ROBUST DESIGN VIA OPERABILITY

57th CSChE Conference

Session on Process Design and Analysis

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Thomas E. Marlin
Department of Chemical Engineering
And McMaster Advanced Control Consortium
www.macc.mcmaster.ca

McMASTER UNIVERSITY

1280 Main Street West, Hamilton, ON, Canada L8S 4L7

GOALS OF THE PRESENTATION

- Provide a (not the) definition of operability

  - A taxonomy of issues

- Demonstrate that operability is not a collection of "tricks"

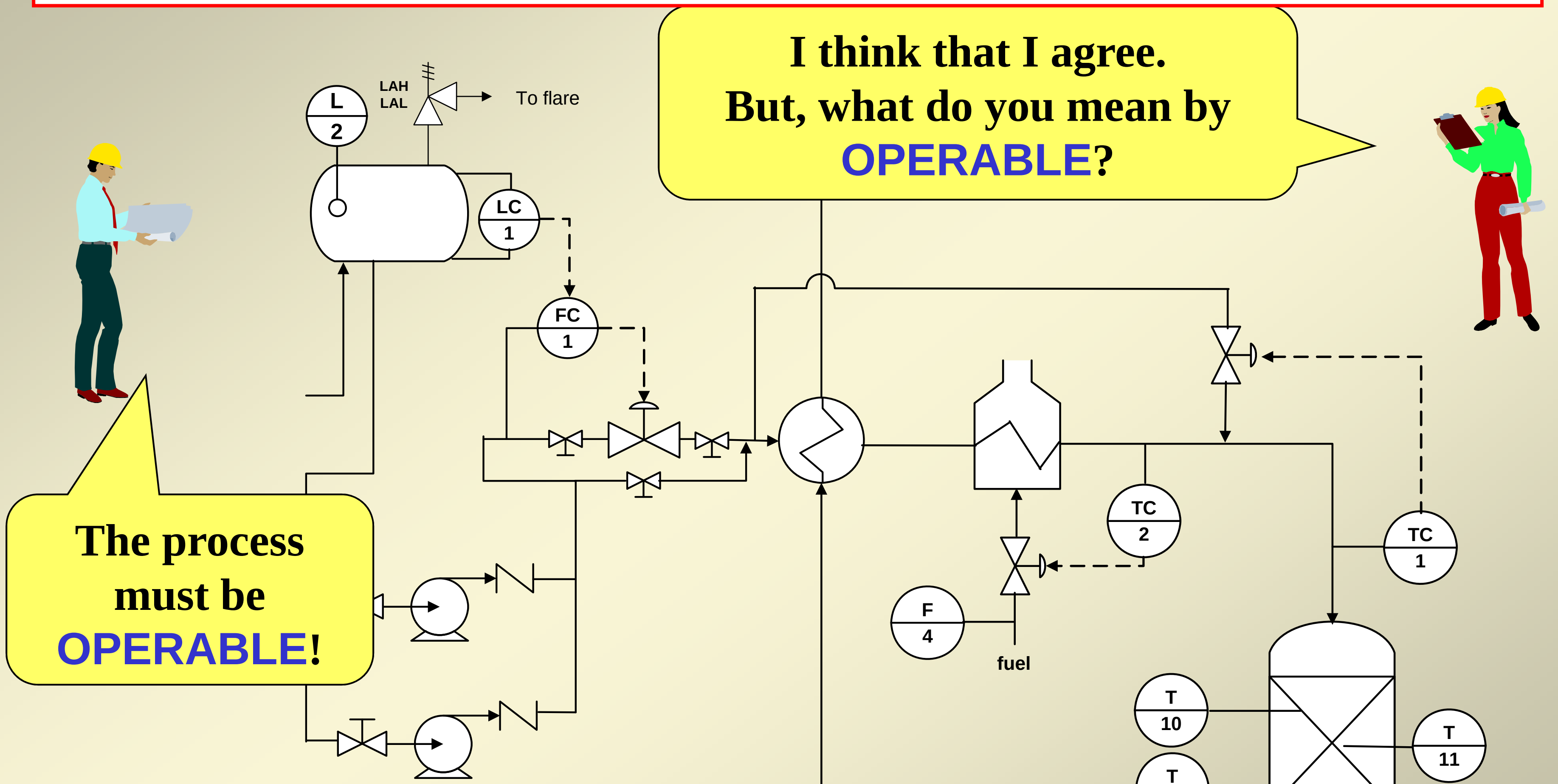
  - Improves teaching of fundamentals
  - Motivates students to learn/apply

- Whet your appetite, refer to WEB site for expanded coverage – with workshops

- Suggest that instructors share teaching materials to improve our understanding and to reduce teaching load

