Key Operability issues

1. Operating window
2. Flexibility/ controllability
3. Reliability
4. Safety & equipment protection
5. Efficiency & profitability
6. Operation during transitions
7. Dynamic Performance
8. Monitoring & diagnosis

Flexibility

In this lesson, we will learn

- Why do we need flexibility in a design?

  - Distillation

- Deciding what to achieve (control)

  - Principles: Control Objectives

  - Example: Bioreactor

- Locating the flexibility: how many and where?

  - Principles: Degrees of freedom and Controllability

  - Blending, CSTR, heat exchange, bioreactor

Flexibility

Without flexibility, the process

unacceptable

- Does not respond to changes in set points
- Responds to all disturbances that change product qualities, production rates and can lead to unsafe operation!

With flexibility, the process

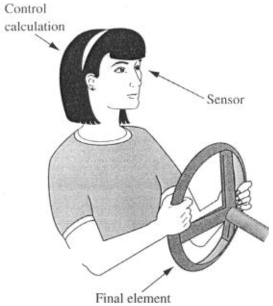


FIGURE 1.1

We need to "steer" the process

- Achieves set points
- Compensates for all disturbances so that product qualities, production rates and safety are achieved.

Flexibility

Flexibility enables us to adjust the plant operation ***after*** the equipment has been designed. It requires spare capacity in selected equipment and extra equipment to adjust operation.

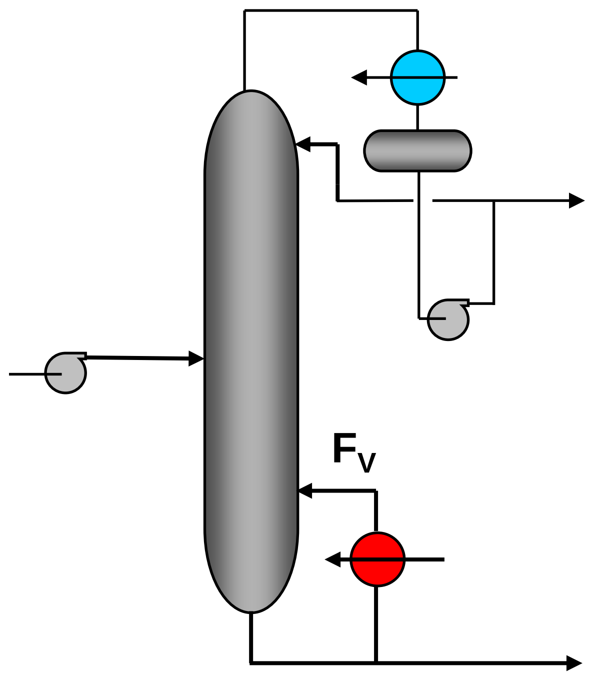
- Spare capacity in pumps, valve, heat exchangers, vessels, motor speed, etc.
- Additional equipment includes pipes and valves

- Adjust flows (especially utility) to equipment;
  utility = cooling water, steam, fuel, air,
  nitrogen, hydrogen, ….

- Enable flow to (partially) by-pass equipment

Flexibility

We have designed for an operating window. Now we must move around in it to achieve the desired point. What equipment must we add to the distillation tower?



What defines a "point"

- Feed flow rate
- Pressure
- Levels
- Distillate composition
- Bottoms composition

What uncertainty exists?

- L-V equil, heat transfer, flow, etc.

What disturbances occur?

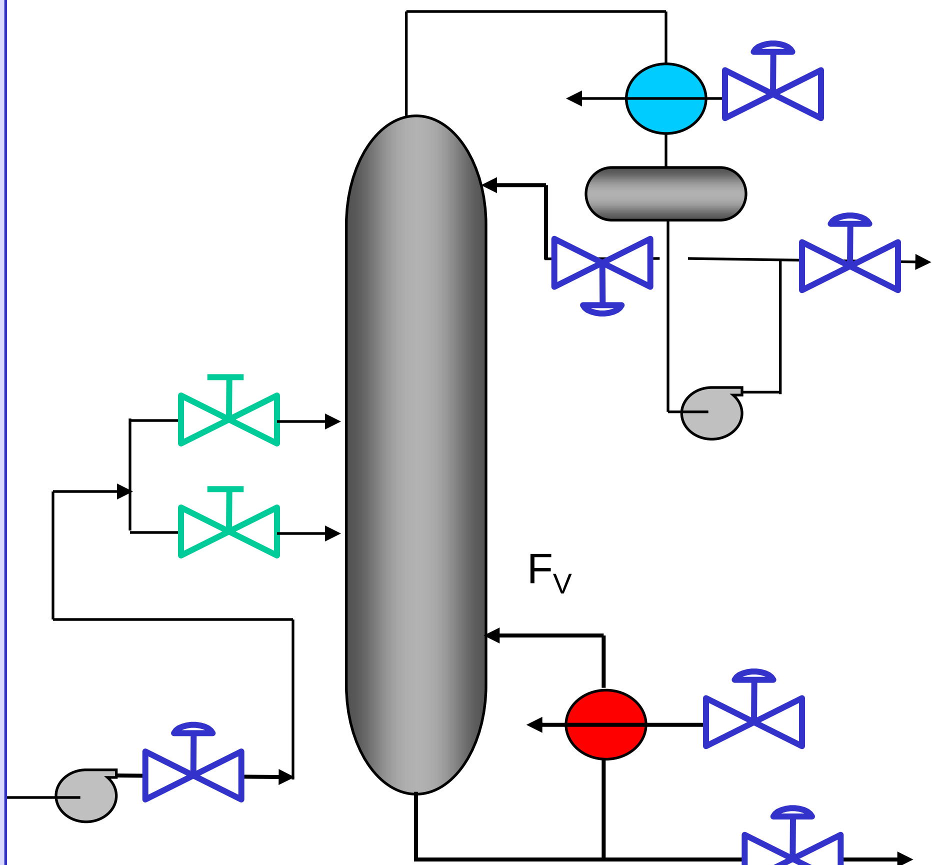
- Feed composition, enthalpy, & rate
- CW temperature
- Reboiler temperature

What is adjusted

- ??
- ??
- ??

