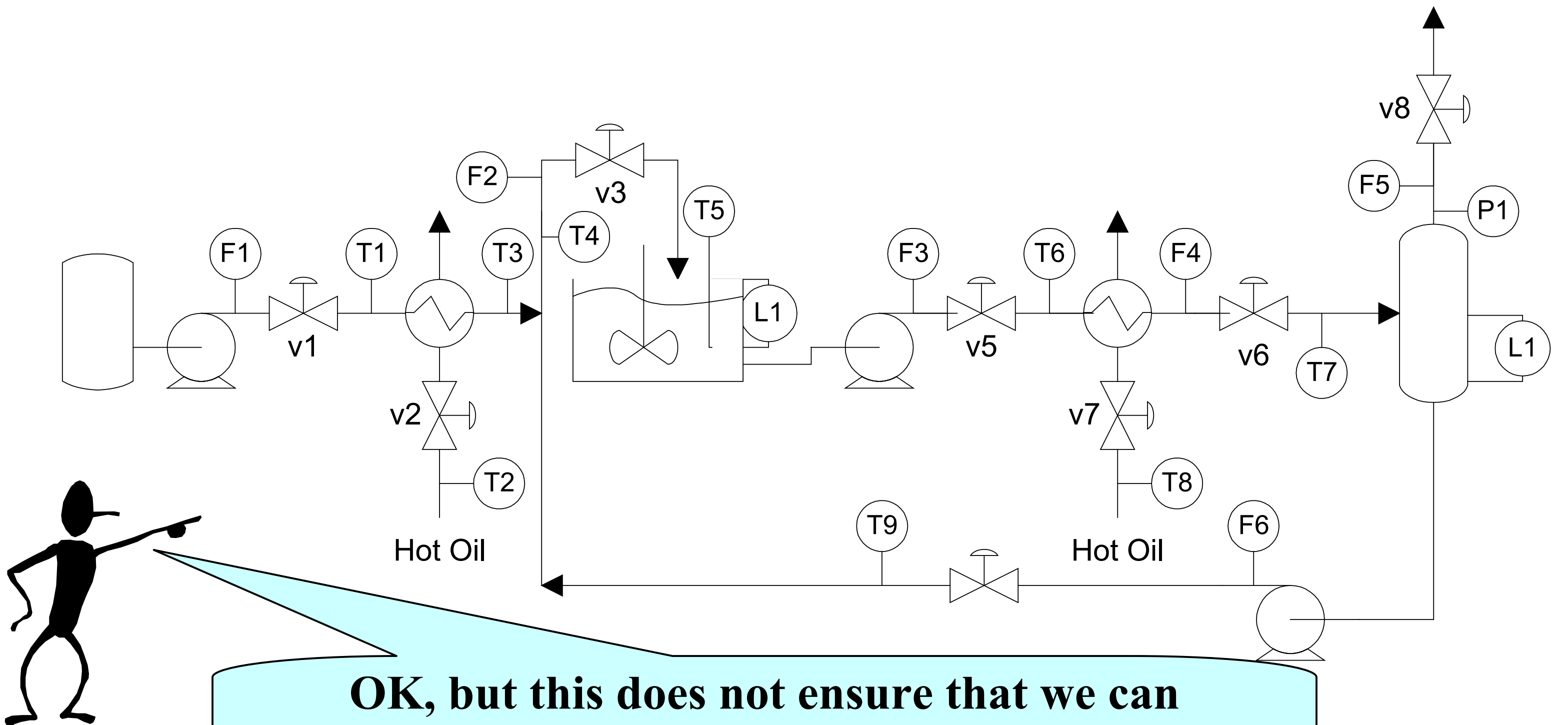


# CONTROL OF MULTIVARIABLE PROCESSES

## DEGREES OF FREEDOM

**A requirement for a successful design is:**

**The number of valves $\geq$ number of CV to be controlled**




**OK, but this does not ensure that we can control the CVs that we want to control!**

# CONTROL OF MULTIVARIABLE PROCESSES

## CONTROLLABILITY

**A system is controllable if its CVs can be maintained at their set points, in the steady-state, in spite of disturbances entering the system.**

**Model for 2x2 system**

$$\begin{bmatrix} CV_1 \\ CV_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{bmatrix} MV_1 \\ MV_2 \end{bmatrix} + \begin{bmatrix} K_{d1} \\ K_{d2} \end{bmatrix} D$$

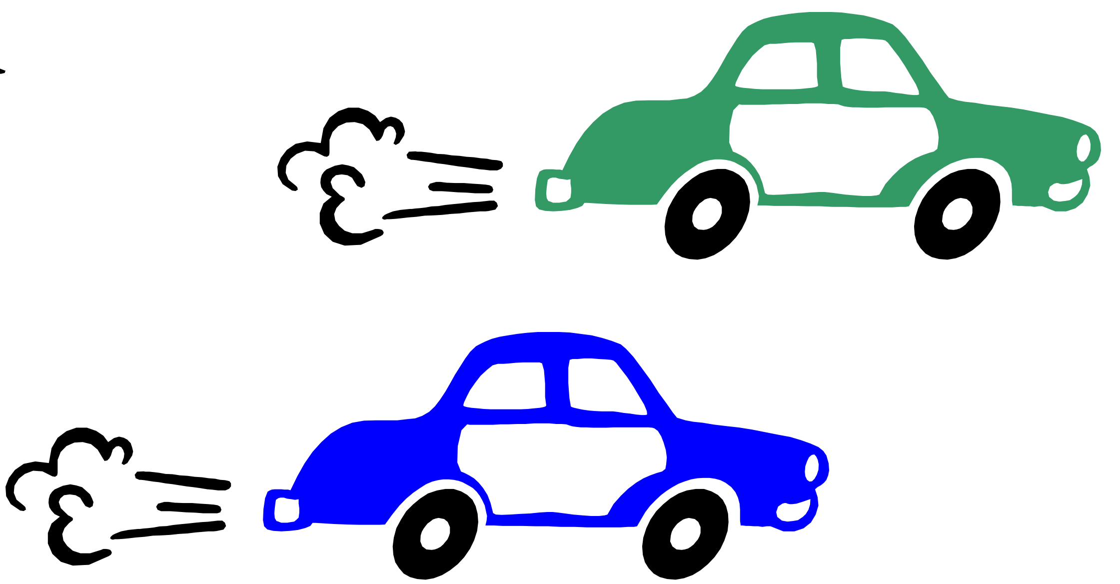
**A system is controllable when the matrix of process gains can be inverted, i.e., when the determinant of K ≠ 0.**

**I am in desperate need of examples**

# CONTROL OF MULTIVARIABLE PROCESSES


**<u>For the autos in the figure</u>**

- **Are they independently controllable?**
- **Does interaction exist?**



# CONTROL OF MULTIVARIABLE PROCESSES

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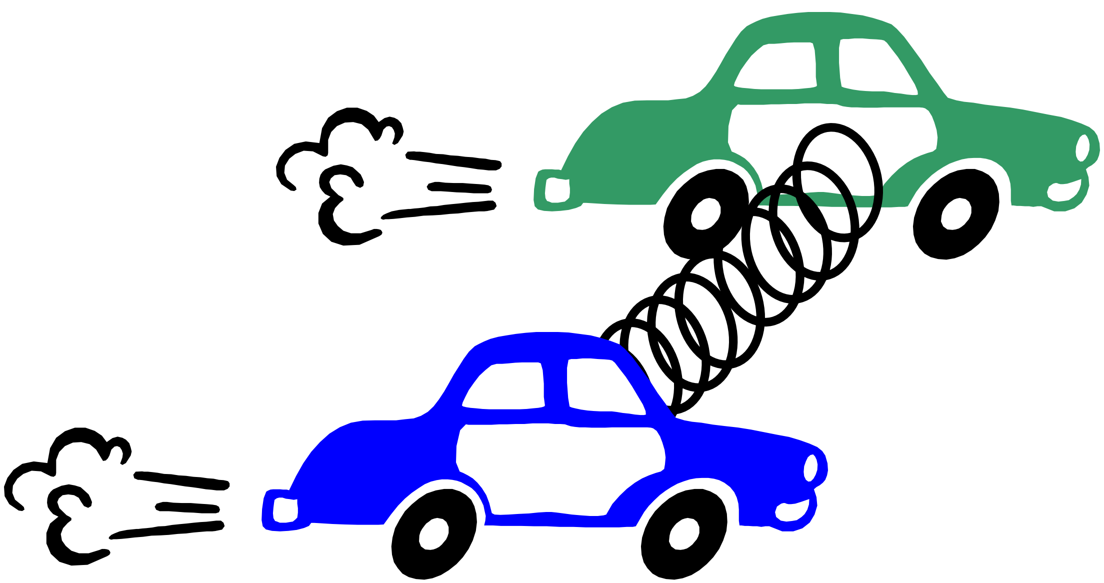

**Connected by spring**

# CONTROL OF MULTIVARIABLE PROCESSES

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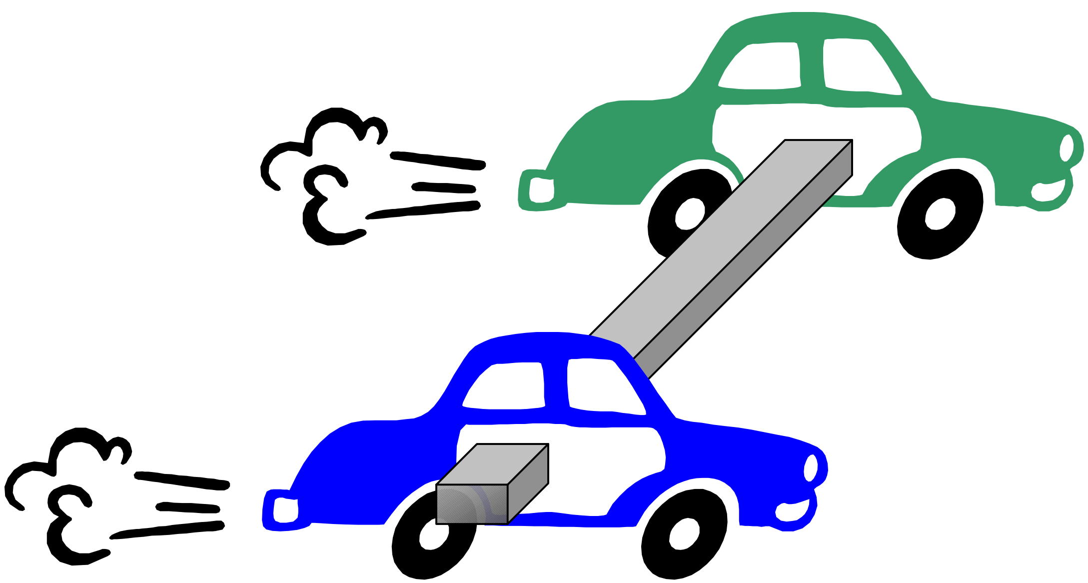
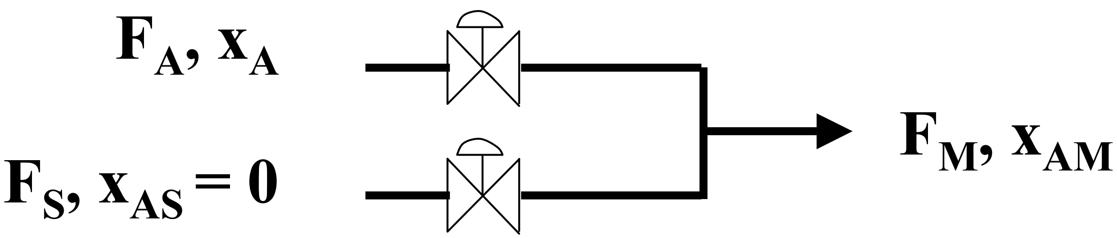


**Connected by beam**

# CONTROL OF MULTIVARIABLE PROCESSES

**For process Example #1: the blending process**

- **Are the CVs independently controllable?**
- **Does interaction exist?**




$$F'_M = F'_A + F'_S$$

$$x'_{AM} = \left[\frac{F_S}{(F_s + F_A)^2}\right]_{ss} F'_A + \left[\frac{-F_A}{(F_s + F_A)^2}\right]_{ss} F'_S$$

# CONTROL OF MULTIVARIABLE PROCESSES

**For process Example #1: the blending process**

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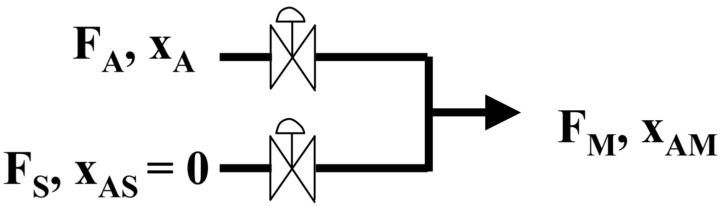


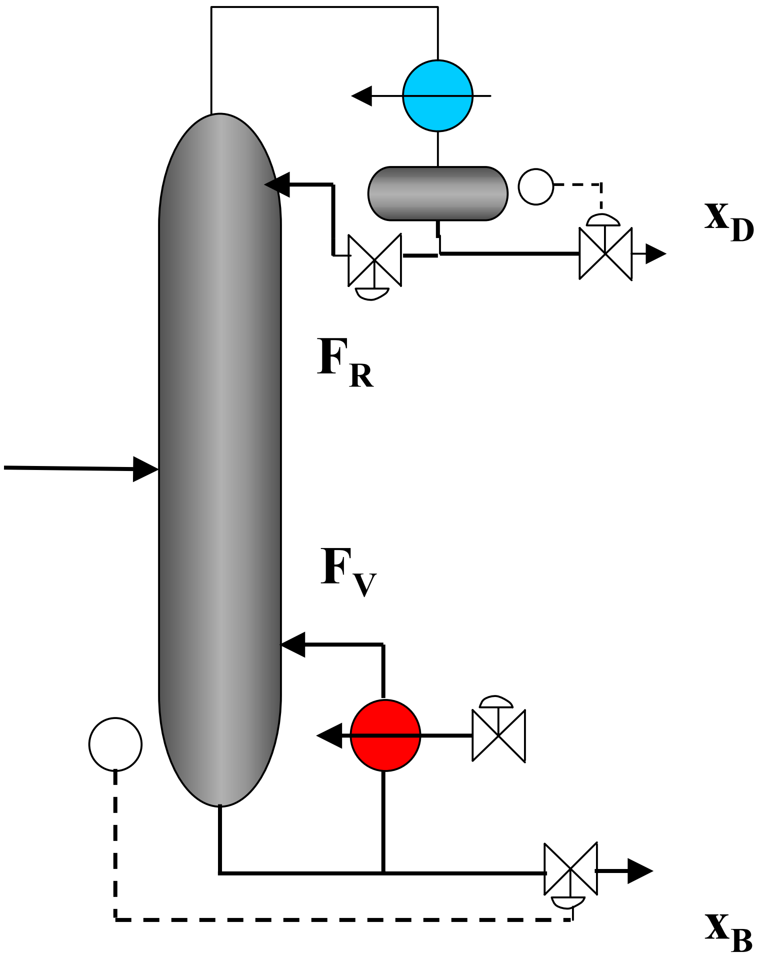

$$F'_M = F'_A + F'_S$$

$$x'_{AM} = \left[\frac{F_S}{(F_s + F_A)^2}\right]_{ss} F'_A + \left[\frac{-F_A}{(F_s + F_A)^2}\right]_{ss} F'_S$$

$$\mathrm{Det}(K) = \frac{-F_A^2}{(F_A + F_S)^2} - \frac{F_S^2}{(F_A + F_S)^2} \neq 0$$