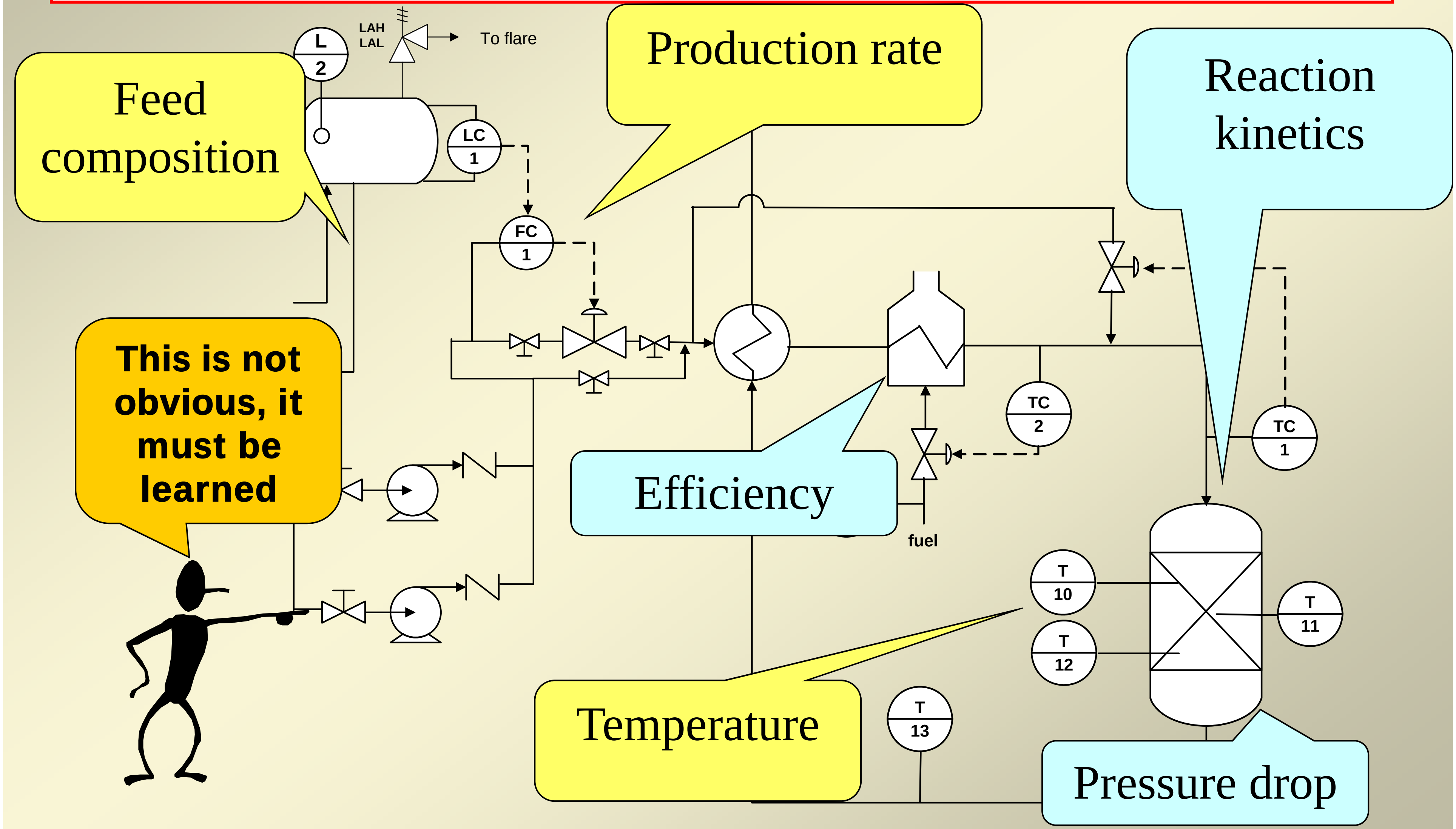
Too little time!

WE DO NOT HAVE A CONSISTENT UNDERSTANDING OF THE ISSUES INVOLVED IN OPERABILITY



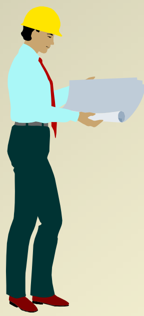
We have recently encountered a communication difficulty, so
Process Operability = Robust Design

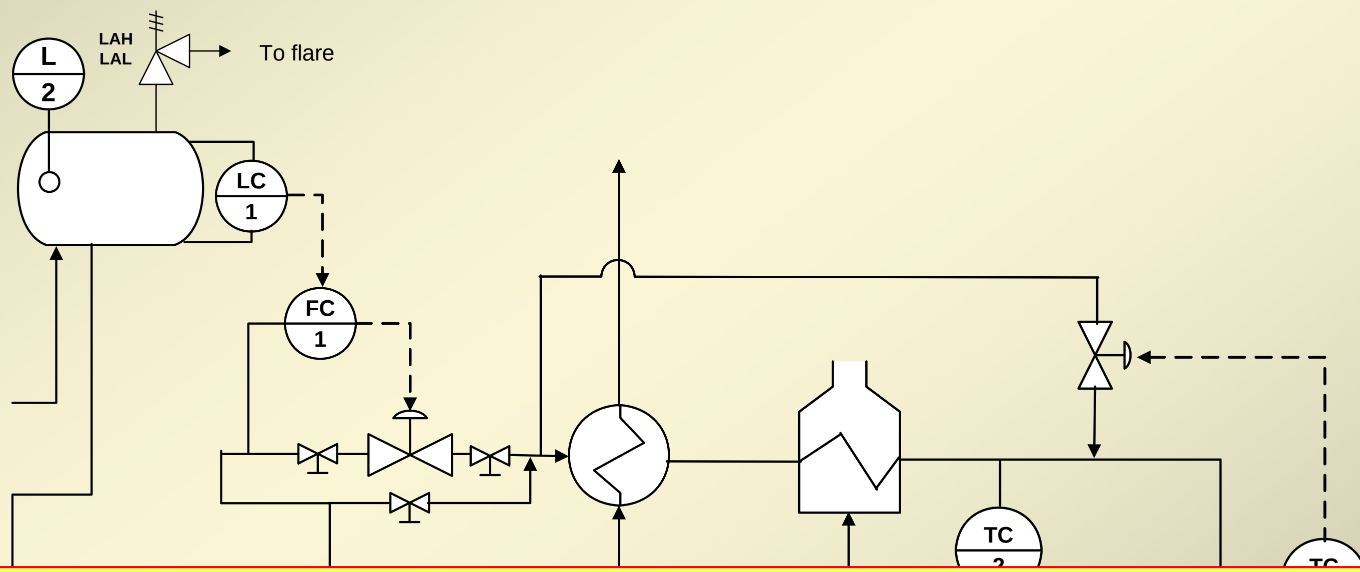
OPERABILITY BECOMES ESSENTIAL WHEN WE CONSIDER REALISTIC VARIABILITY AND UNCERTAINTY