Flexibility

What equipment must we add to the distillation tower?



We add a valve to every adjustable flow.

We could have alternative feed trays, with manual valves used to change the tray.

Naturally, the equipment must have capacity

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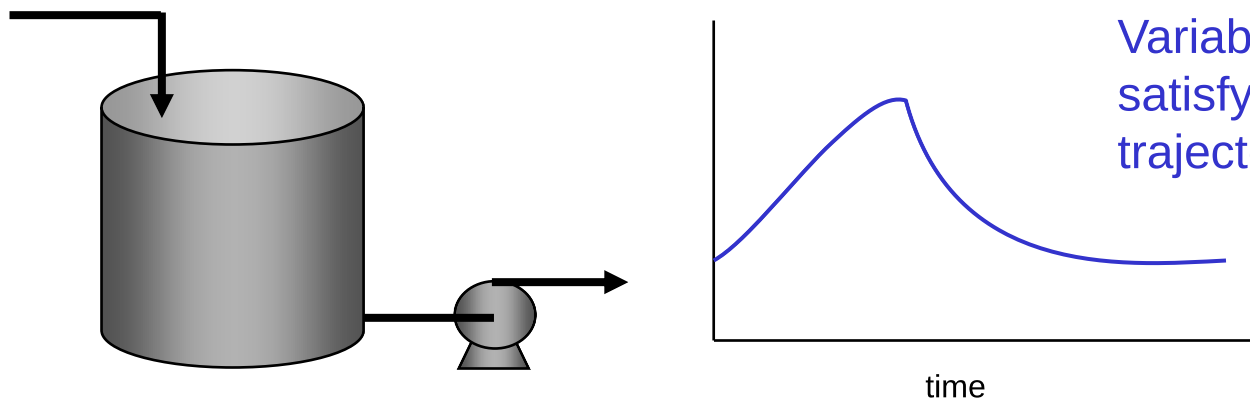
Flexibility

We are designing a batch bioreactor. Define the control objectives, specifically the variables to be controlled.



Variables to satisfy desired trajectory

For example:

We will require careful control of the tank temperature during the batch.

Furthermore, dissolved oxygen, pH, and substrate concentration must remain within bounds (the bounds change throughout the batch)

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Flexibility

How do we decide what to manipulate?

How much - We provide capacity to achieve an operating window with specified ”size”; see Operating Window topic.

- How many – How many flexible items are needed?
- Where - We need flexibility (adjustable variables) that influence the operating variables that define the point we want to achieve.

We can check a point using a flowsheeting program. We can determine which manipulated variables change and by how much. But, this takes lots of time to check many points.

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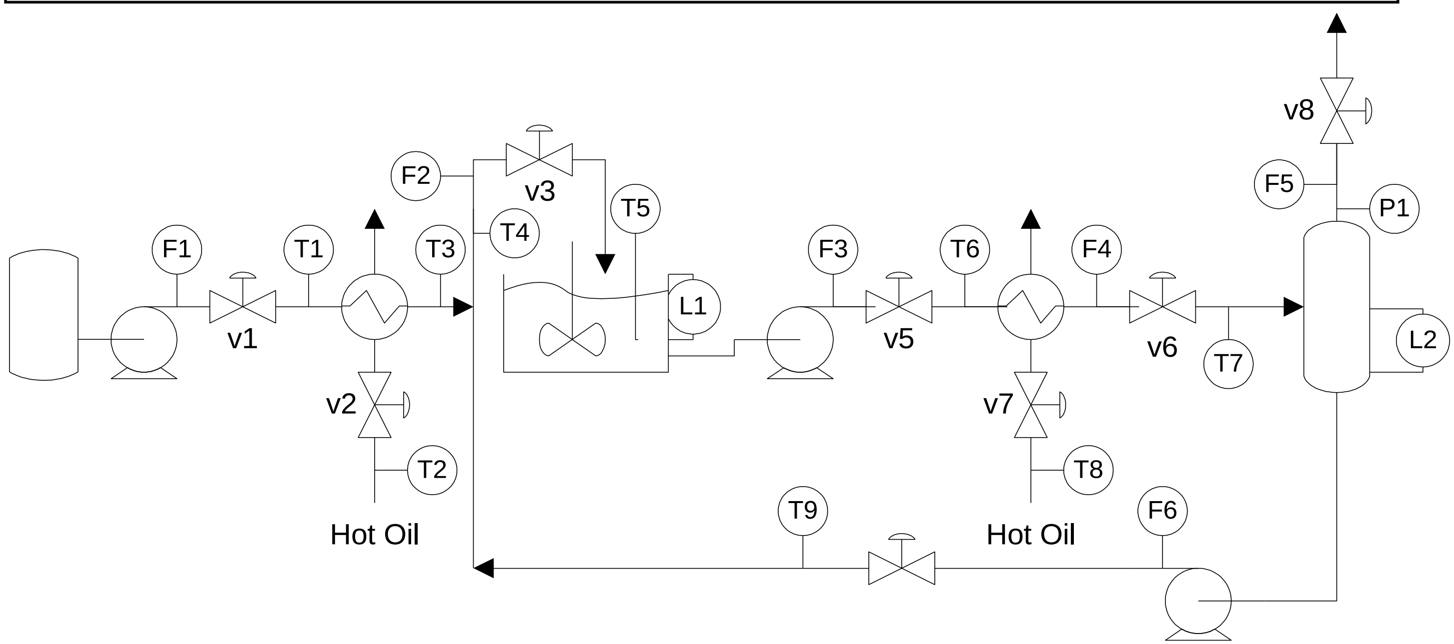
Flexibility

How many degrees of freedom?