**Yes, this system is controllable!**

# CONTROL OF MULTIVARIABLE PROCESSES



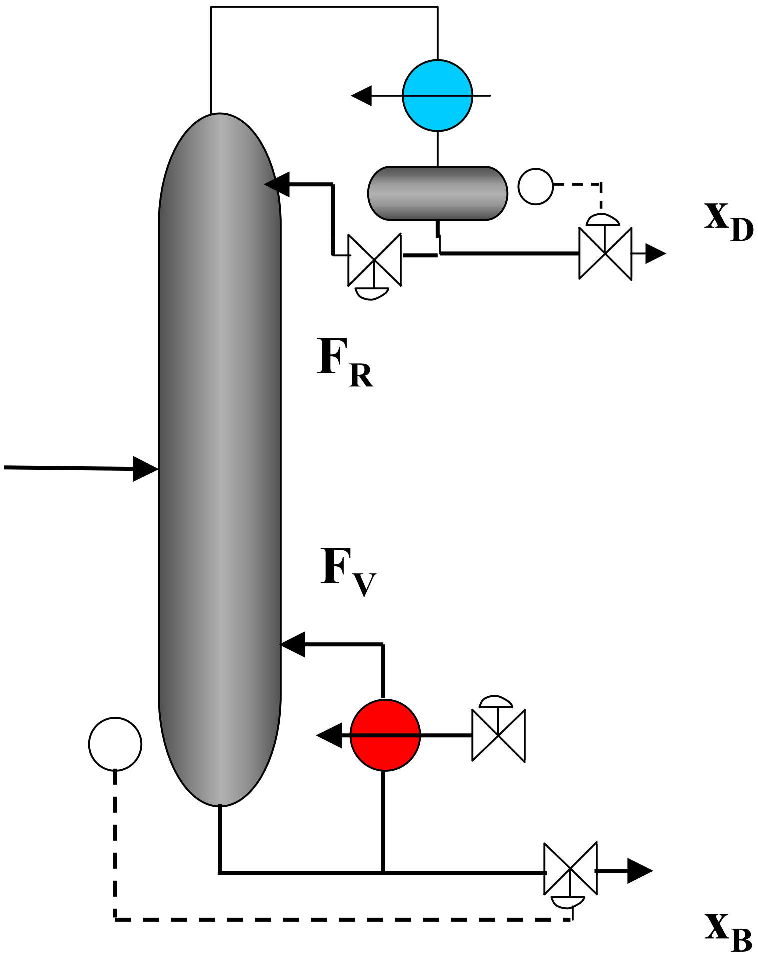

**For process Example #2: the distillation tower**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

$$x_D(s) = \frac{0.0747e^{-3s}}{12s+1}F_R(s) - \frac{0.0667e^{-2s}}{15s+1}F_V(s)$$

$$x_B(s) = \frac{0.1173e^{-3.3s}}{11.7s+1}F_R(s) - \frac{0.1253e^{-2s}}{10.2s+1}F_V(s)$$

# CONTROL OF MULTIVARIABLE PROCESSES

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$$x_B(s) = \frac{0.1173e^{-3.3s}}{11.7s+1}F_R(s) - \frac{0.1253e^{-2s}}{10.2s+1}F_V(s)$$

**Det (K) = 1.54 x $10^{-3} \neq 0$**

**Small but not zero (each gain is small)**

**The system is controllable!**

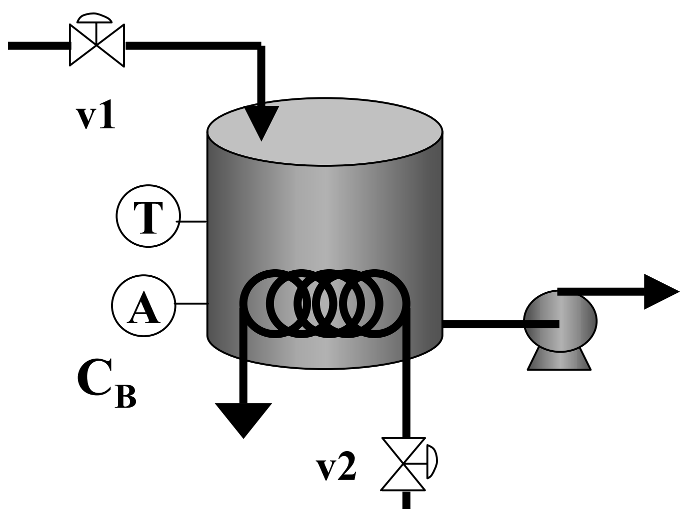
# CONTROL OF MULTIVARIABLE PROCESSES

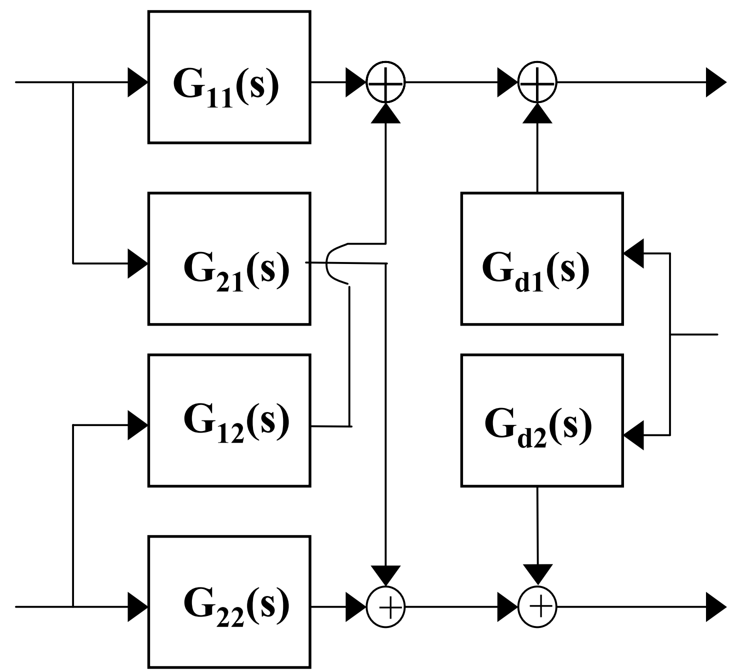
**For process Example #3: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

$$A \rightarrow B$$

$$-r_A = k_0\, e^{-E/RT}\, C_A$$



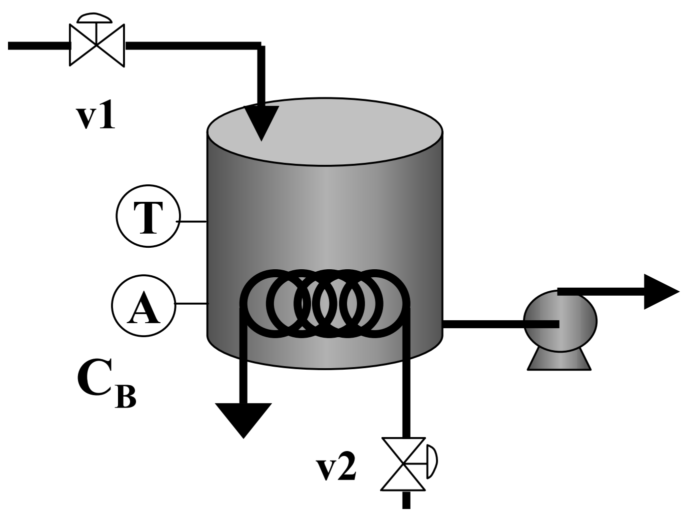
# CONTROL OF MULTIVARIABLE PROCESSES

**For process Example #3: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

$$A \rightarrow B$$

$$-r_A = k_0 \, e^{-E/RT} \, C_A$$




**The interaction can be strong**

**In general, the temperature and conversion (extent of reaction) can be influenced.**

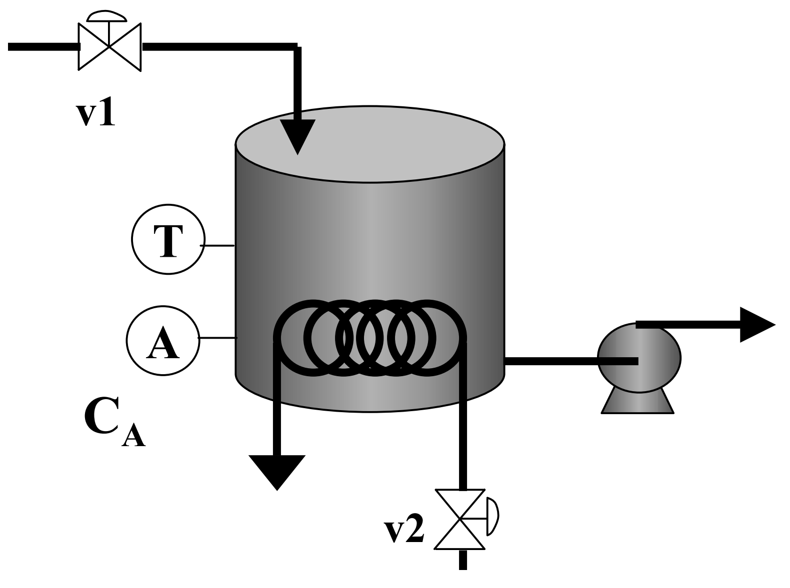
**The system is controllable.**

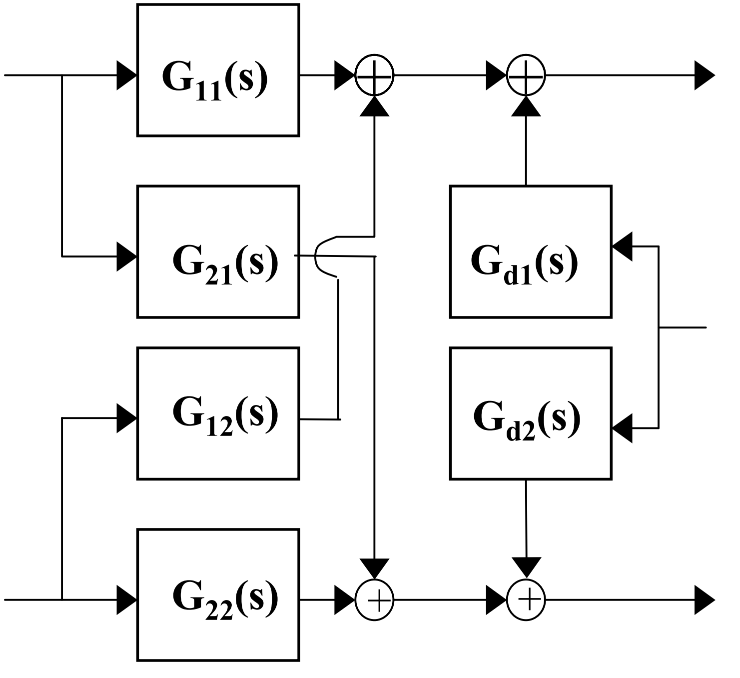
**(See Appendix 3 for examples)**

# CONTROL OF MULTIVARIABLE PROCESSES

**For process Example #4: the mixing tank**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

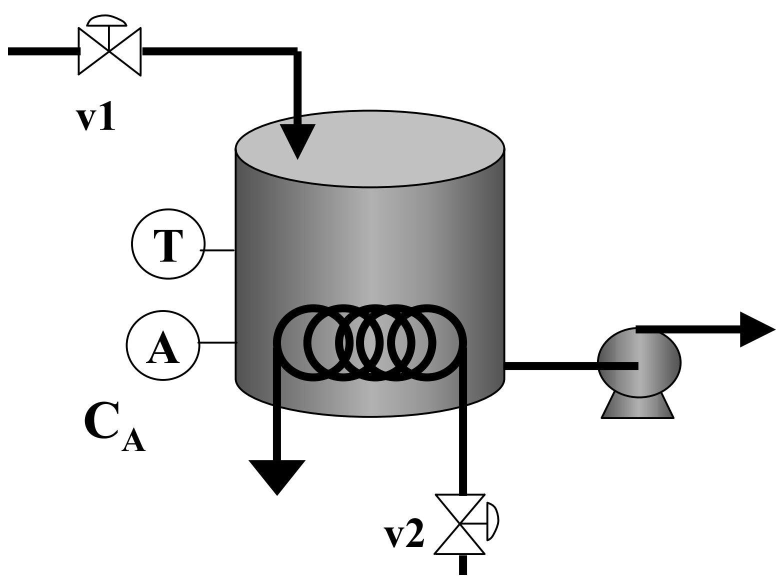


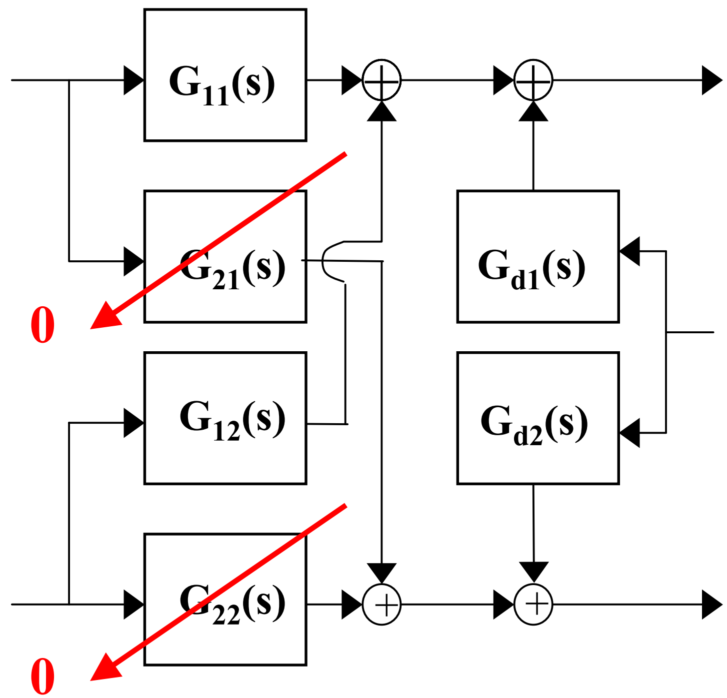



# CONTROL OF MULTIVARIABLE PROCESSES

**<u>For process Example #4: the mixing tank</u>**

- **Are the CVs independently controllable?**
- **Does interaction exist?**




**Nothing affects composition at S-S; the system is NOT controllable.**

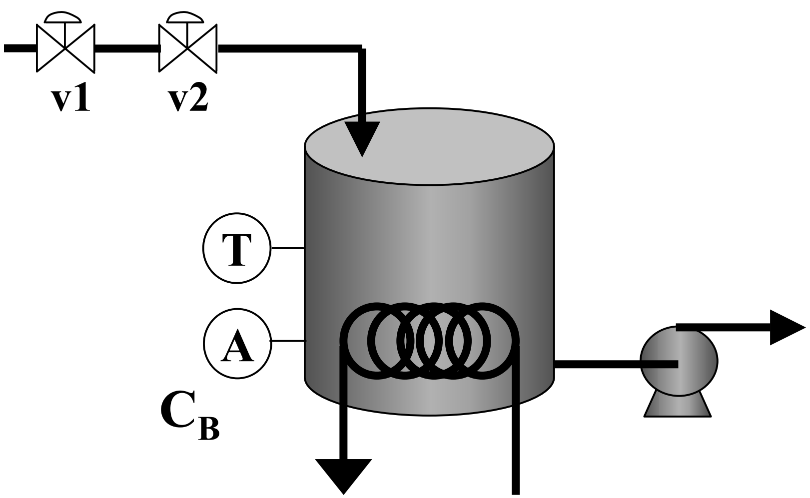
# CONTROL OF MULTIVARIABLE PROCESSES

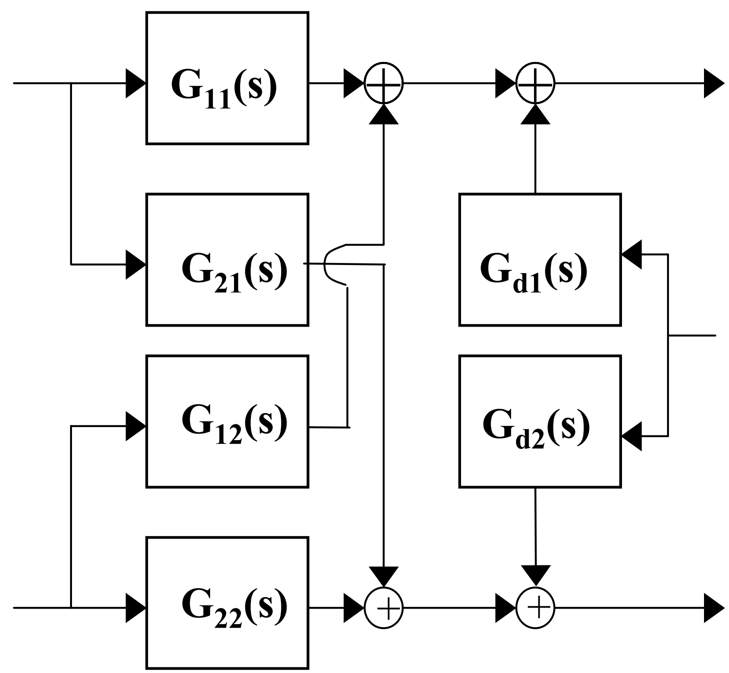
**For process Example #5: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