OPERABILITY CAN NOT BE “ADDED-ON” AT THE END OF THE DESIGN

We must introduce appropriate equipment to ensure that a process is operable





“The principle sins of flowsheets used for economic evaluation are sins of omission … frequently omitted items include storage tanks, surge tanks, duplicated equipment (for reliability), startup equipment, emergency safety equipment, ..” (Valle-Riestra, 1983).

CRITERIA FOR SELECTING OPERABILITY TOPICS

- **Generic issues that apply to wide range of systems**
- **Reinforce fundamental principles**
- **Introduce common issues and solutions in engineering practice**

  - Not comprehensive for any particular process

  - Demonstrates principles, students can expand to other issues and technical solutions

  - Leading to respect for making a real physical system function
- **Prepares for performing a major project**

Key Operability issues

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

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Feed ta

Key Operability Topics

1. Operating window
2. Flexibility/controllability
3. Reliability
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5. Operation during transitions
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7. Efficiency
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Key Operability issues

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Key Challenge

How do we enable students to solve complex problems with multiple objectives?

- Provide superstructure for knowledge
- Tie to professional skills: problem solving, group skills,report writing, oral presentation, etc.
- Link to basics
- Show compelling, practical examples (within the students grasp)
- Encourage (require) students to investigate, discover and evaluate issues in real processes

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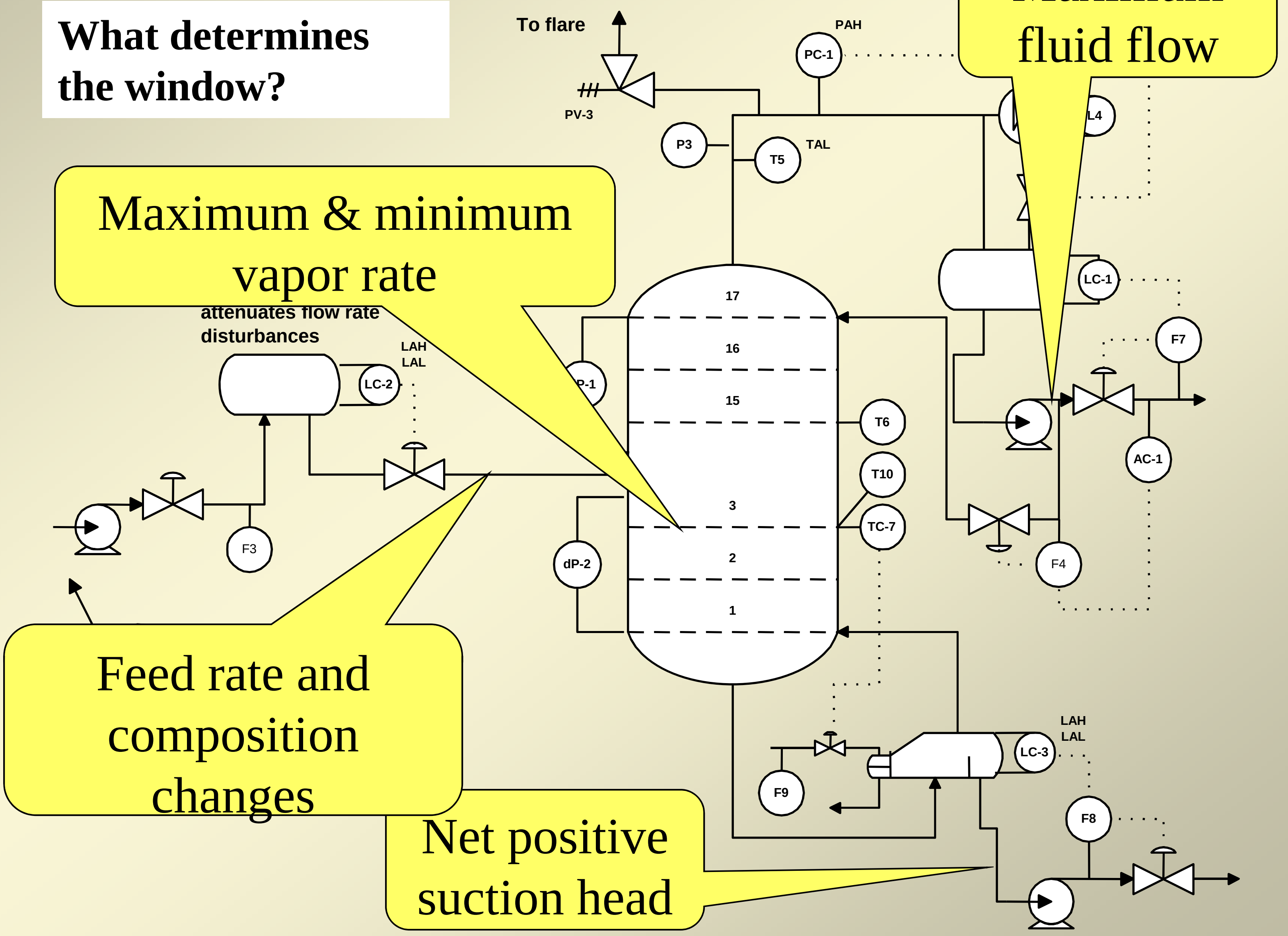
OPERATING WINDOW