How do we determine the maximum number of variables that be controlled in a process?

How do we determine the minimum number of adjustable variables to achieve desired values for specified variables?



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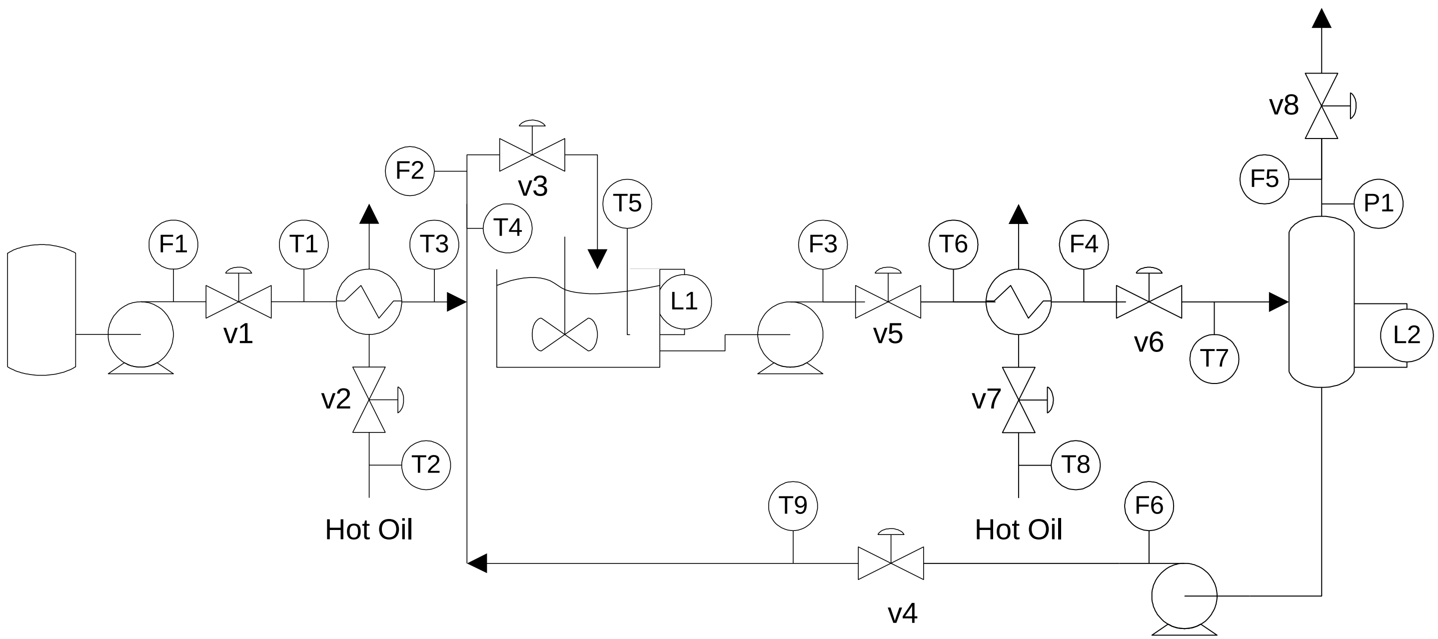
Flexibility

How many degrees of freedom?

A requirement for a successful design is:

The number of valves (adjustable variables) ≥ number of variables to be achieved (controlled)



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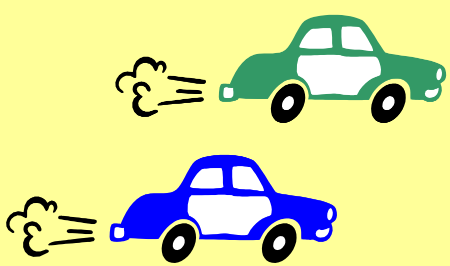
Flexibility: where?

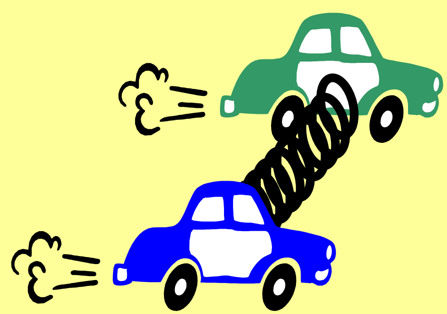
We need independent causal relationships between the adjusted and controlled variables. Remember, interaction can exist, but desired points must be able to be achieved. See three cases from Process Control.

Two drivers can achieve independent positions without interaction



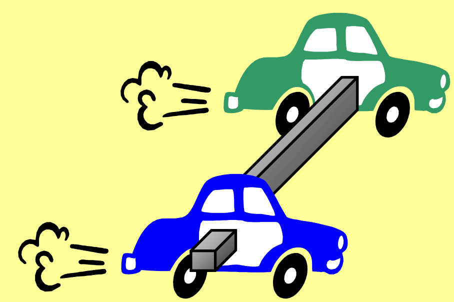
Independent

Two drivers can achieve independent positions with interaction



Interaction

Two drivers cannot achieve independent positions. They are “linked”



Linearly dependent

Flexibility: where?