$$A \rightarrow B$$

$$-r_A = k_0\, e^{-E/RT}\, C_A$$



# CONTROL OF MULTIVARIABLE PROCESSES

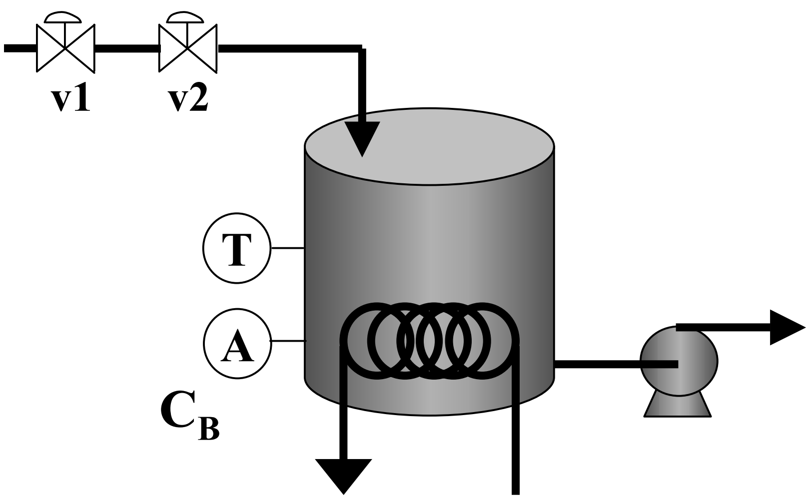
## For process Example #5: the non-isothermal CSTR

- **Are the CVs independently controllable?**
- **Does interaction exist?**

**Solution continued on next slide**

$$A \rightarrow B$$

$$-r_A = k_0\, e^{-E/RT}\, C_A$$



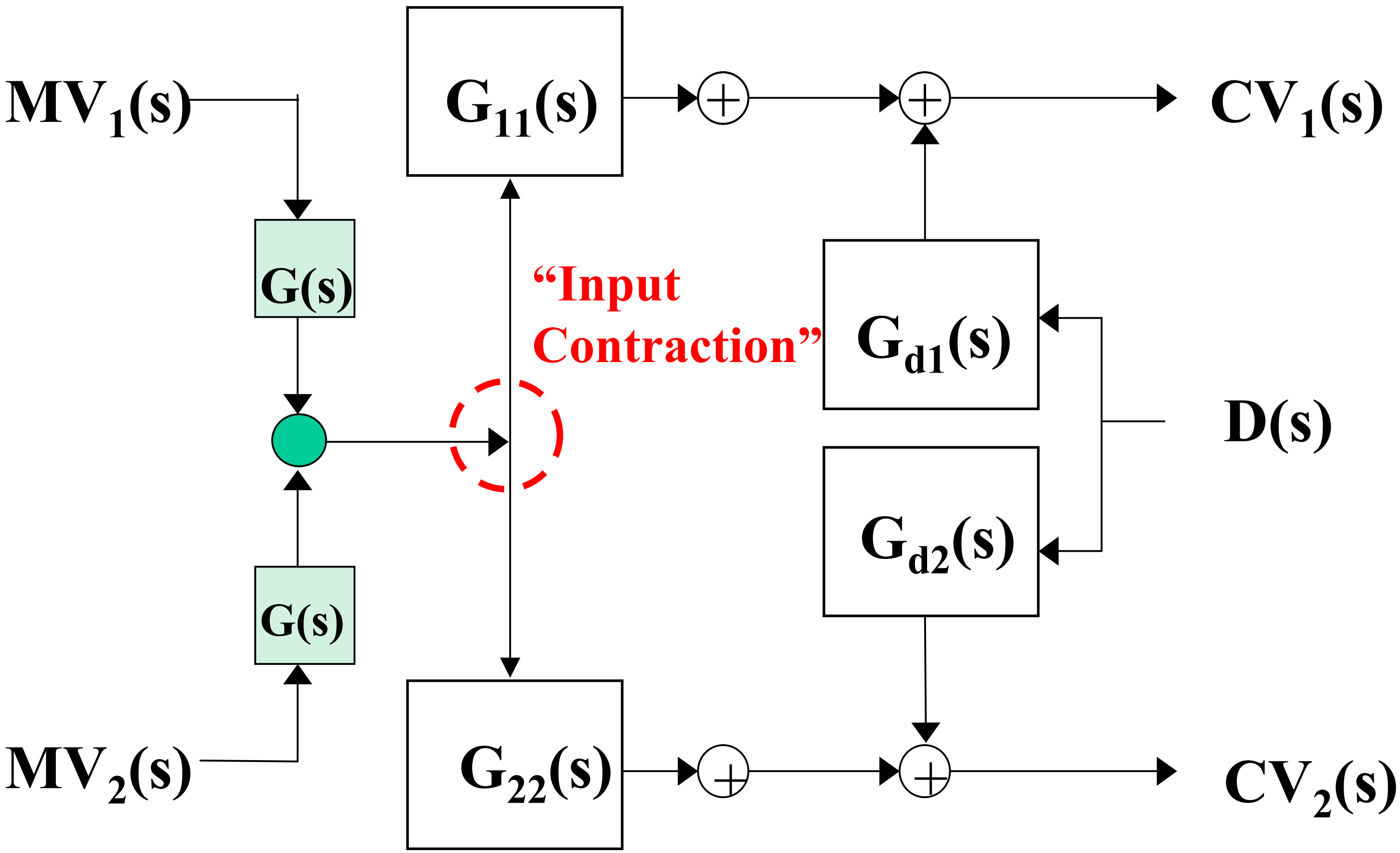

**Both valves have the same effects on both variables; the only difference is the magnitude of the flow change (μ = constant).**

$$\begin{bmatrix} C_B \\ T \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} K_{11} & \mu\, K_{11} \\ K_{21} & \mu\, K_{21} \end{bmatrix} \begin{bmatrix} MV_1 \\ MV_2 \end{bmatrix}$$

**Det (K) = 0; not controllable!**

## For process Example #5: the non-isothermal CSTR

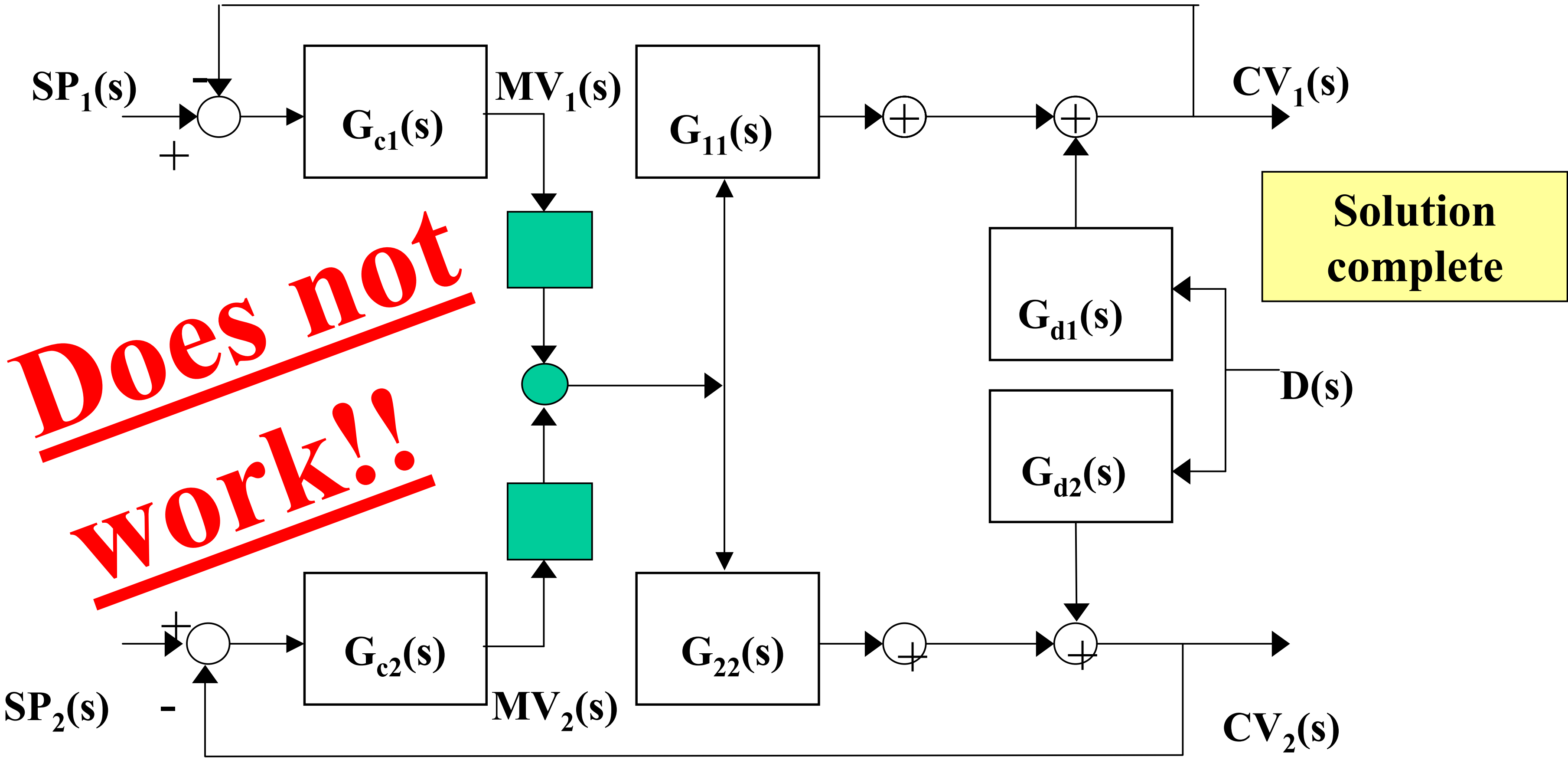
**In this case, both MVs affect ONE common variable, and this common variable affects both CVs. We can change both CVs, but we cannot move the CVs to independent values!**




Solution continued on next slide

**For process Example #5: the non-isothermal CSTR**

**For input contraction, multivariable feedback control is not possible; the system is not controllable! We can change both CVs, but we cannot move the CVs to independent values!**



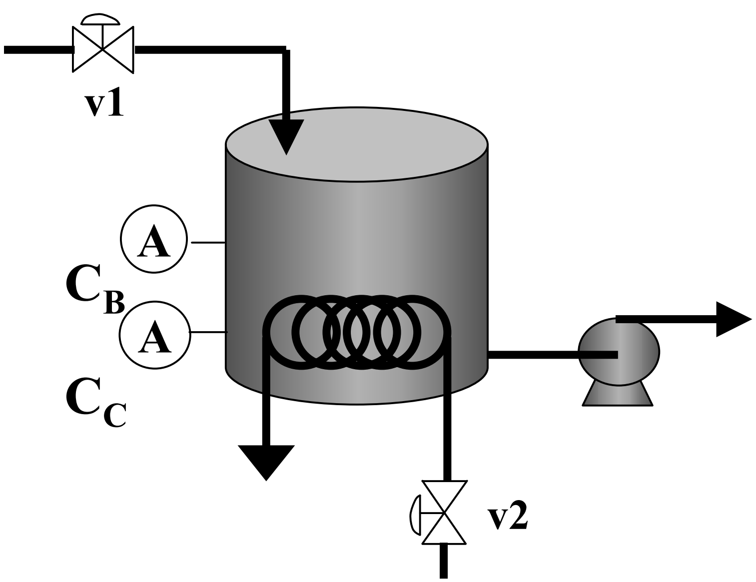
# CONTROL OF MULTIVARIABLE PROCESSES

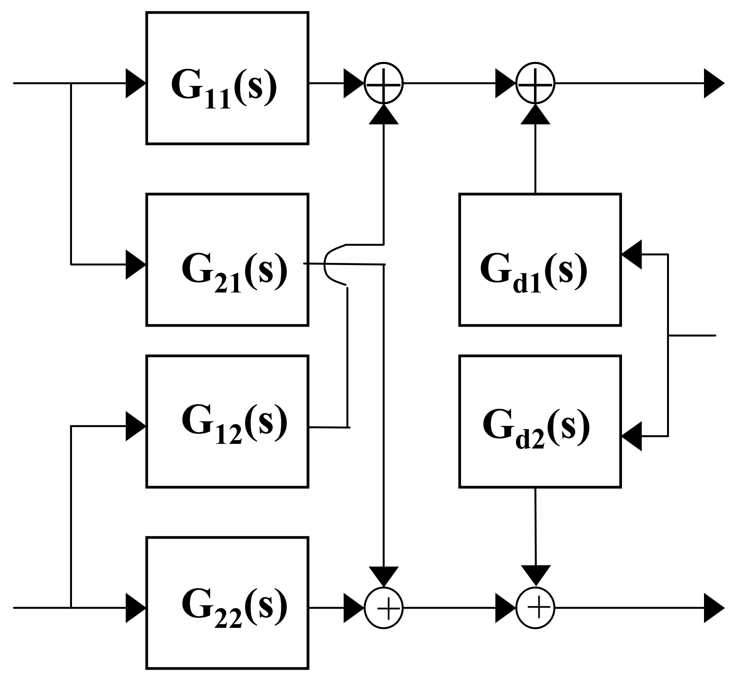
**For process Example #6: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

$$A \rightarrow B + 2C$$

$$-r_A = k_0 \, e^{-E/RT} \, C_A$$



# CONTROL OF MULTIVARIABLE PROCESSES

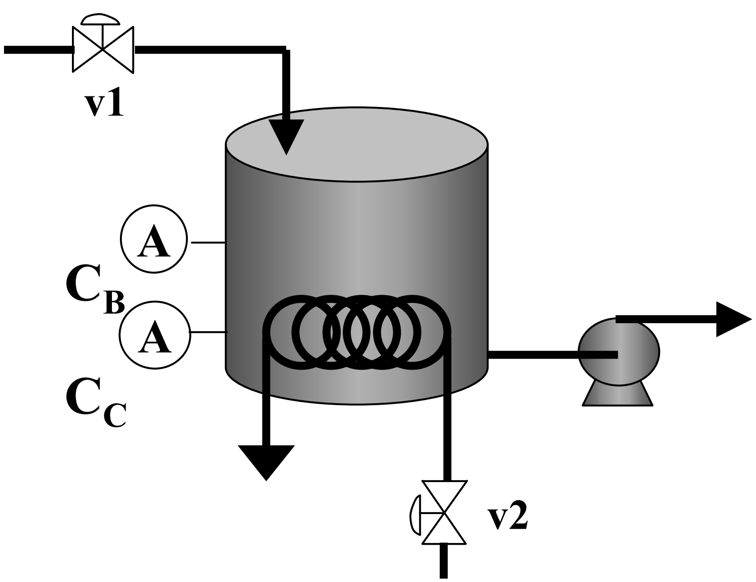
**For process Example #6: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