What determines the window?



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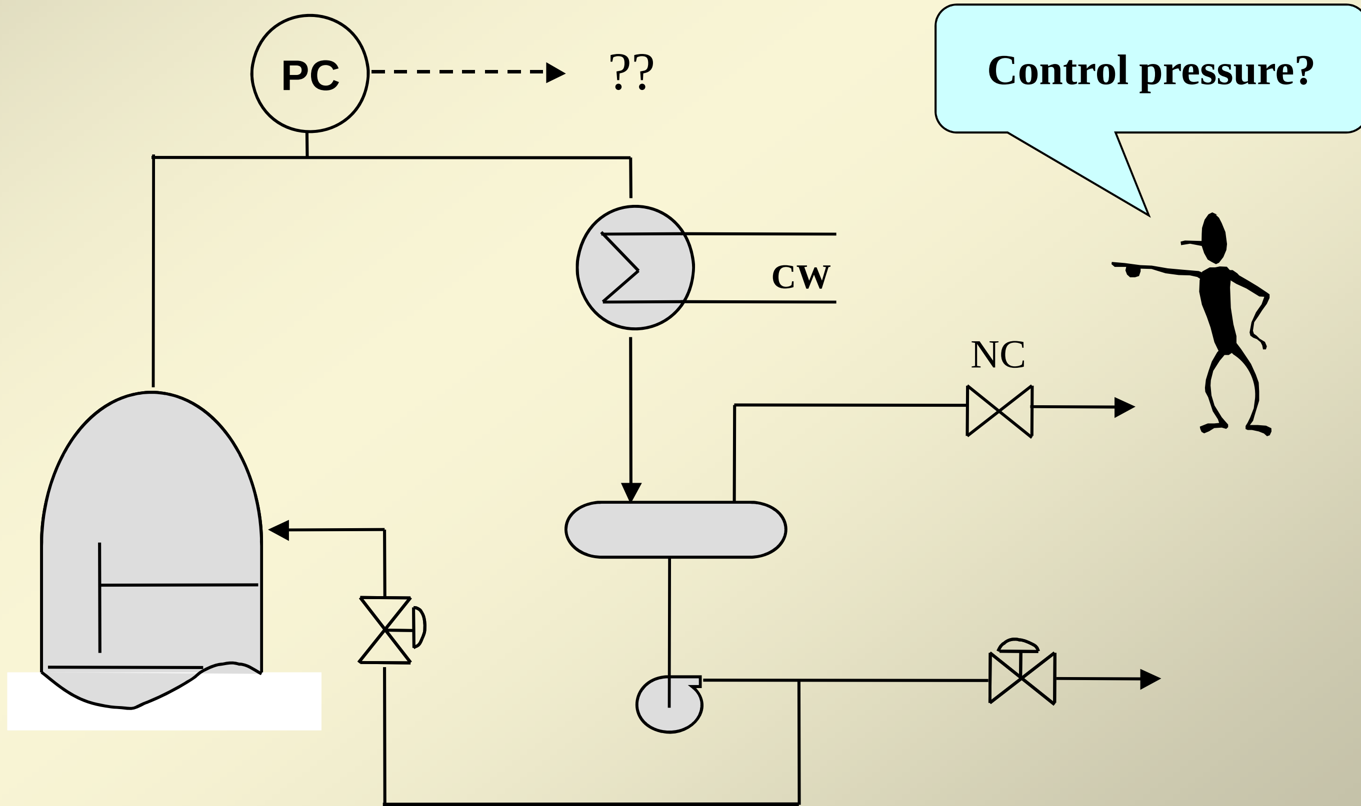
FLEXIBILITY AND CONTROLLABILITY