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

Model for 2x2 system in deviation variables

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

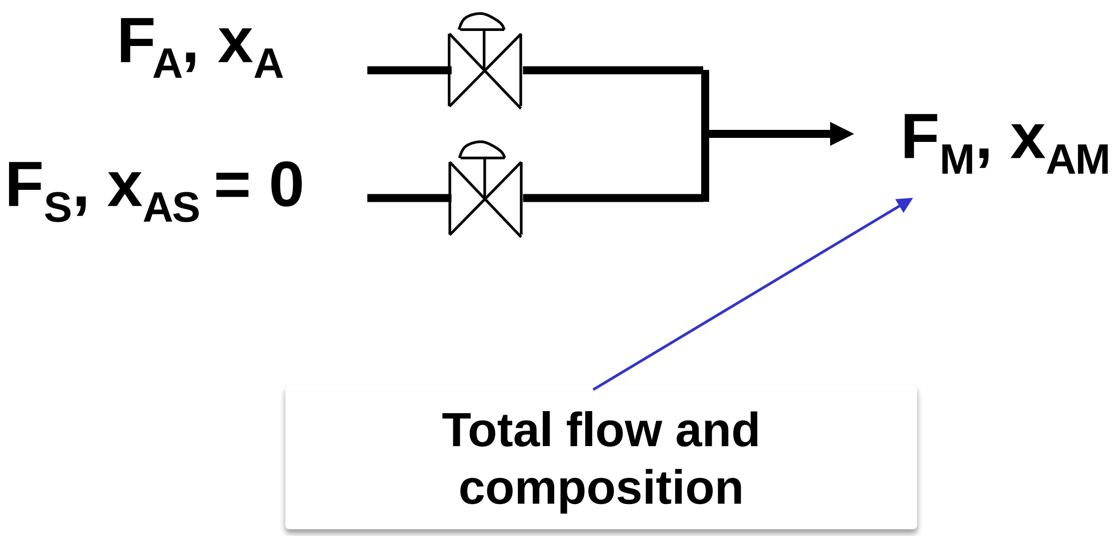
A system is controllable when the matrix of process gains can be inverted, i.e., when

the determinant of K $\neq$ 0.

Flexibility

Can we achieve desired blended flow, $\mathbf{F_M}$, and the blend composition, $\mathbf{x_{AM}}$, by adjusting the valves?

Blending process



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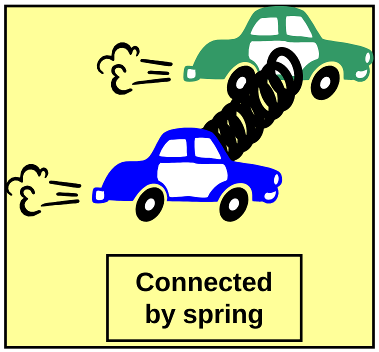
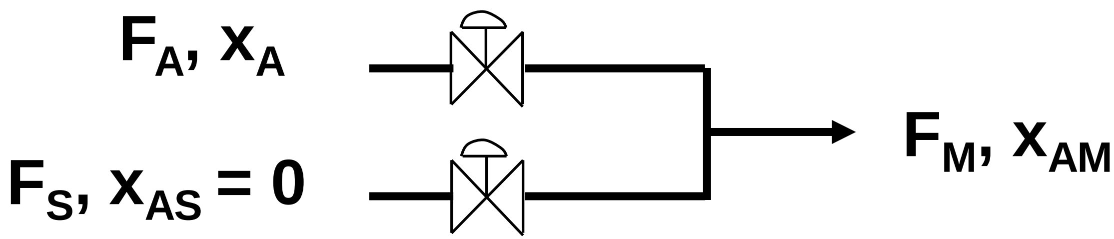
Flexibility

Can we achieve desired blended flow and composition by adjusting the valves?



Blending process



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

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

Yes, this system is controllable!

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

Key Operability issues

1. Operating window

2. Flexibility/ controllability

3. Reliability

4. Safety & equipment protection

5. Efficiency & profitability

6. Operation during transitions

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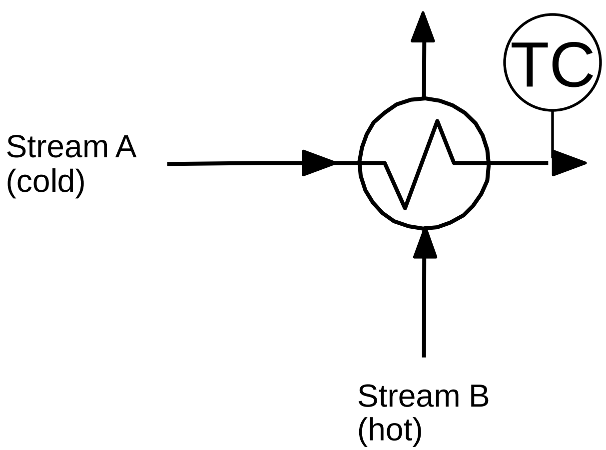
8. Monitoring & diagnosis

Flexibility

Add flexibility (piping, valves, *etc*) to the heat exchanger to achieve the goal for three different cases.

Goal: Maintain cold effluent T_{cold} at a desired value



You have freedom to adjust flows as follows:

	Stream A	Stream B
1.	Constant	Adjustable
2.	Adjustable	Constant
3.	Constant	Constant

Key Operability issues

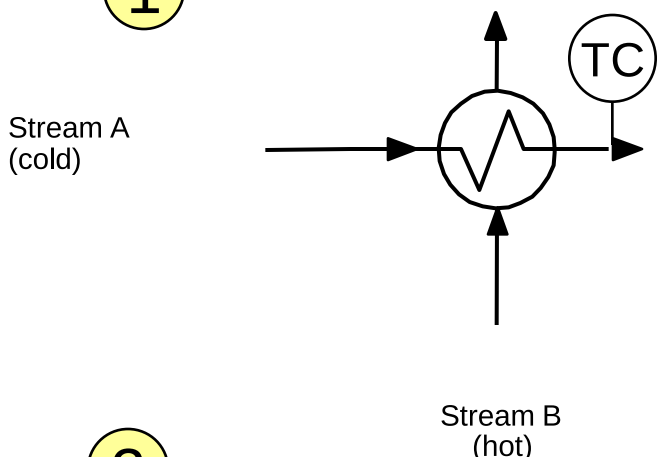
1. **Operating window**
2. **Flexibility/ controllability**
3. **Reliability**
4. **Safety & equipment protection**
5. **Efficiency & profitability**
6. **Operation during transitions**
7. **Dynamic Performance**
8. **Monitoring & diagnosis**