**Solution continued on next slide**

$$A \rightarrow B + 2C$$

$$-r_A = k_0\, e^{-E/RT}\, C_A$$




**Using the symbol $N_i$ for the number of moles of component "i" that reacts, we have the following.**

$$N_B = -N_A \qquad N_C = -2N_A$$

**Because of the stoichiometry,**

$$N_C = 2\, N_B$$

**and the system is not controllable!**

# CONTROL OF MULTIVARIABLE PROCESSES

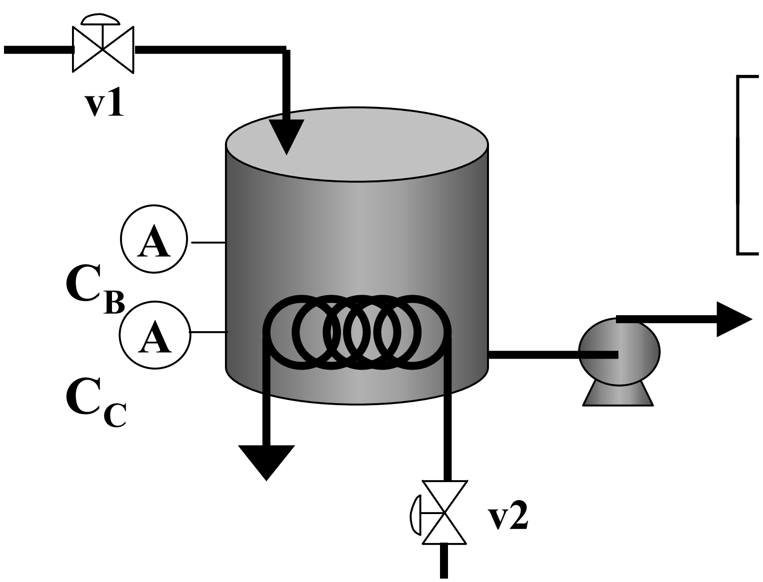
**For process Example #6: the non-isothermal CSTR**

- **Are the CVs independently controllable?**
- **Does interaction exist?**

**Solution continued on next slide**

$$\mathbf{A \rightarrow B + 2C}$$

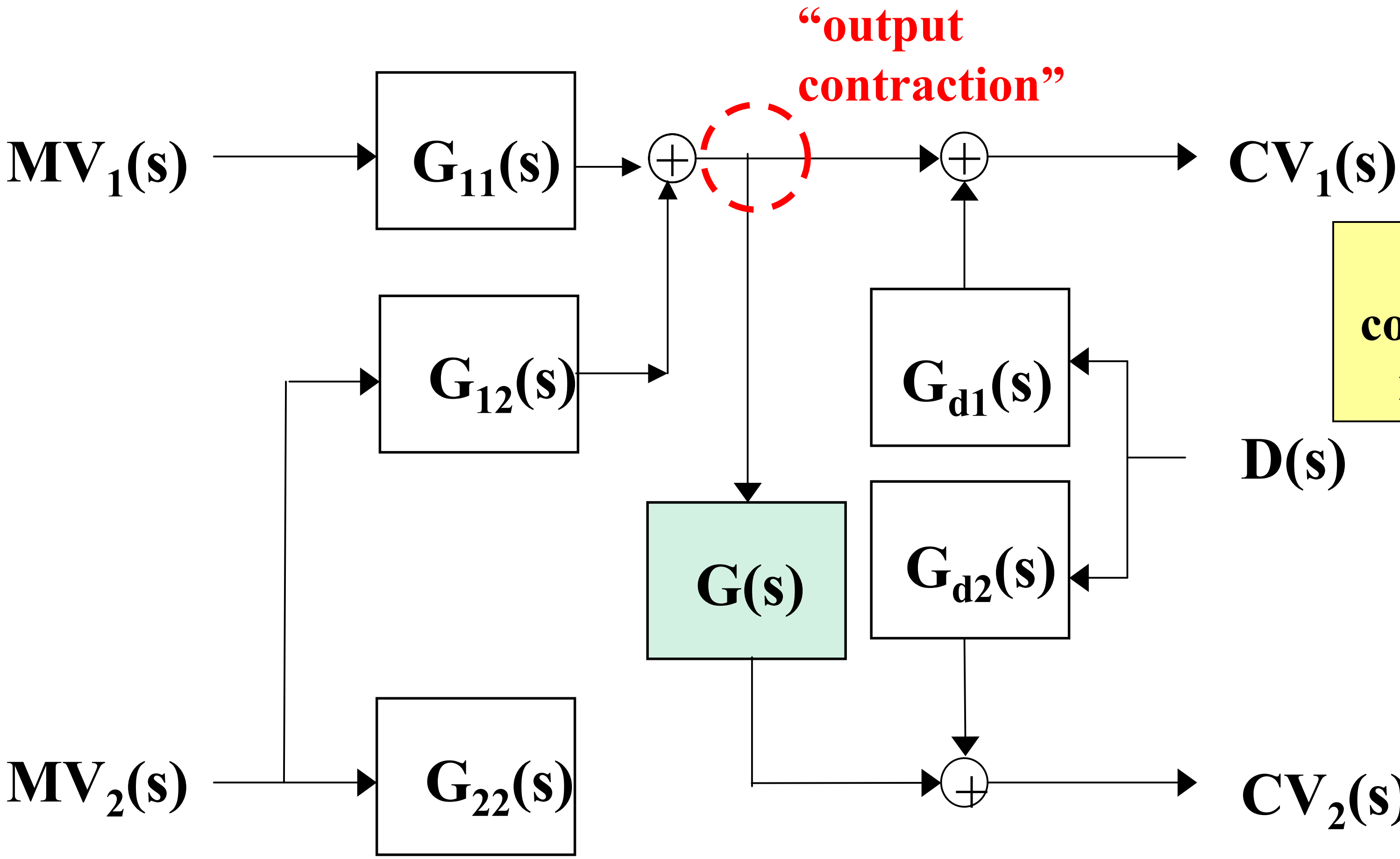
$$-r_A = k_0\, e^{-E/RT}\, C_A$$




$$\begin{bmatrix} C_B \\ C_C \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} K_{11} & K_{11} \\ 2K_{21} & 2\,K_{21} \end{bmatrix} \begin{bmatrix} MV_1 \\ MV_2 \end{bmatrix}$$

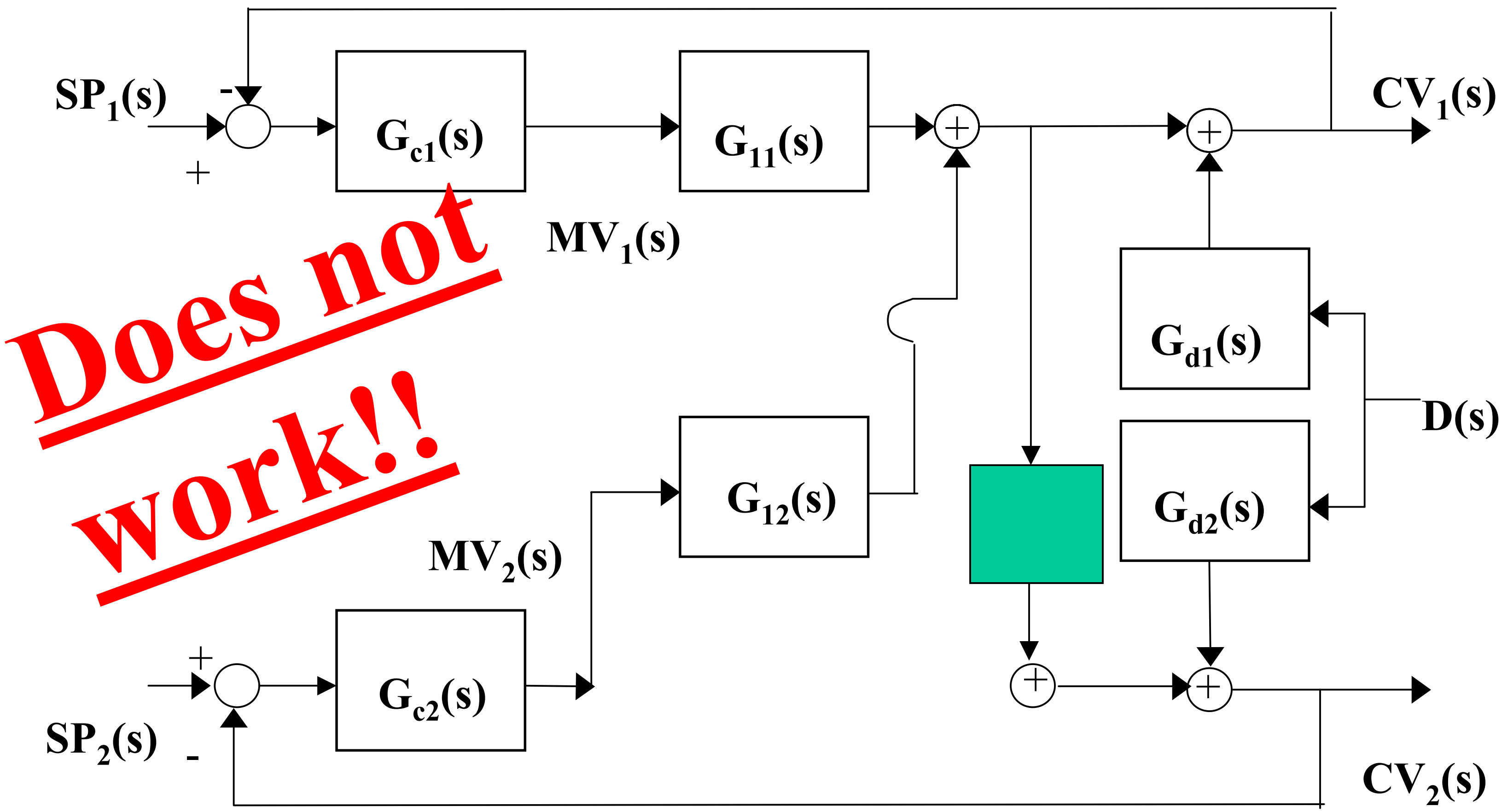
**Det (K) = 0; not controllable!**

**For output contraction, both MVs affect both CVs, but the CVs are related through the physics and chemistry. We can change both CVS, but we cannot move the CVs to <u>independent</u> values!**




**Solution continued on next slide**

In this case, multivariable feedback control is not possible; the system is uncontrollable!




Solution complete

# CONTROL OF MULTIVARIABLE PROCESSES

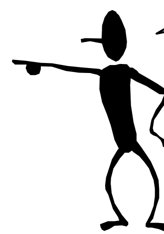
## CONTROLLABILITY

### Conclusions about determining controllability

Lack of controllability when

1. One CV cannot be affected by any valve

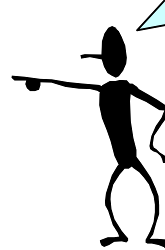
This is generally easy to determine.



3. Lack of <u>independent</u> effects.

   Look for "contractions"

This requires care and process insight or modelling to determine.



# CONTROL OF MULTIVARIABLE PROCESSES

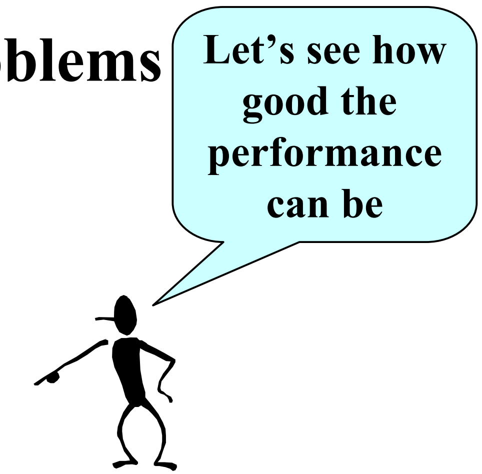
**Some key questions whose answers help us design a multiloop control system.**

## IS INTERACTION PRESENT?

- If no interaction $\Rightarrow$ All single-loop problems

## IS CONTROL POSSIBLE?

- How many degrees of freedom exist?
- Can we control CVs with MVs?

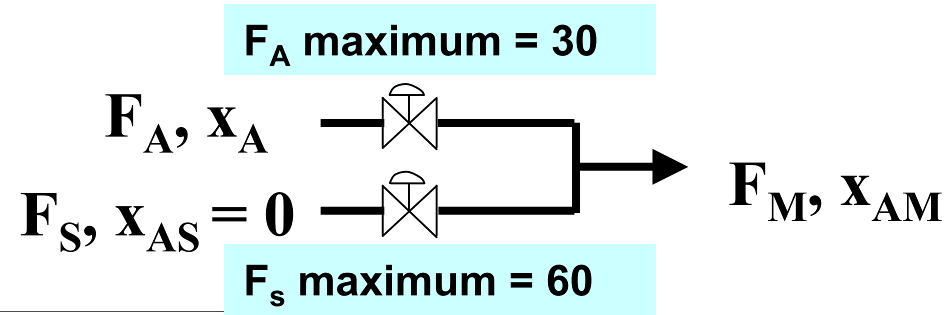


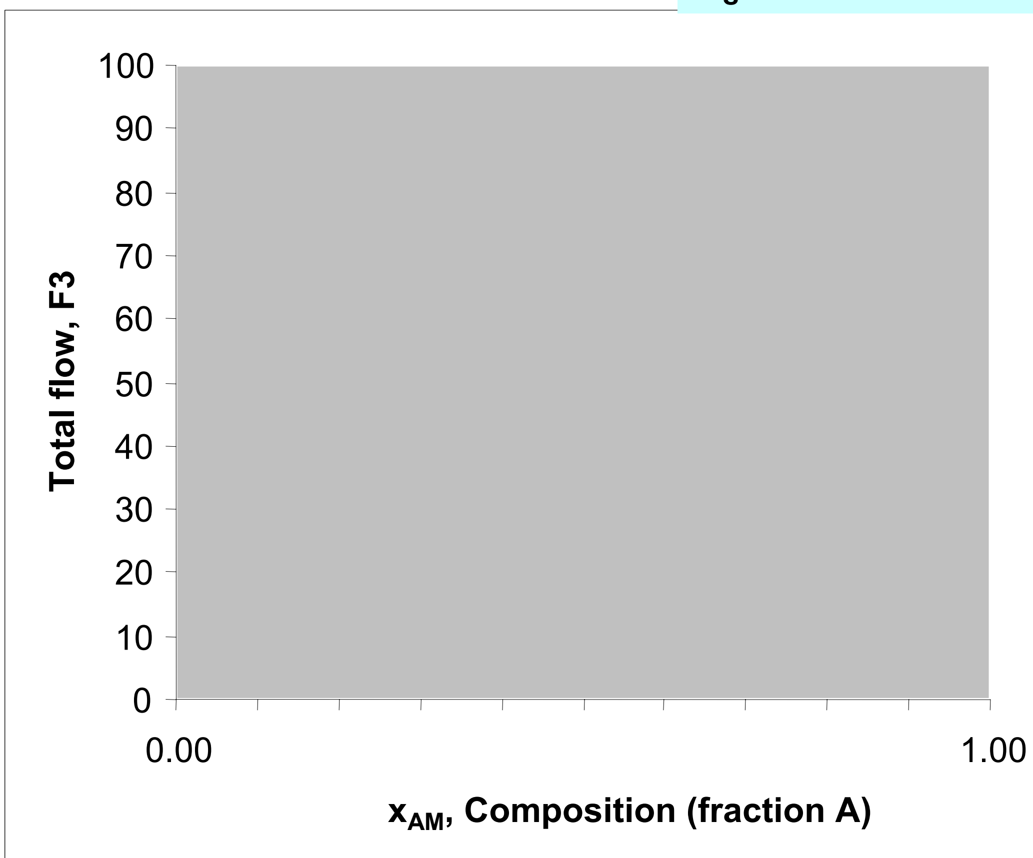

## 3. WHAT IS S-S AND DYNAMIC BEHAVIOR?

- Over what range can control keep CVs near the set points?