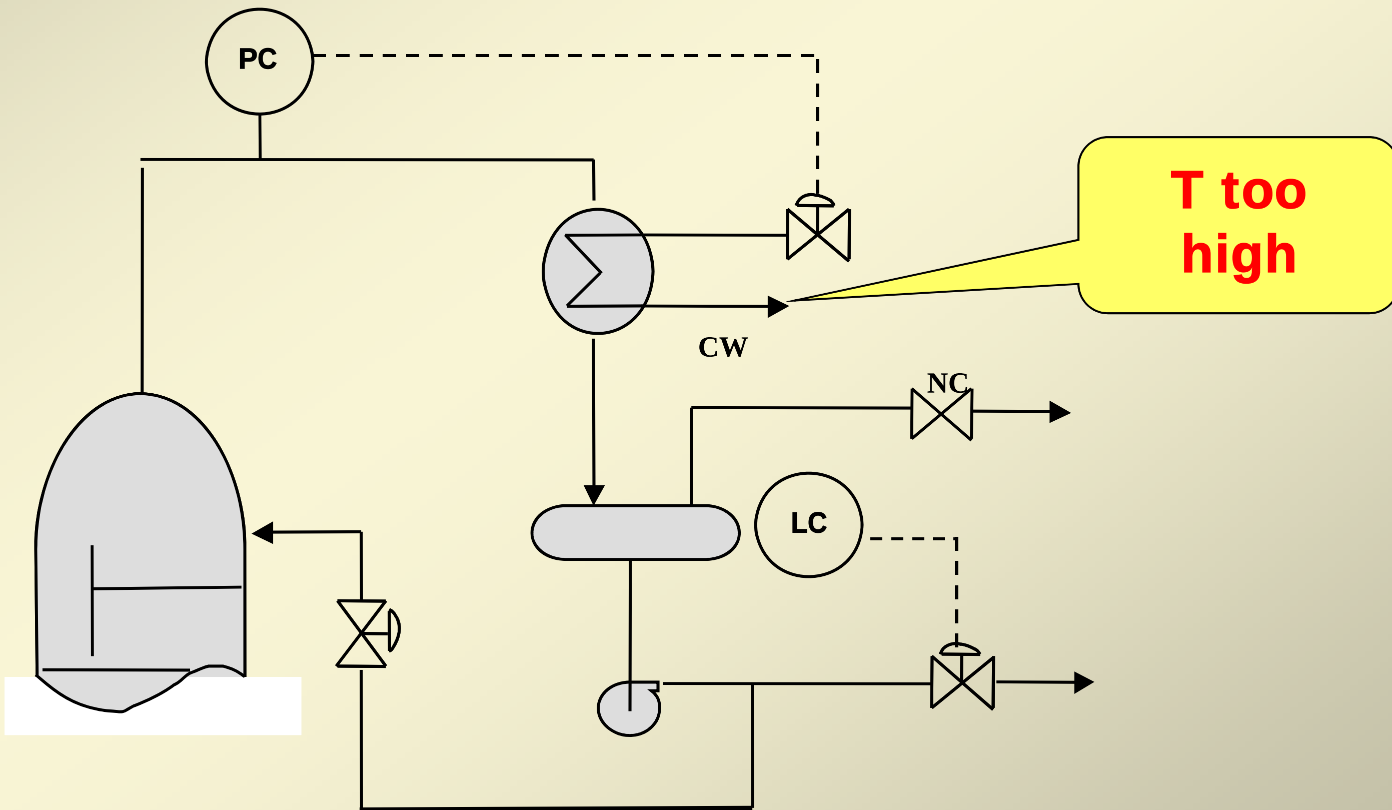
Where must we provide adjustable equipment to maintain the process in safe and profitable operation?



Principle: Q = U A (ΔT)   Which to influence?

FLEXIBILITY AND CONTROLLABILITY

$Q = U\,A\,(\Delta T)$ Which to influence?



Not recommended!

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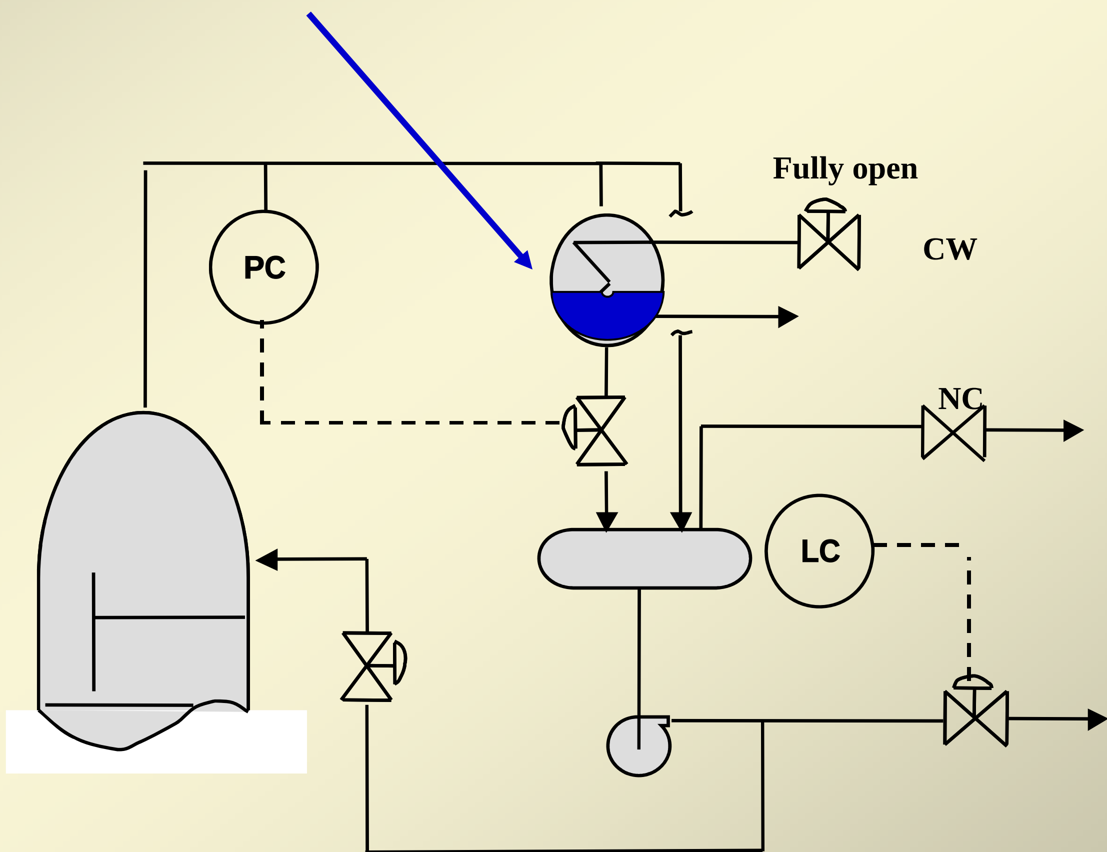
FLEXIBILITY AND CONTROLLABILITY