Flexibility

You have freedom to adjust flows as follows:

	Stream A	Stream B
1.	Constant	Adjustable
2.	Adjustable	Constant
3.	Constant	Constant

1



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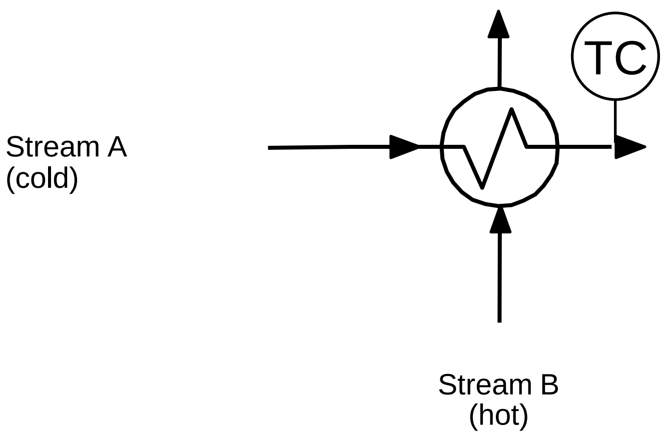
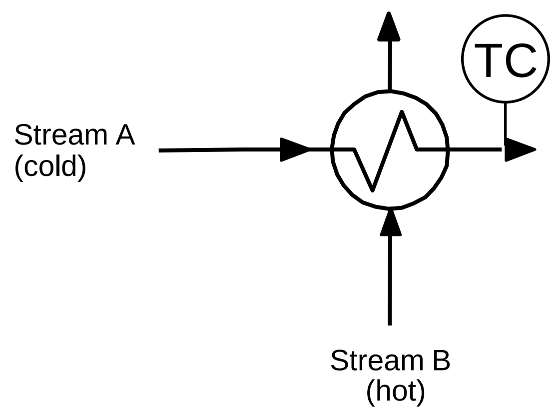


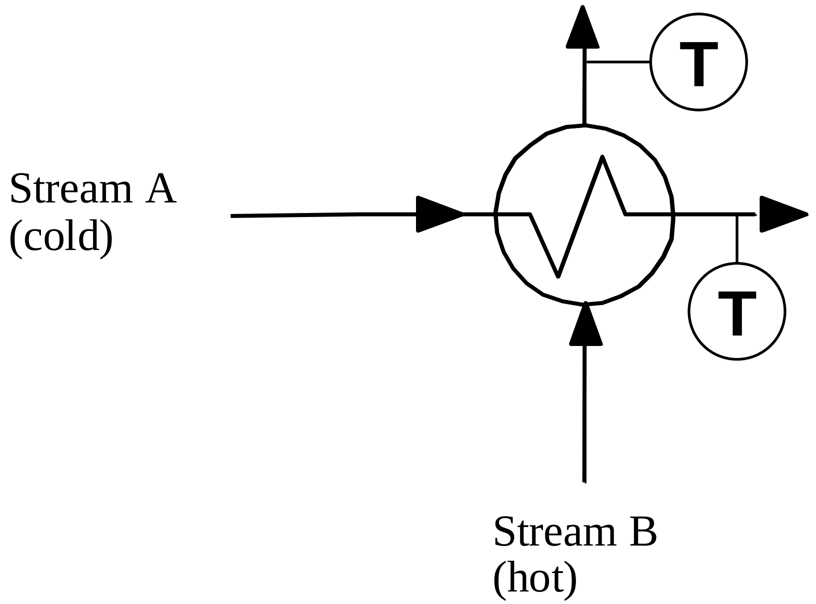
3



Flexibility

Add flexibility (piping, valves, *etc*) to the heat exchanger to achieve the goals.

Goals: Maintain cold effluent at T_{cold} and
Maintain hot effluent at T_{hot}



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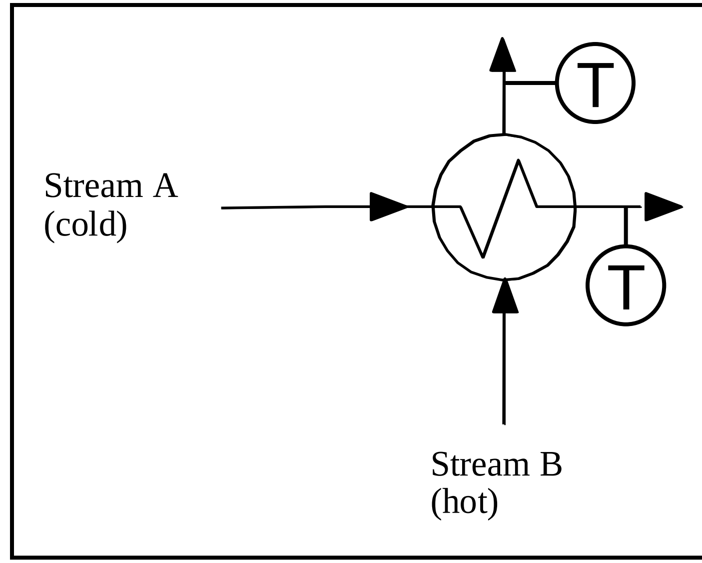
Flexibility