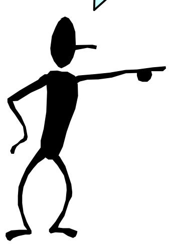
# CONTROL OF MULTIVARIABLE PROCESSES

**How does interaction affect the steady-state behavior of the blending process?**



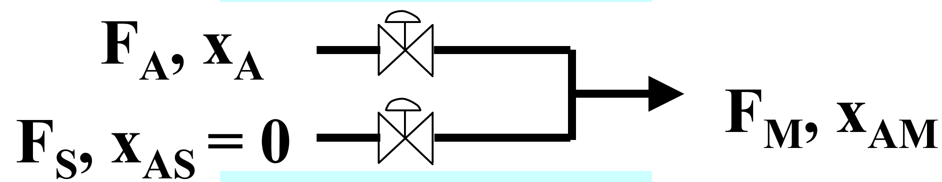

Please sketch the achievable values



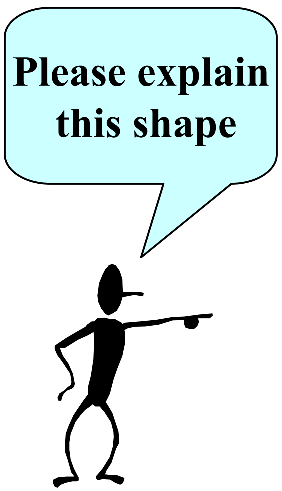
# CONTROL OF MULTIVARIABLE PROCESSES

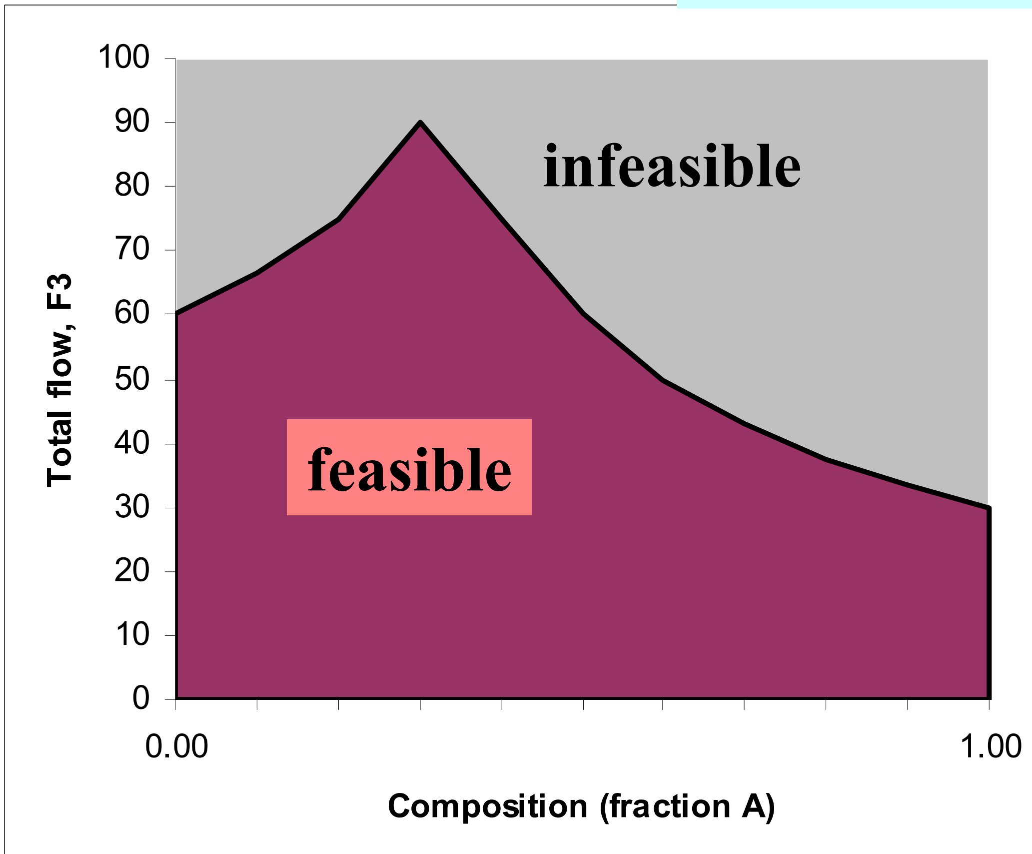
**How does interaction affect the steady-state behavior of the blending process?**

$F_A$ maximum = 30




$F_s$ maximum = 60



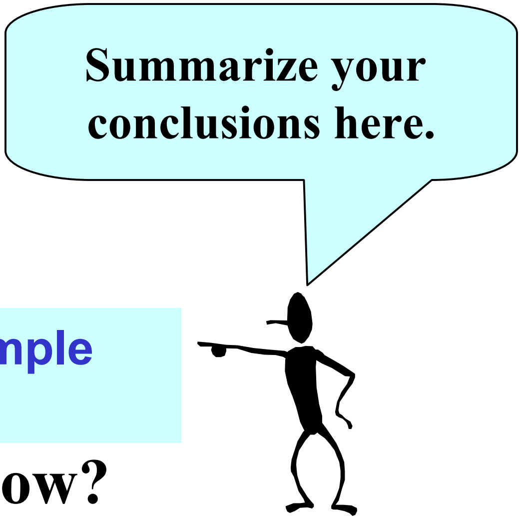

**Note:**

**This shows a range of set points that can be achieved (without disturbances).**

# CONTROL OF MULTIVARIABLE PROCESSES

## STEADY-STATE OPERATING WINDOW

**Conclusions about the steady-state behavior of a multivariable process**




1. **Shape of the Window**

   The operating window is not generally a simple shape, like a rectangle.

2. **What influences the size of the Window?**

   The operating window is influenced by process chemistry, equipment capacity, disturbances …

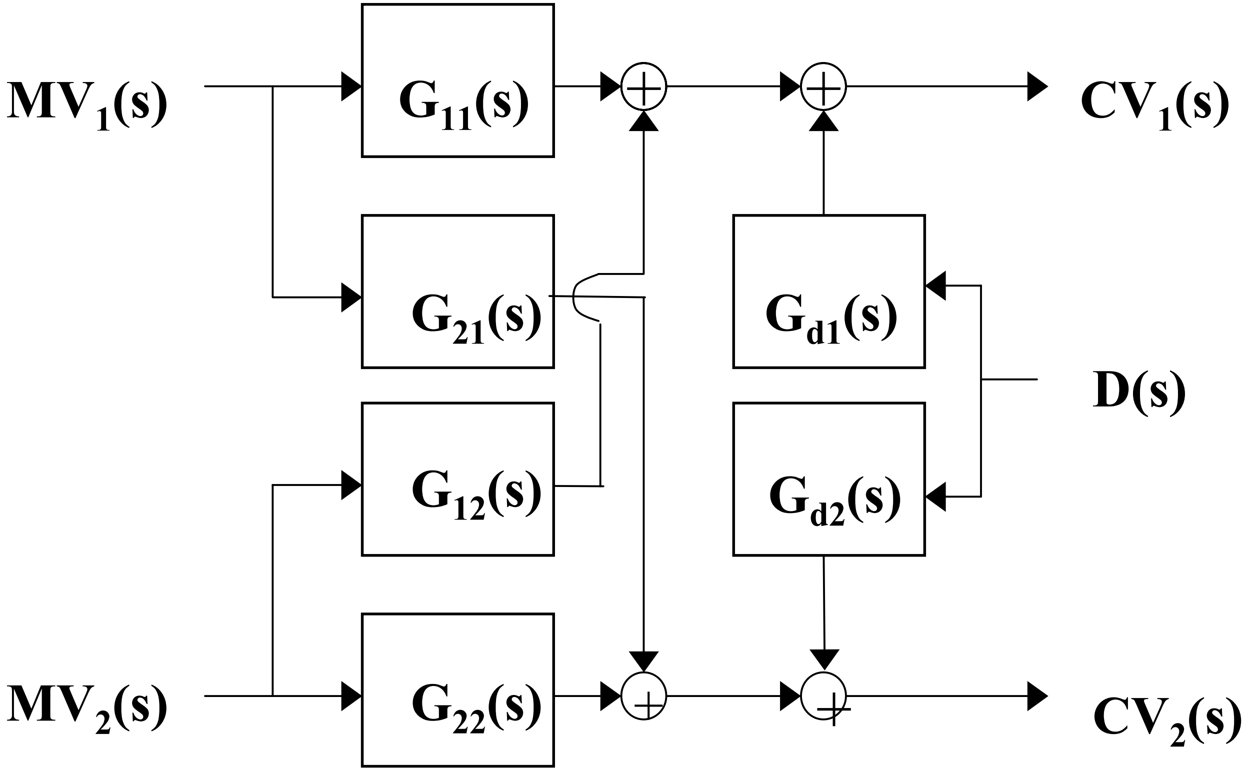
3. **How does Window relate to Controllability?**

   Process cannot be "moved" (controlled) outside of the window. If operating window is empty, the system is not controllable.

# CONTROL OF MULTIVARIABLE PROCESSES

## NOW, LET'S LOOK AT THE DYNAMIC BEHAVIOR

1. How many experiments are needed to tune controllers?
2. Which controller should be implemented first?



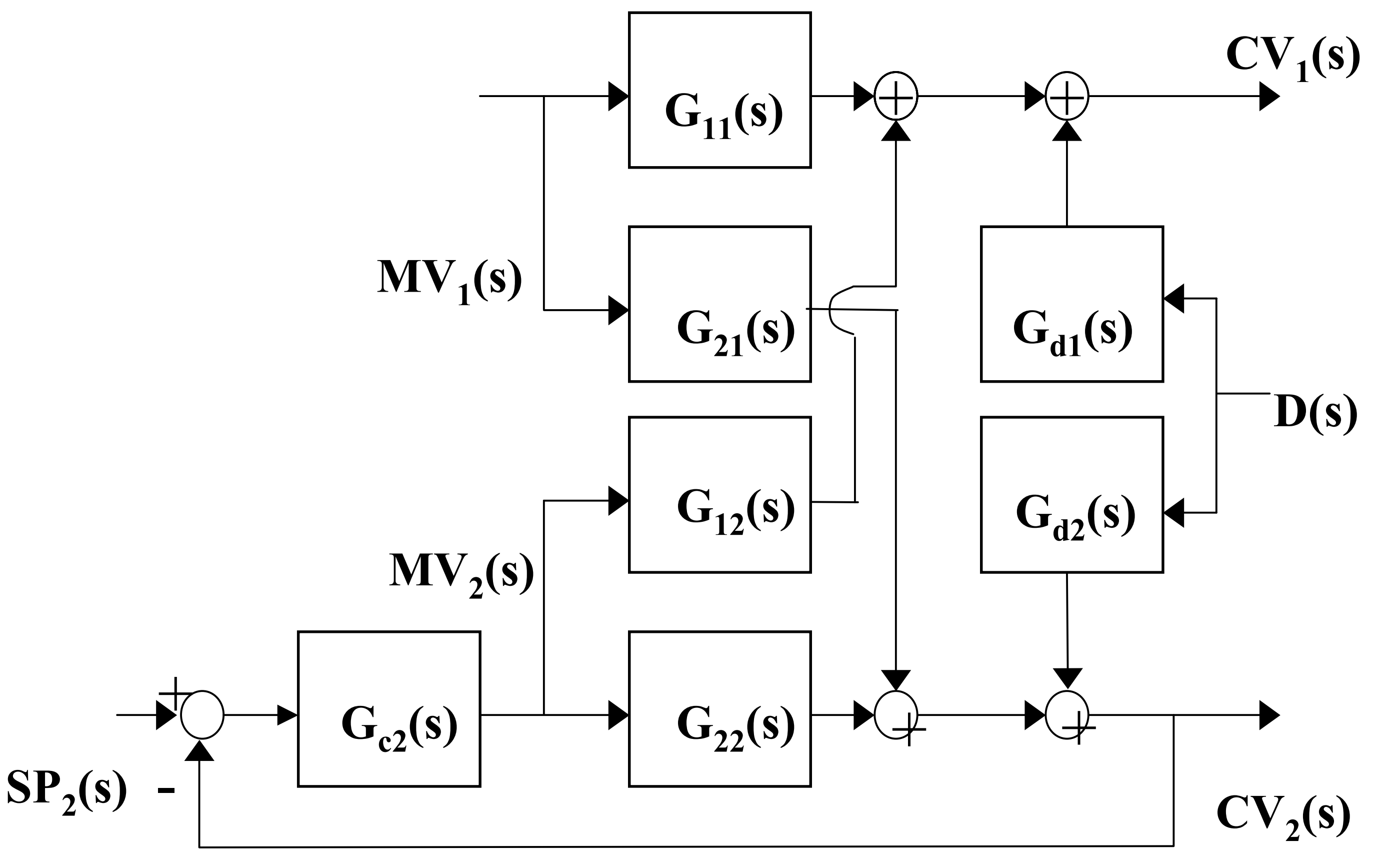

$$\frac{CV_1(s)}{MV_1(s)}$$

**To tune each controller, we need**

$$\frac{CV_2(s)}{MV_2(s)}$$

# CONTROL OF MULTIVARIABLE PROCESSES

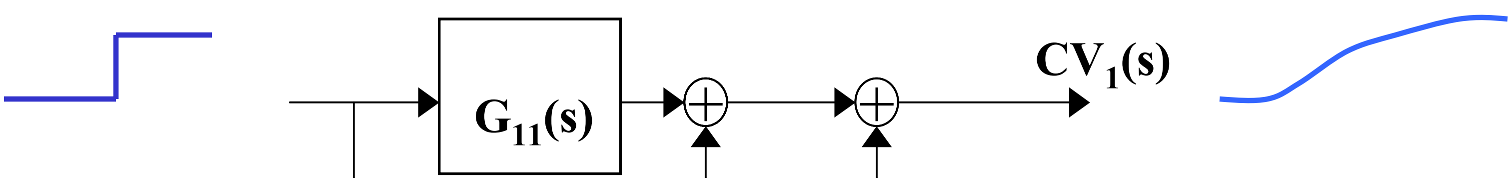
3. We have implemented one controller. What do we do now?