$Q = U\,A\,(\Delta T)$ **Which to influence?**



Recommended!

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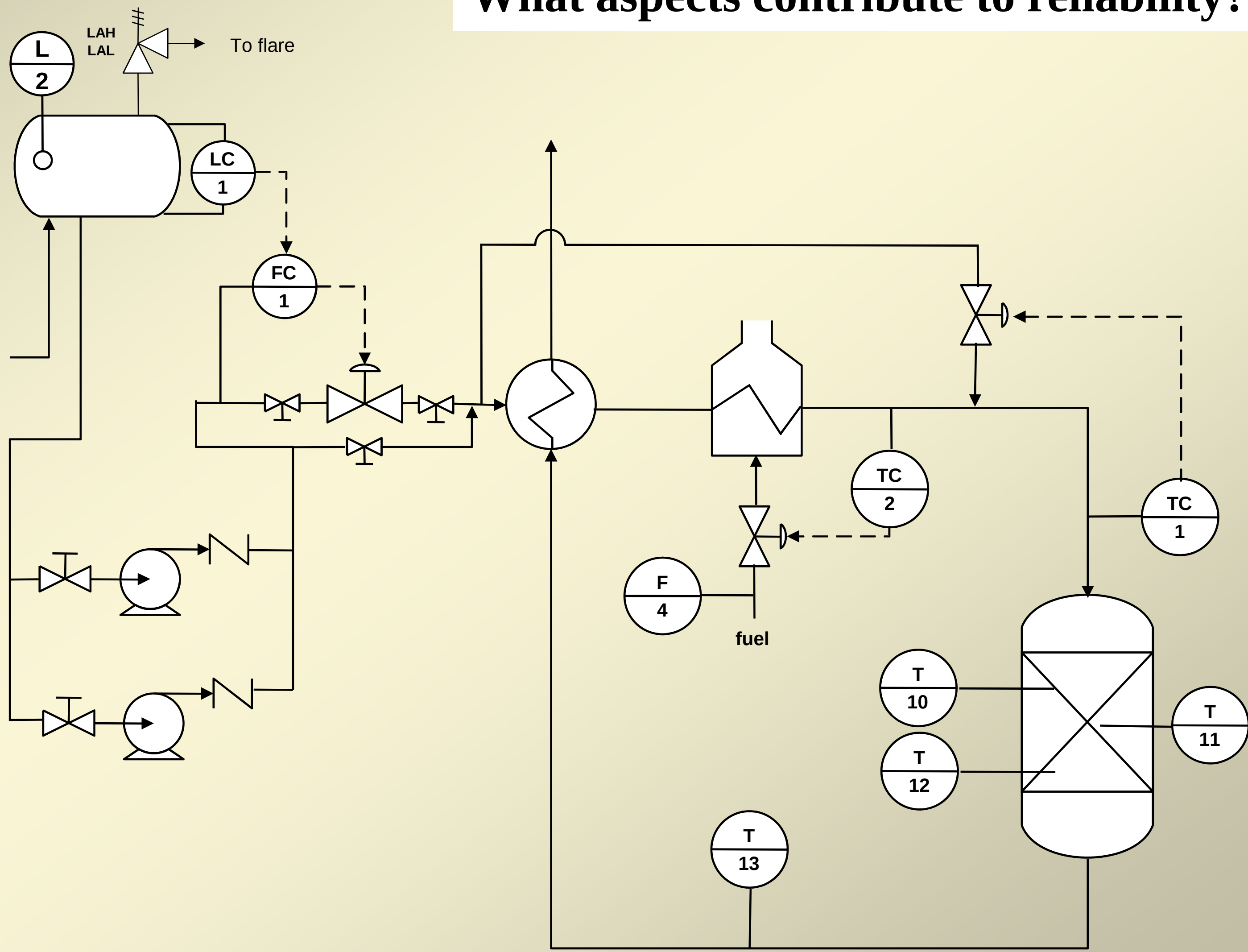
RELIABILITY

What aspects contribute to reliability?