Goals: Maintain cold effluent at T_{cold} and maintain hot effluent at T_{hot}

Energy balance on each stream

$$Q_{Hot} = F_{Hot} C_{p_H} (T_{Hout} - T_{Hin})$$

$$Q_{Cold} = F_{Cold} C_{p_C} (T_{Cout} - T_{Cin})$$



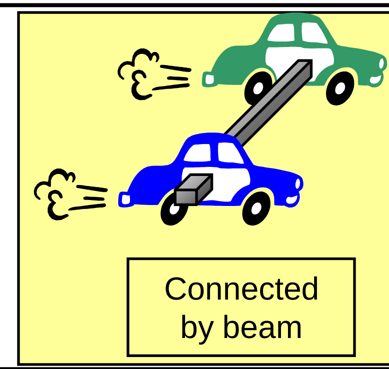
Equipment model with

U= f(F_H, F_C)

$$Q = UA\Delta T_{lm}$$

From an energy balance on entire system:

$$Q_{Hot} = Q_{cold}$$



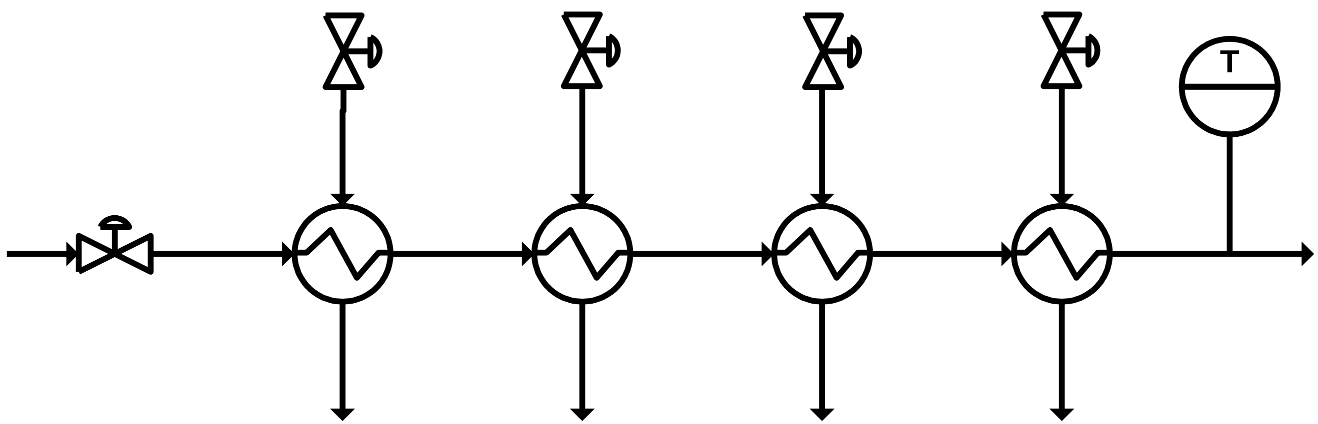
It is not possible to satisfy both energy balances by adjusting the flows. (We would have to adjust the inlet temperatures, which would seem to defeat the purpose of the heat exchanger.)

Flexibility

We heat a stream with several other process streams (not utility streams), which recovers energy efficiently.

- What disturbances can occur?
- What set point changes can occur?

If none of the 4 stream flow rates can be manipulated, what flexibility is needed to achieve the desired outlet temperature?



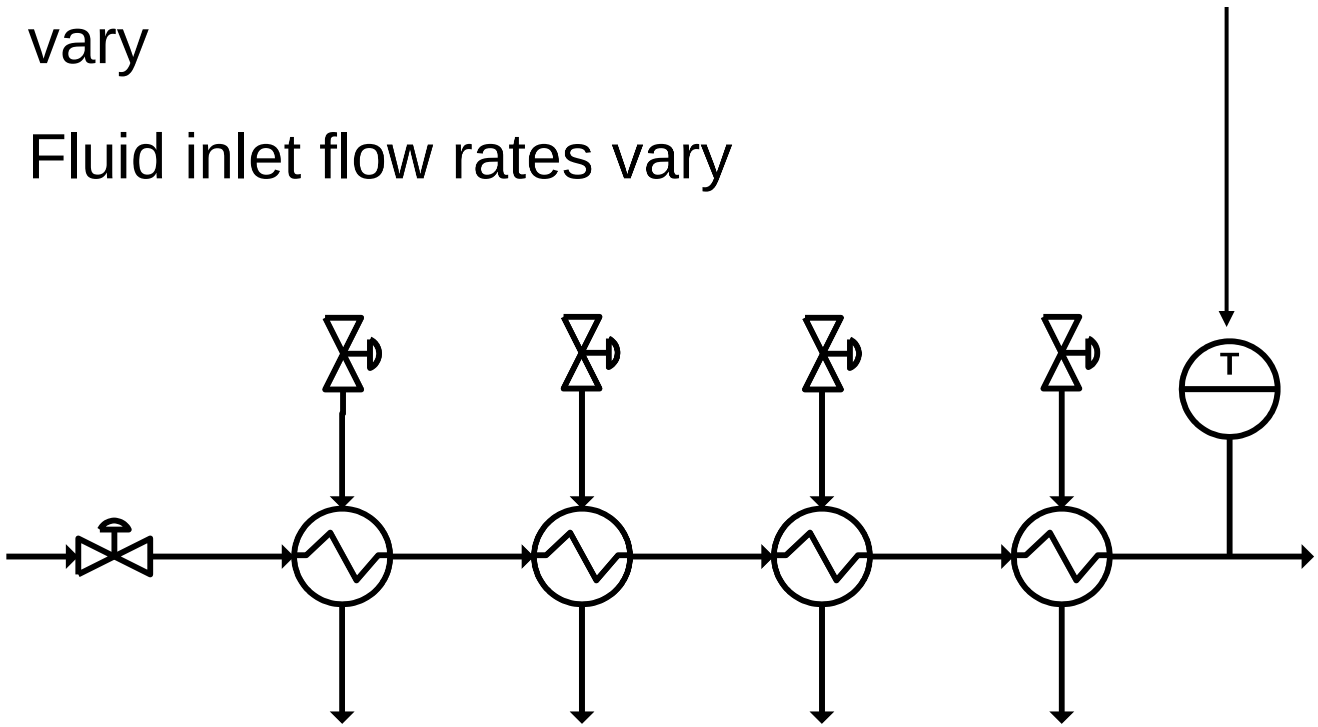
Flexibility

Disturbances:

- Fluid inlet temperatures vary
- Fluid inlet flow rates vary

Set points:

- This outlet temperature



Add flexibility to the network so the set point can be changed, despite disturbances arriving.