# CONTROL OF MULTIVARIABLE PROCESSES

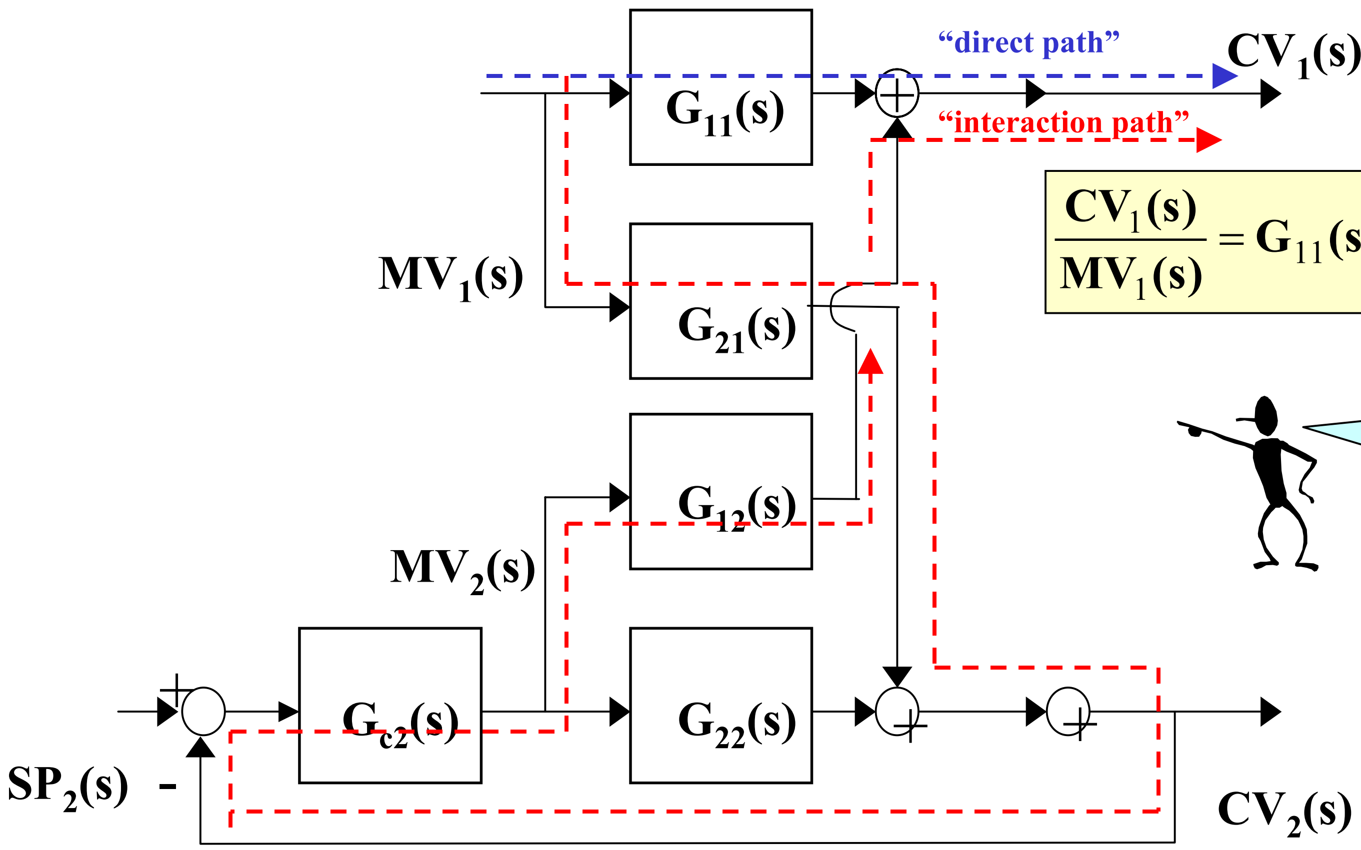
4. What if we perform another experiment to learn the dynamics between $MV_1$ and $CV_1$, with controller #2 in automatic?

   Is the dynamic behavior different from without second controller ($G_{C2}$)? What elements does the behavior depend upon?

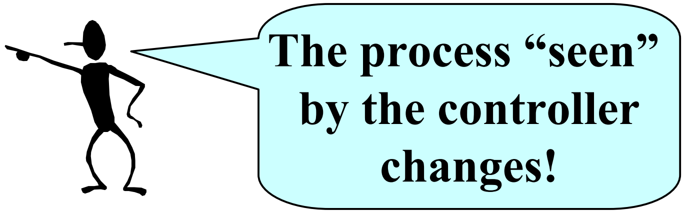


# CONTROL OF MULTIVARIABLE PROCESSES

**4. Is the dynamic behavior different from without second controller ($G_{C2}$)? What elements does the behavior depend upon?**

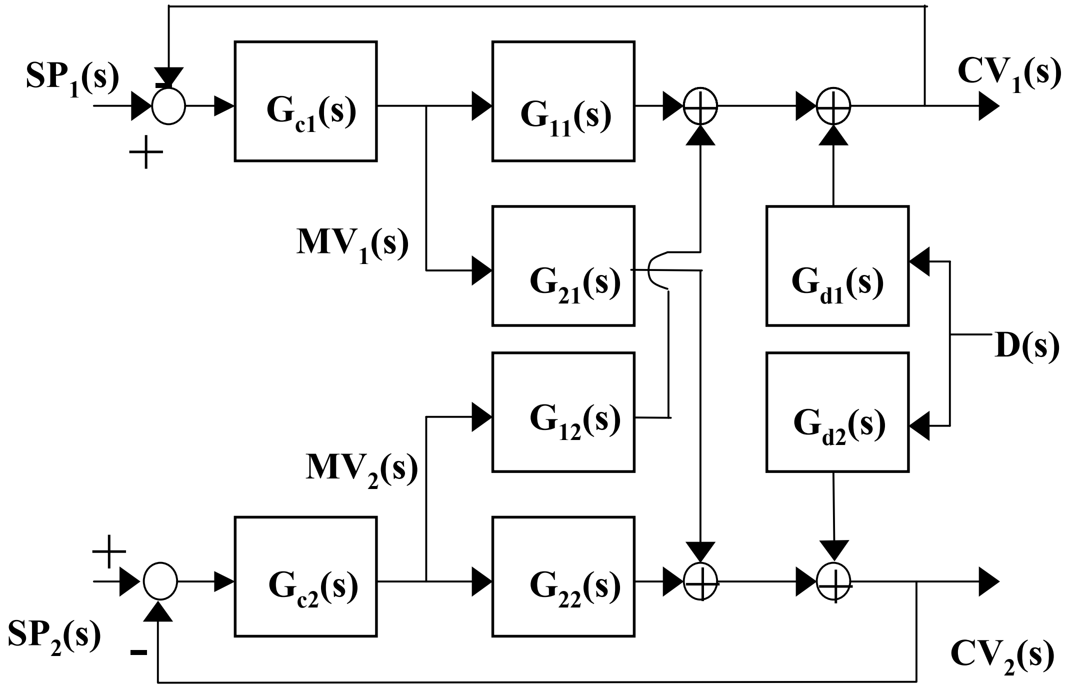



$$\frac{CV_1(s)}{MV_1(s)} = G_{11}(s) - \frac{G_{12}(s)G_{21}(s)G_{c2}(s)}{1+G_{c2}(s)G_{22}(s)}$$



# CONTROL OF MULTIVARIABLE PROCESSES

**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**




- **Tuning that is stable for each loop might not be stable when both are in operation!**
- **We need to tune loops iteratively, until we obtain good performance for all loops!**

**I think that I need an example again!**

# CONTROL OF MULTIVARIABLE PROCESSES

**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**

**Let's look at a simple example with interaction,**

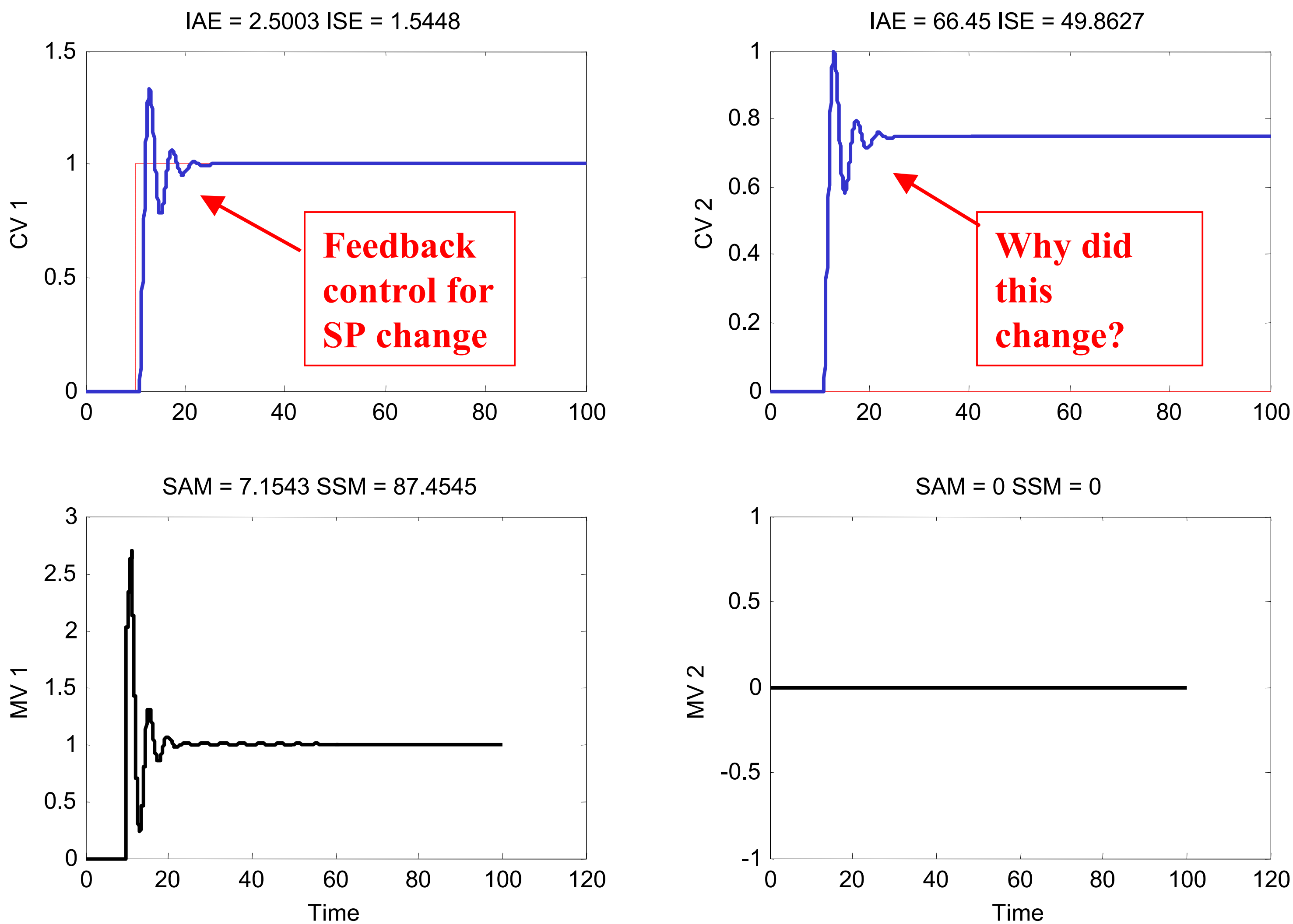
$$\begin{bmatrix} CV_1(s) \\ CV_2(s) \end{bmatrix} = \begin{bmatrix} \dfrac{1.0e^{-1.0s}}{1+2s} & \dfrac{0.75e^{-1.0s}}{1+2s} \\ \dfrac{0.75e^{-1.0s}}{1+2s} & \dfrac{1.0e^{-1.0s}}{1+2s} \end{bmatrix} \begin{bmatrix} MV_1(s) \\ MV_2(s) \end{bmatrix}$$

**We will pair the loops on the "strongest" gains,**

$$MV_1(s) \Rightarrow CV_1(s) \quad \text{and} \quad MV_2(s) \Rightarrow CV_2(s)$$

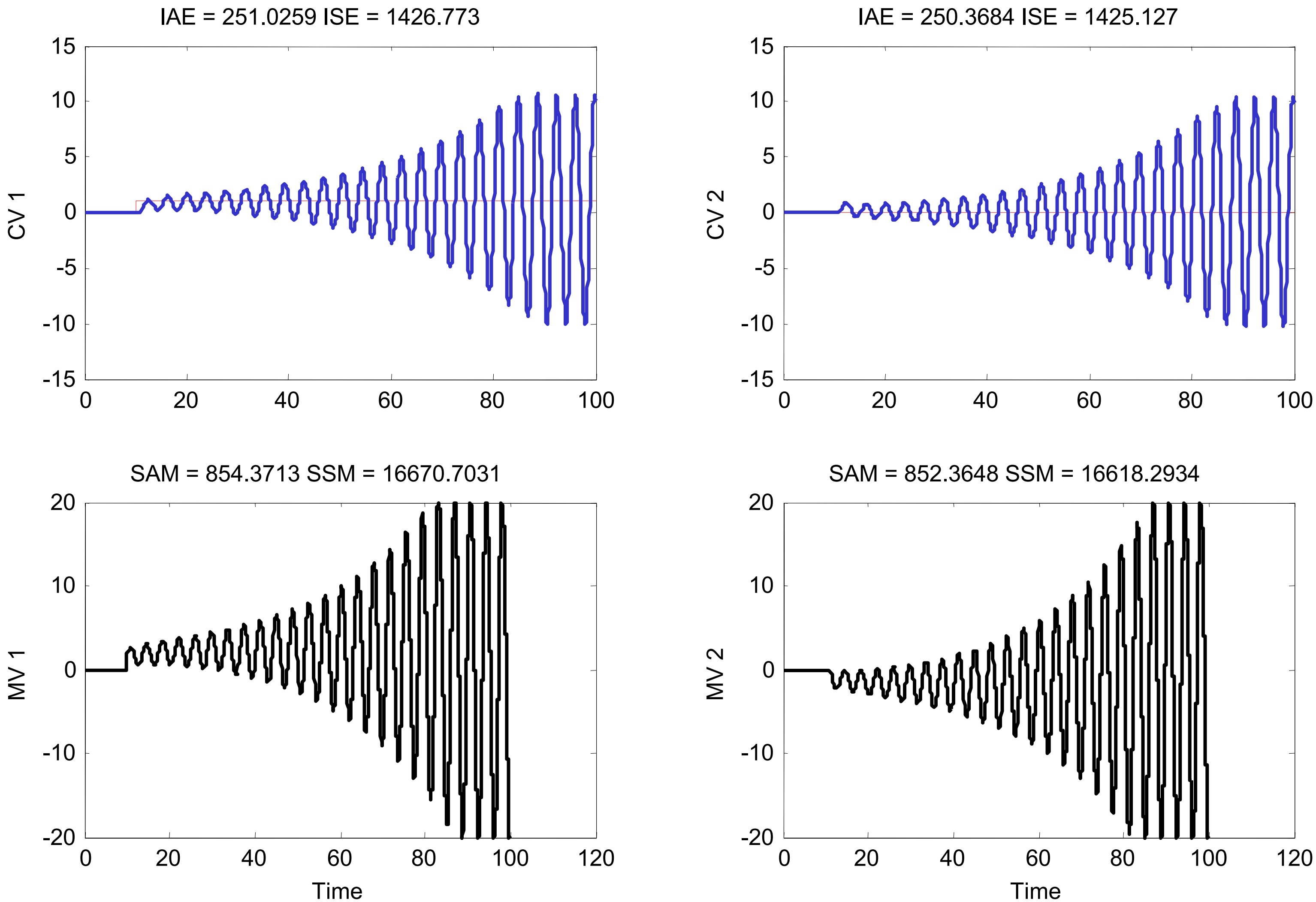
**Results with <u>only one controller</u> in automatic ($K_{C1}$ = 2.0, $T_{I1}$ = 3)**