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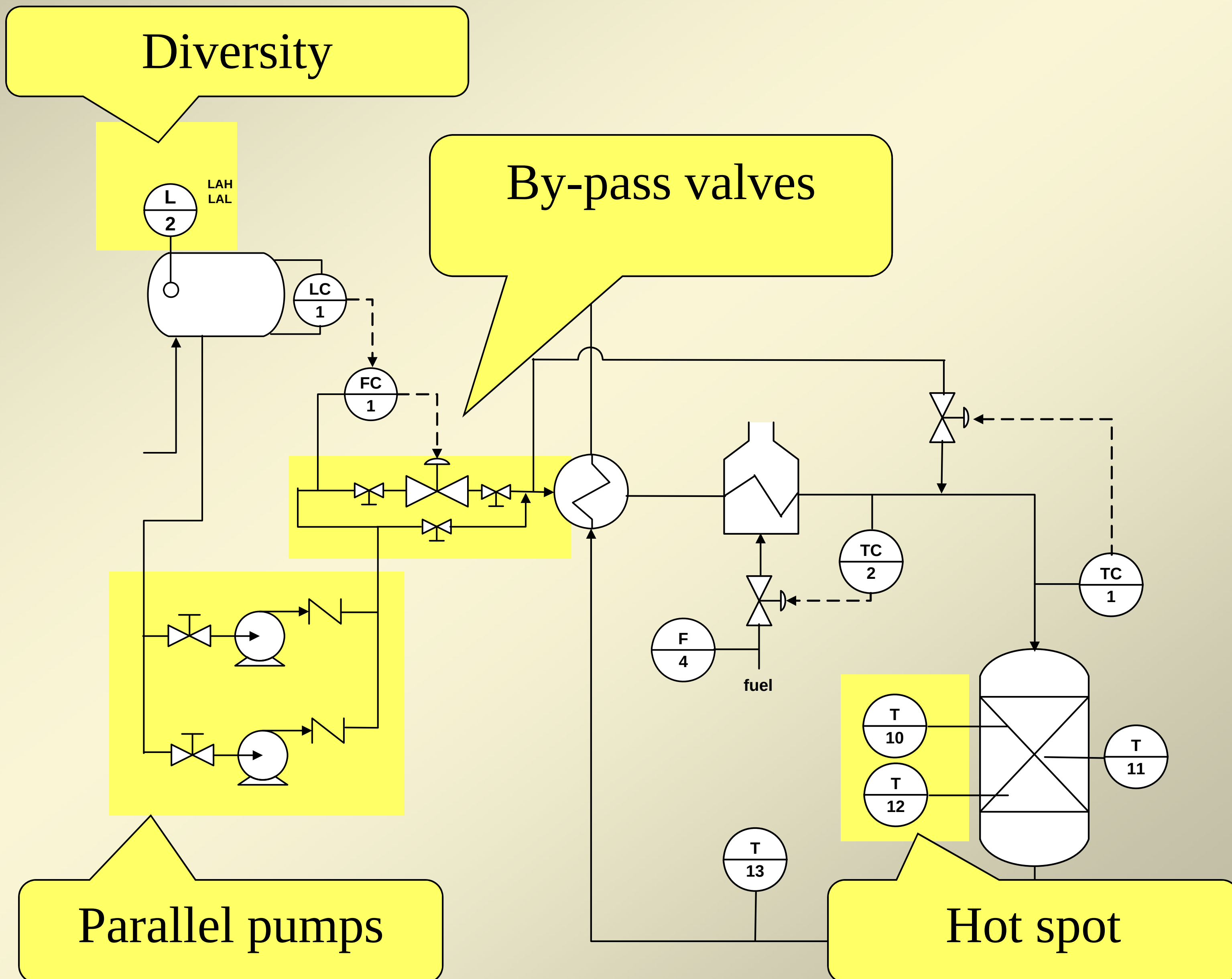
RELIABILITY



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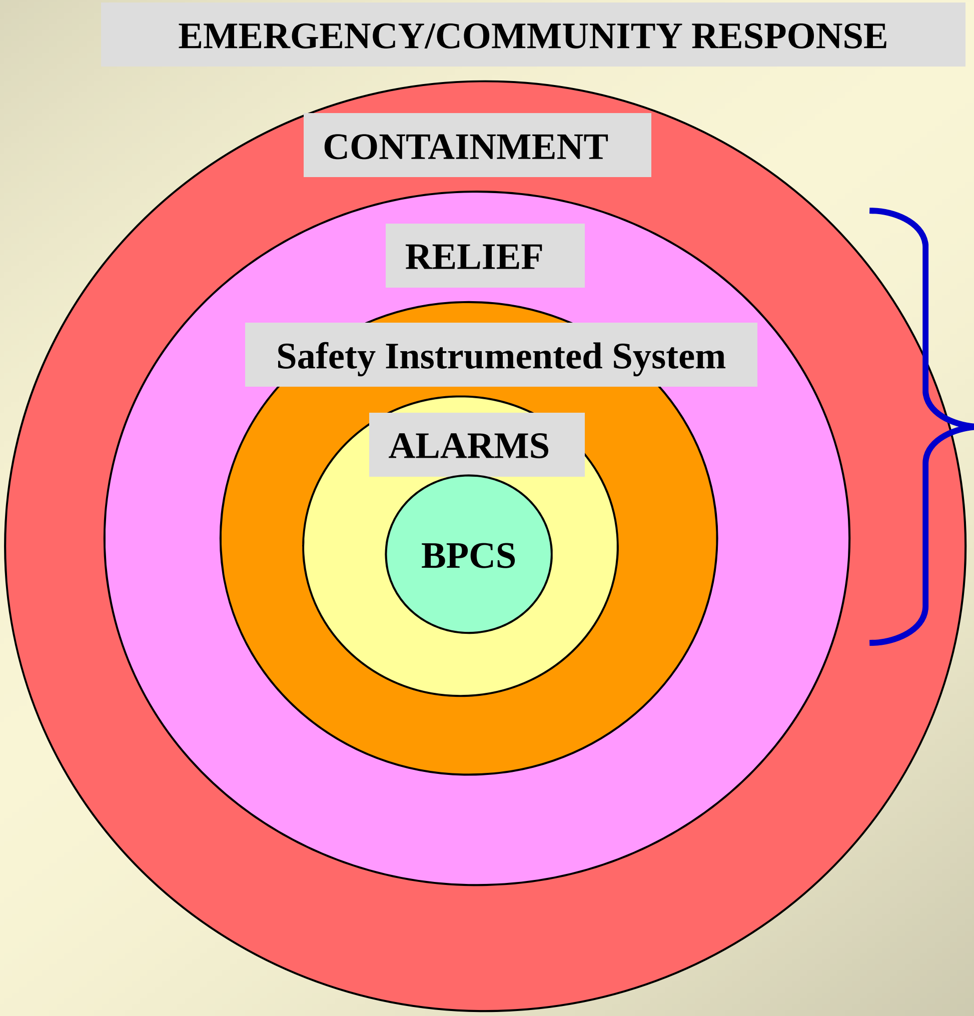
SAFETY & EQUIP. PROTECTION