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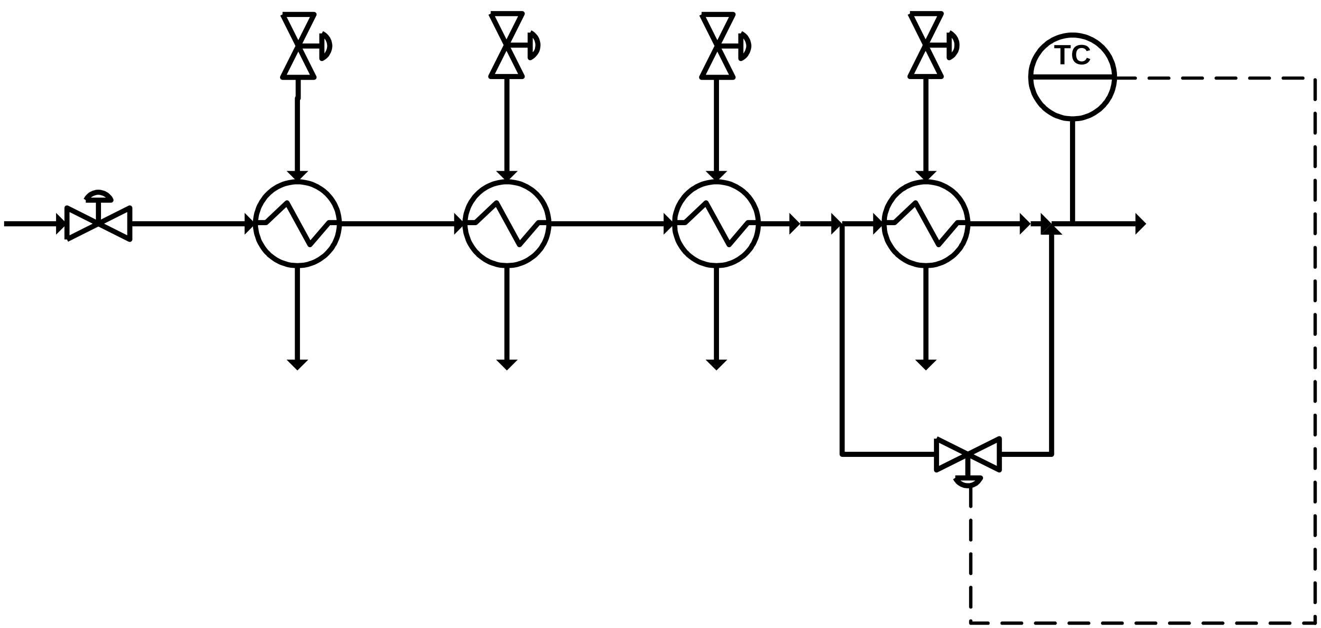
Flexibility

If the final process-fluid heat exchanger has a outlet temperature that is high enough to achieve the desired value, a by-pass could be used.



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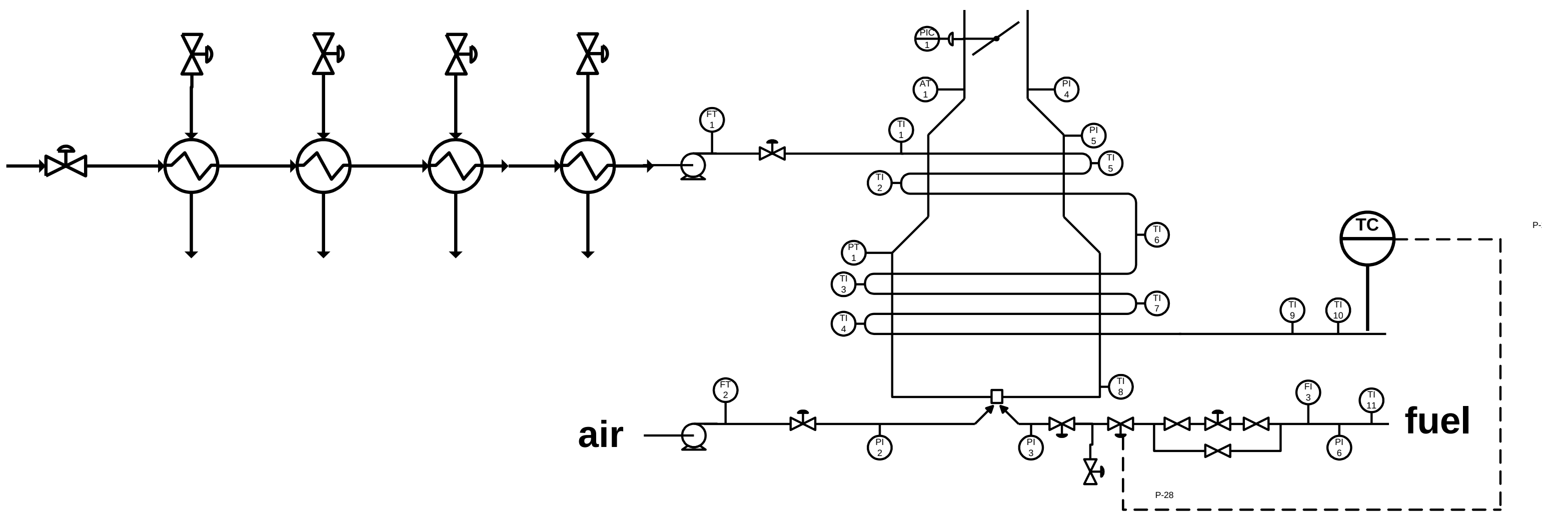
Flexibility

If the final process-fluid heat exchanger has a outlet temperature that is not high enough to achieve the desired value, an additional source is required; here the source is a fired heater.