**This system is stable and perhaps a bit too aggressive.**



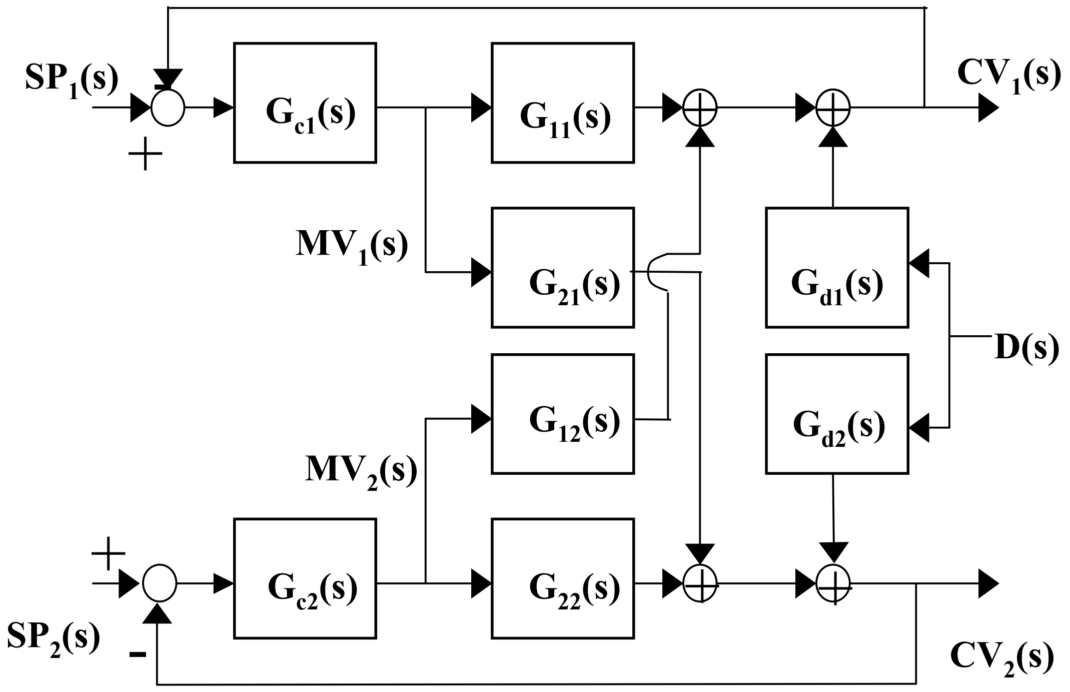
**Results with <u>both controllers</u> in automatic (Kc = 2.0, TI = 3)**

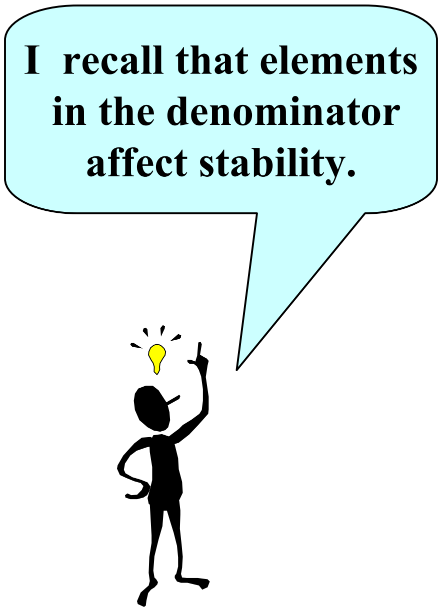
**This system is unstable!! Each was stable by itself!!**



# CONTROL OF MULTIVARIABLE PROCESSES

**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**

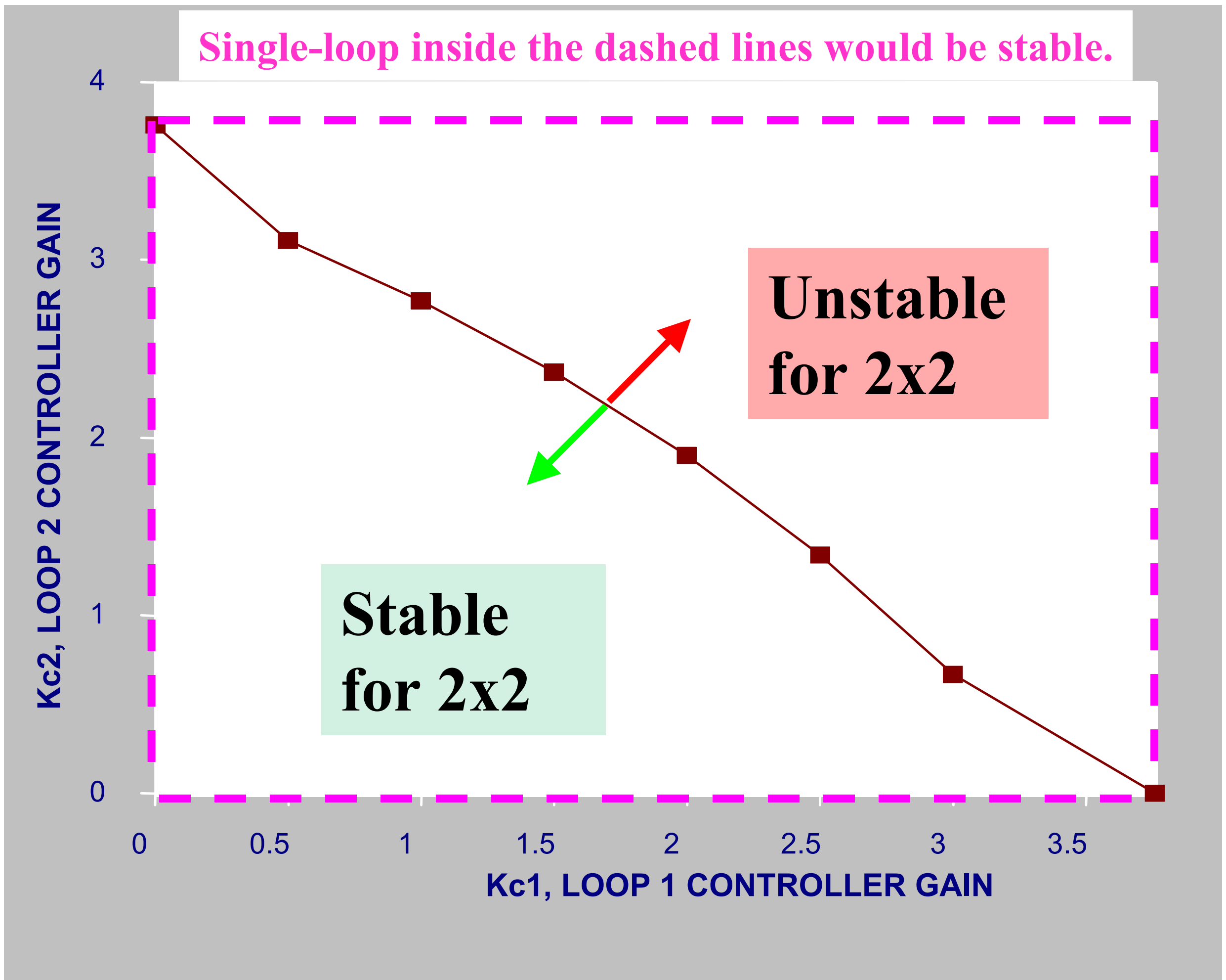



$$\frac{CV_1(s)}{SP_1(s)} = \frac{\text{numerator}(s)}{1 + G_{c1}(s)G_{11}(s) + G_{c2}(s)G_{22}(s) + G_{c1}(s)G_{c2}(s)[G_{11}(s)G_{22}(s) - G_{12}(s)G_{21}(s)]}$$

# CONTROL OF MULTIVARIABLE PROCESSES

**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**

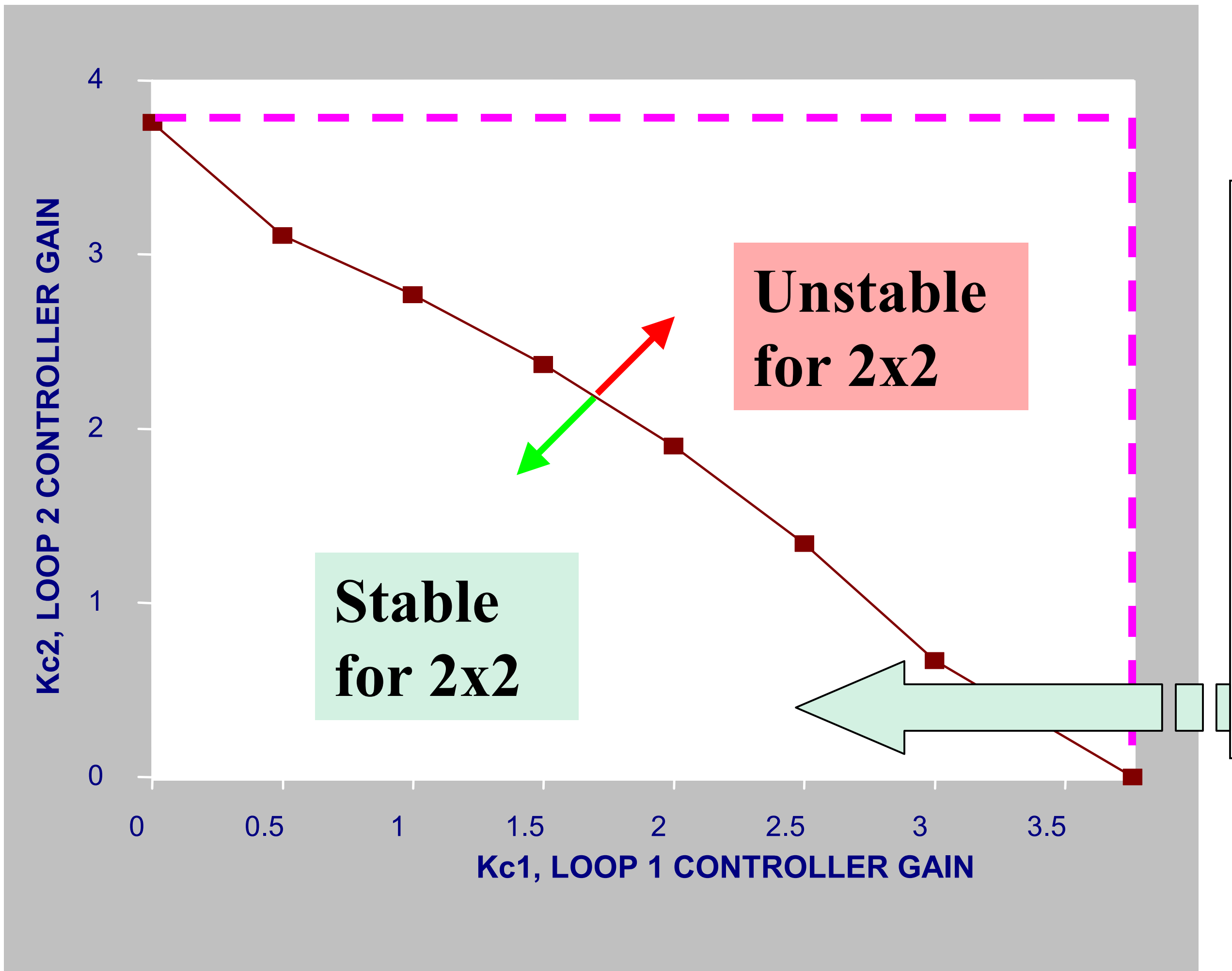



## Notes:

1. TI = 3 for both controllers (reasonable = t63%)
2. KC < 3.75 stable for single-loop feedback
3. KC = 2.0 stable for one loop
4. KC = 2.0 unstable for two loops!!
5. These numerical results are for the example only; concepts are general

# CONTROL OF MULTIVARIABLE PROCESSES

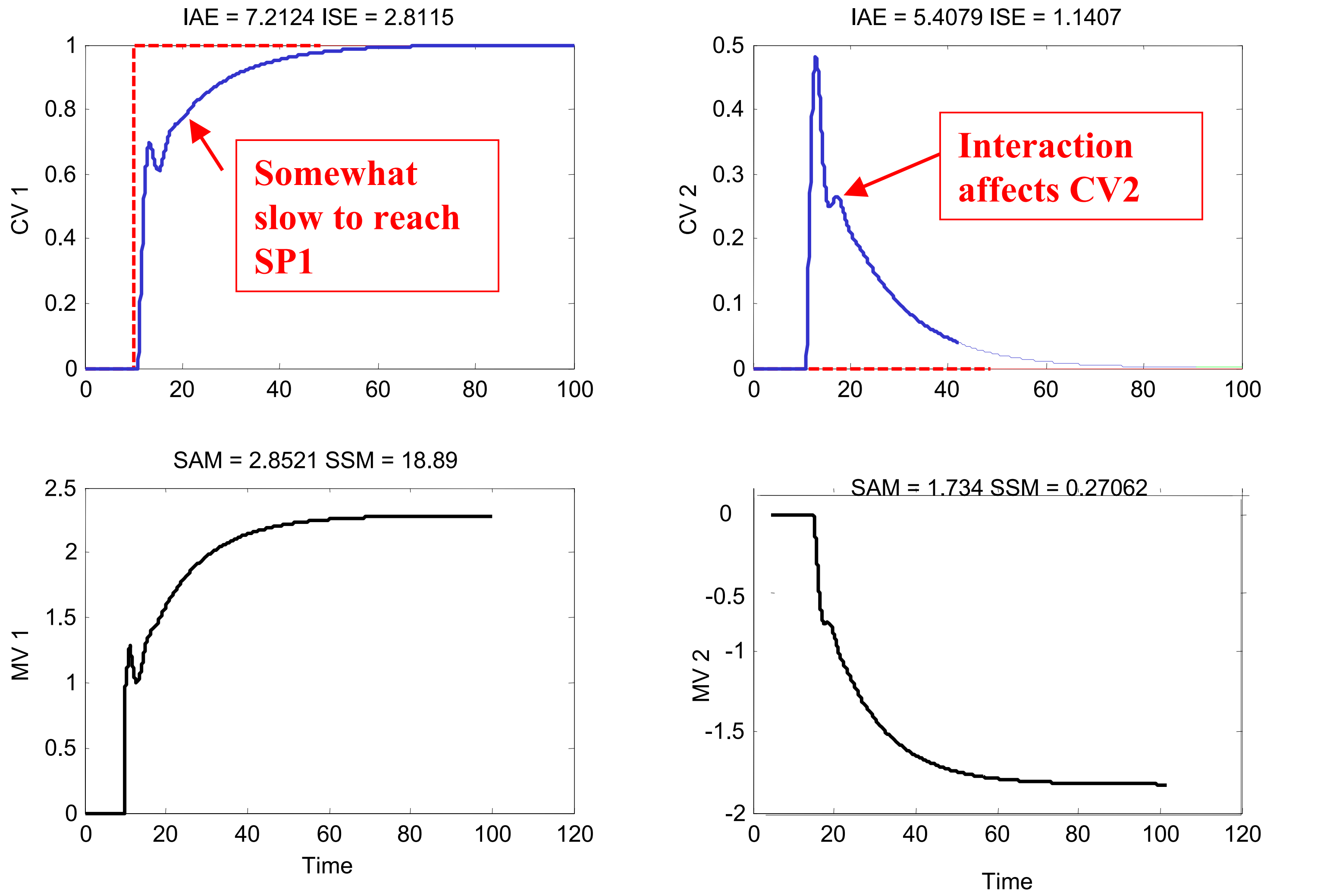
**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**



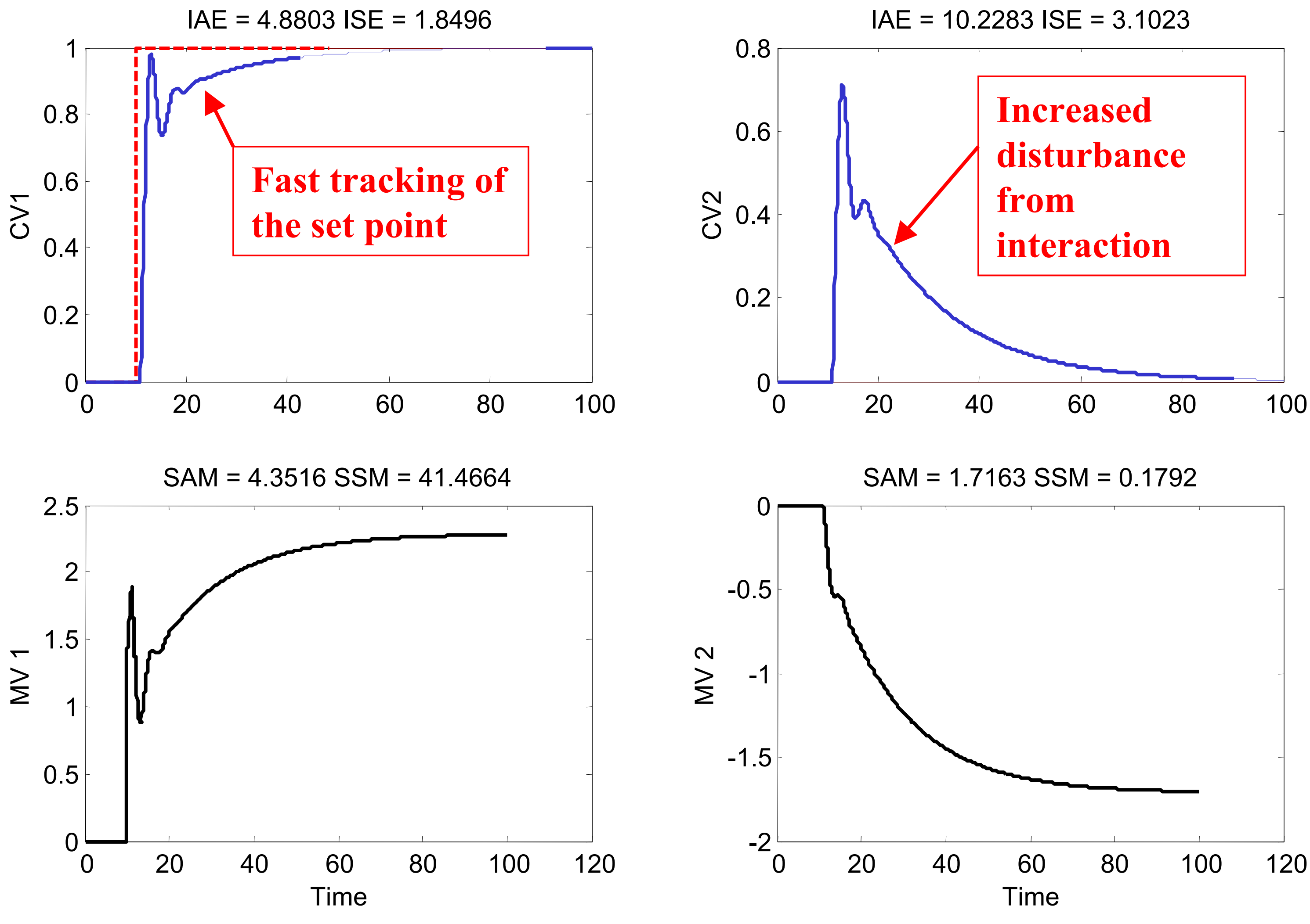

**We can have any values in the stable region.**

**How do we choose the "best".**

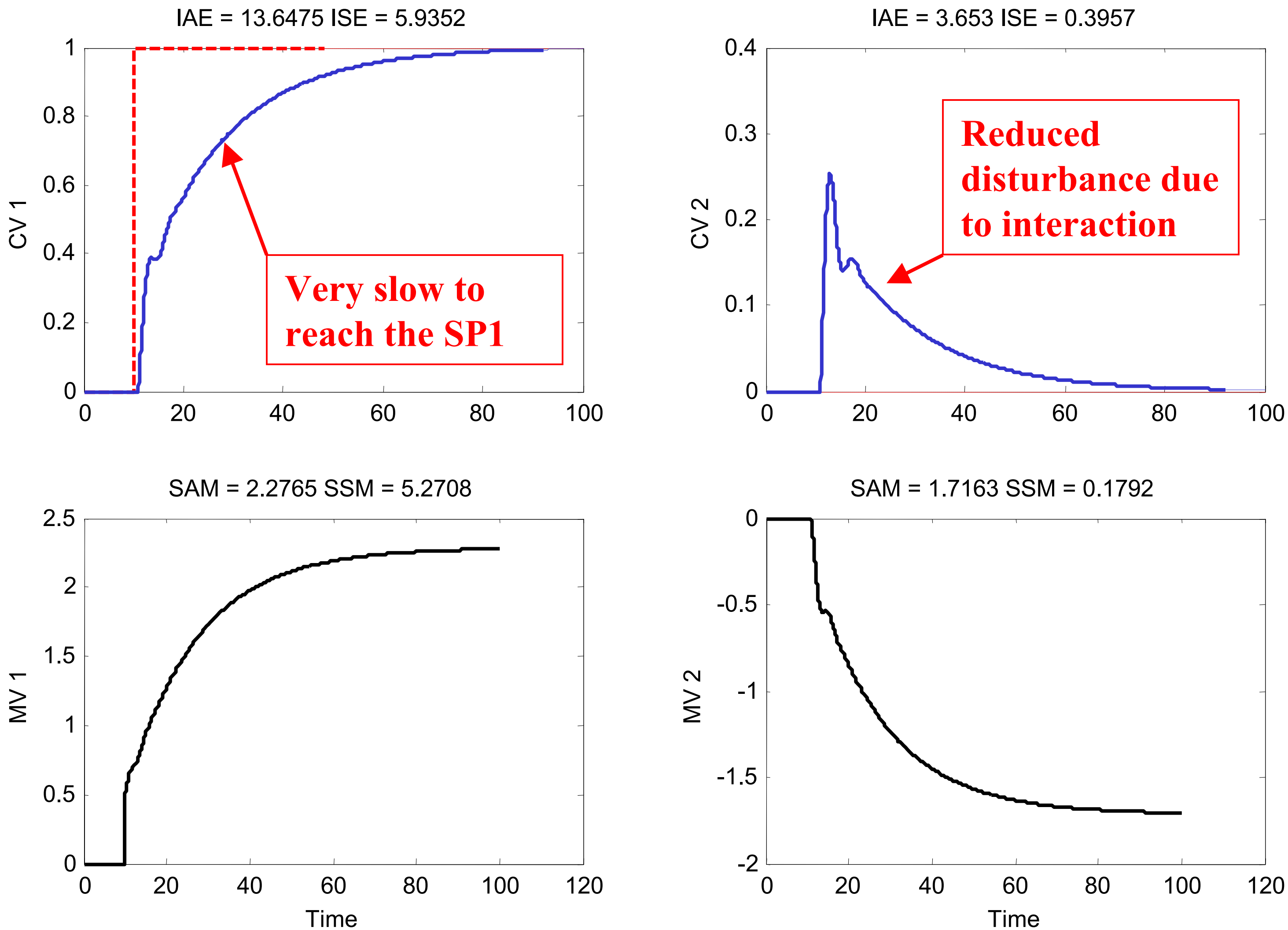
**If both CVs are of equal importance, we would detune both controllers equally.** **(Kc1 = Kc2 = 0.95; TI1 = TI2 = 3.0)**



**If CV1 is more important, we would make Gc1 aggressive and detune Gc2 more.** (Kc1 = 1.40 and Kc2 = 0.50; TI1 = TI2 = 3.0)



**If CV2 is more important, we would make Gc2 aggressive and detune Gc1 more.** (Kc1 = 0.50 and Kc2 = 1.40; TI1 = TI2 = 3.0)



# CONTROL OF MULTIVARIABLE PROCESSES

**In general, the behavior of one loop depends on the interaction and the tuning of the other loop(s).**

**Some conclusions for multiloop PID tuning:**

1. **For multiloop, we generally have to tune the controllers in a less aggressive manner than for single-loop.**
2. **Textbook gives tuning approach, $(Kc)_{ml} \approx 1/2\ (Kc)_{sl}$**
3. **We can tune important loop tightly, if we also detune (make less aggressive) other loops.**

# CONTROL OF MULTIVARIABLE PROCESSES

## Summary of key questions for multiloop control system

1. IS INTERACTION PRESENT?

   - No interaction $\Rightarrow$ All single-loop problems

   - We use models to determine interaction

     Fundamental or empirical

2. IS CONTROL POSSIBLE?

3. WHAT IS S-S AND DYNAMIC BEHAVIOR?

CONTROL OF MULTIVARIABLE PROCESSES

## Summary of key questions for multiloop control system

1. IS INTERACTION PRESENT?

2. IS CONTROL POSSIBLE?

   - DOF: The # of valves $\geq$ # of controlled variables

   - Controllable: Independently affect every CV

     Check if det [K] $\neq$ 0

     Look for "contractions"

3. WHAT IS S-S AND DYNAMIC BEHAVIOR?

# CONTROL OF MULTIVARIABLE PROCESSES

## Summary of key questions for multiloop control system

1. **IS INTERACTION PRESENT?**

2. **IS CONTROL POSSIBLE?**

3. **WHAT IS S-S AND DYNAMIC BEHAVIOR?**

   **- The operating window is:**

   **strongly affected by interaction**

   **strongly affected by equipment capacities**

   **not a rectangle or symmetric**

# CONTROL OF MULTIVARIABLE PROCESSES

## Summary of key questions for multiloop control system

1. IS INTERACTION PRESENT?

2. IS CONTROL POSSIBLE?

3. WHAT IS S-S AND DYNAMIC BEHAVIOR?

   - Interaction affects loop stability

   - We have to detune to retain stability margin

   - We can improve some loops by tight tuning, but we have to detune and degrade other loops

# CONTROL OF MULTIVARIABLE PROCESSES

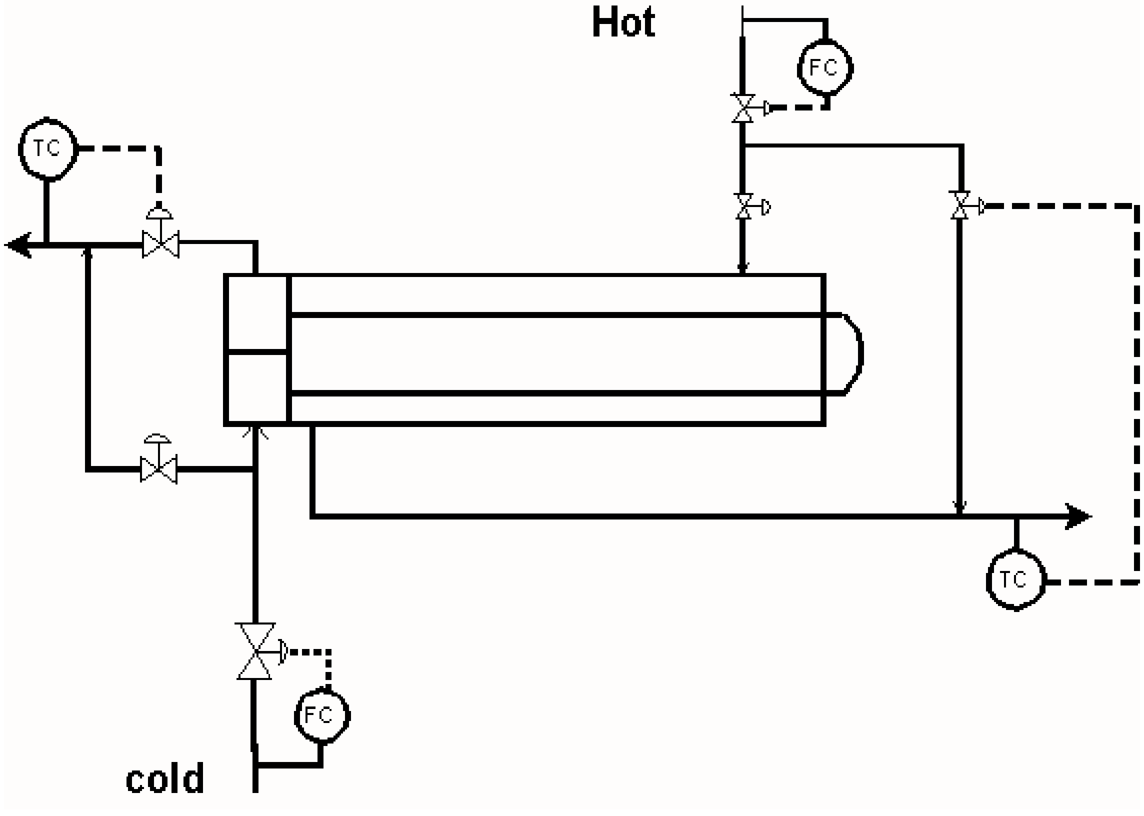
## Workshop in Interaction in Multivariable Control Systems

# CONTROL OF MULTIVARIABLE PROCESSES

## Workshop Problem # 1

You have been asked to evaluate the control design in the figure.

Discuss good and poor aspects and decide whether you would recommend the design.



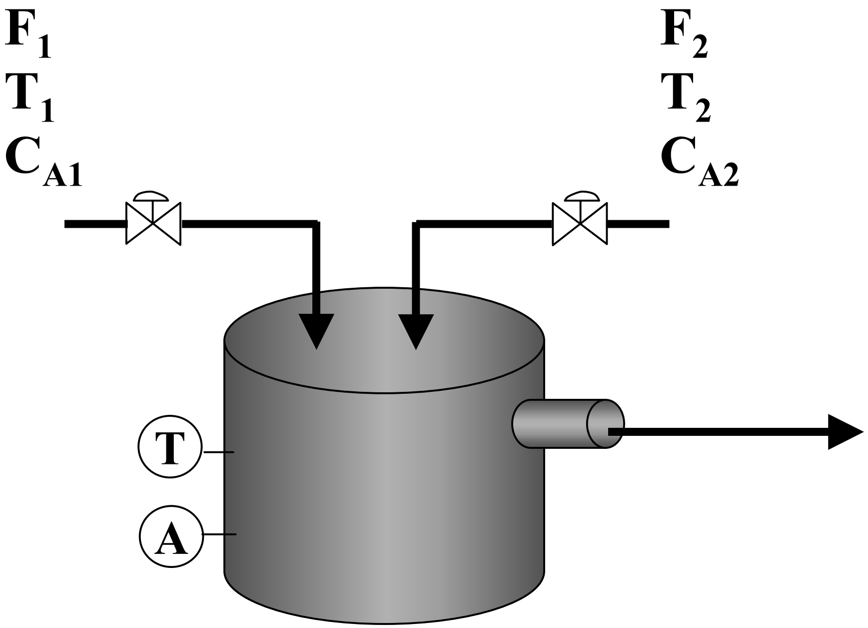
# CONTROL OF MULTIVARIABLE PROCESSES

## Workshop Problem # 2

We need to control the mixing tank effluent temperature and concentration.

You have been asked to evaluate the design in the figure.

Discuss good and poor aspects and decide whether you would recommend the design.



# CONTROL OF MULTIVARIABLE PROCESSES

## Workshop Problem # 3

**Summarize the underlying principles that can lead to a "contraction" and to a loss of controllability. These principles will be applicable to many process examples, although the specific variables could be different.**

**Hint: Review the examples in the lecture and identify the root cause for each.**