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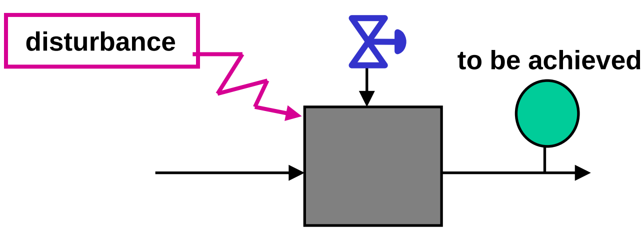
Flexibility

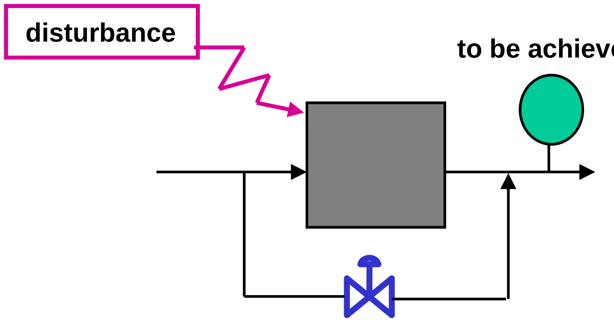
Generalization: From the heat exchanger examples, we see that flexibility can be achieved by adjusting utilities or in some cases, with a by-pass.

Adjust flows (especially utility)

utility = cooling water, steam, fuel, air, nitrogen, hydrogen, ….



Enable flow to (partially) by-pass equipment



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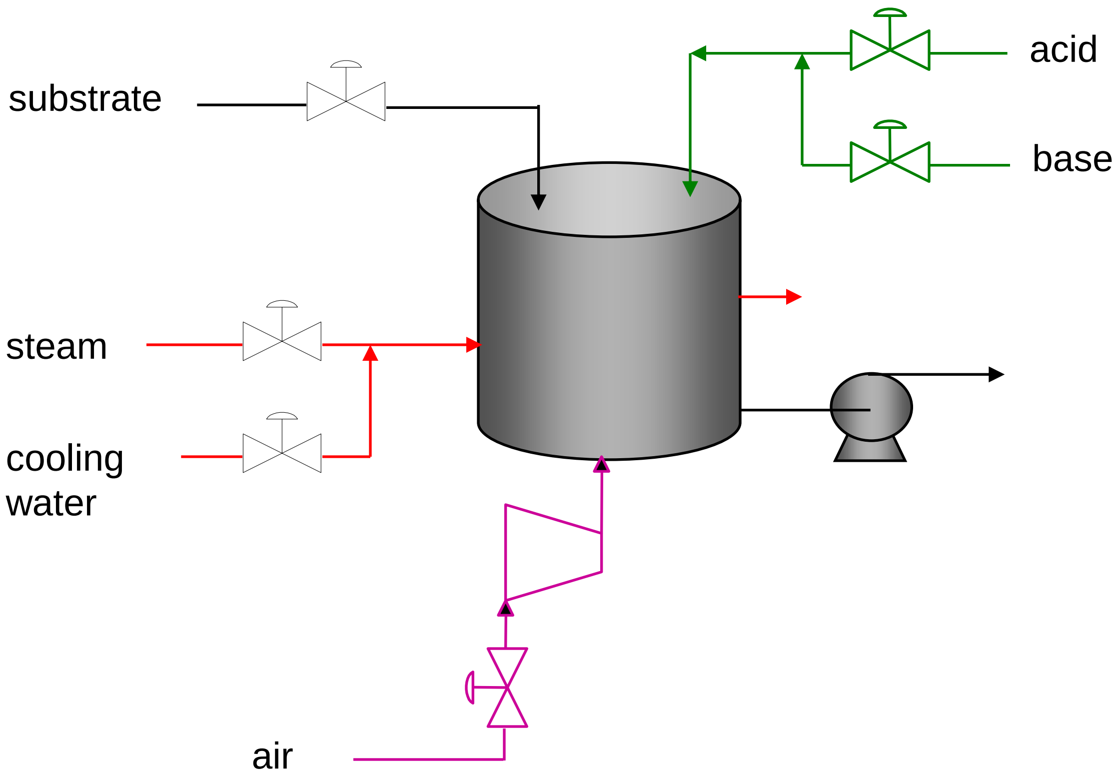
Flexibility

Batch bioreactor example: added valves and ability to control the trajectory during the batch.



Flexibility

Industrial practice

1. Flexibility enables achieving points in the operating window.

2. The choice of adjustable equipment is based on principles and experience.

3. Controllability is often determined by qualitative analysis; however, flowsheeting can be used to see if the dependent variable values can be achieved by changing the selected adjustable variables.

4. Whether the adjustable variable is manipulated by process control or by a person depends on the response time required.

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Flexibility

Industrial practice

(1) Model uncertainty
(2) Disturbances
(3) Set point values
(4) Production variation

"Know where you are going"

(Remember for 4W04)

The plant "Design Specification" must include definitions of items (2) to (4)

The engineer must understand all items when items are significant and must be accommodated with extra capacity or improved sensor technology.