Layers of Safety Protection



- Concentrate on the first four layers
- Stay close to the process

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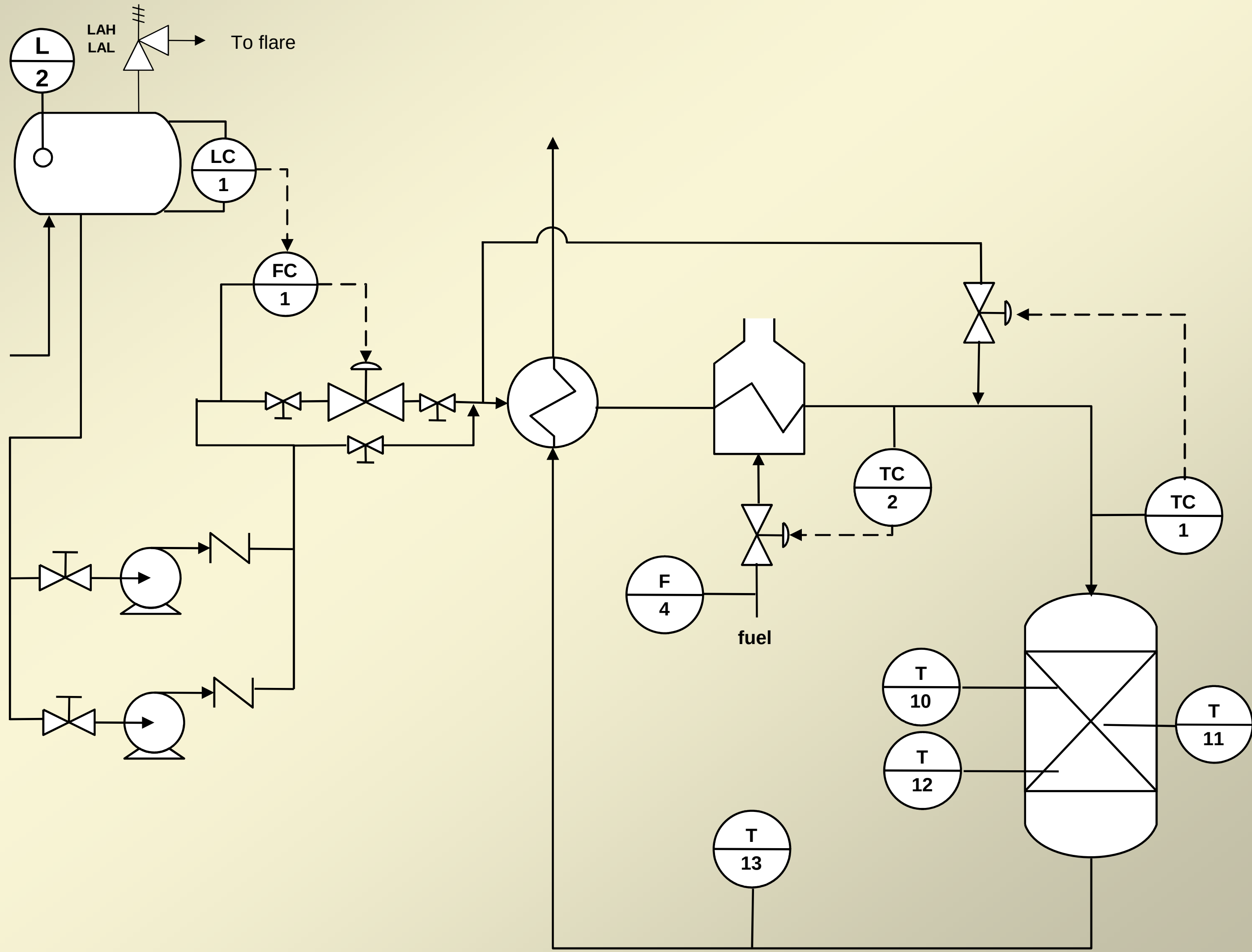
SAFETY & EQUIP. PROTECTION

What aspects contribute to safety?



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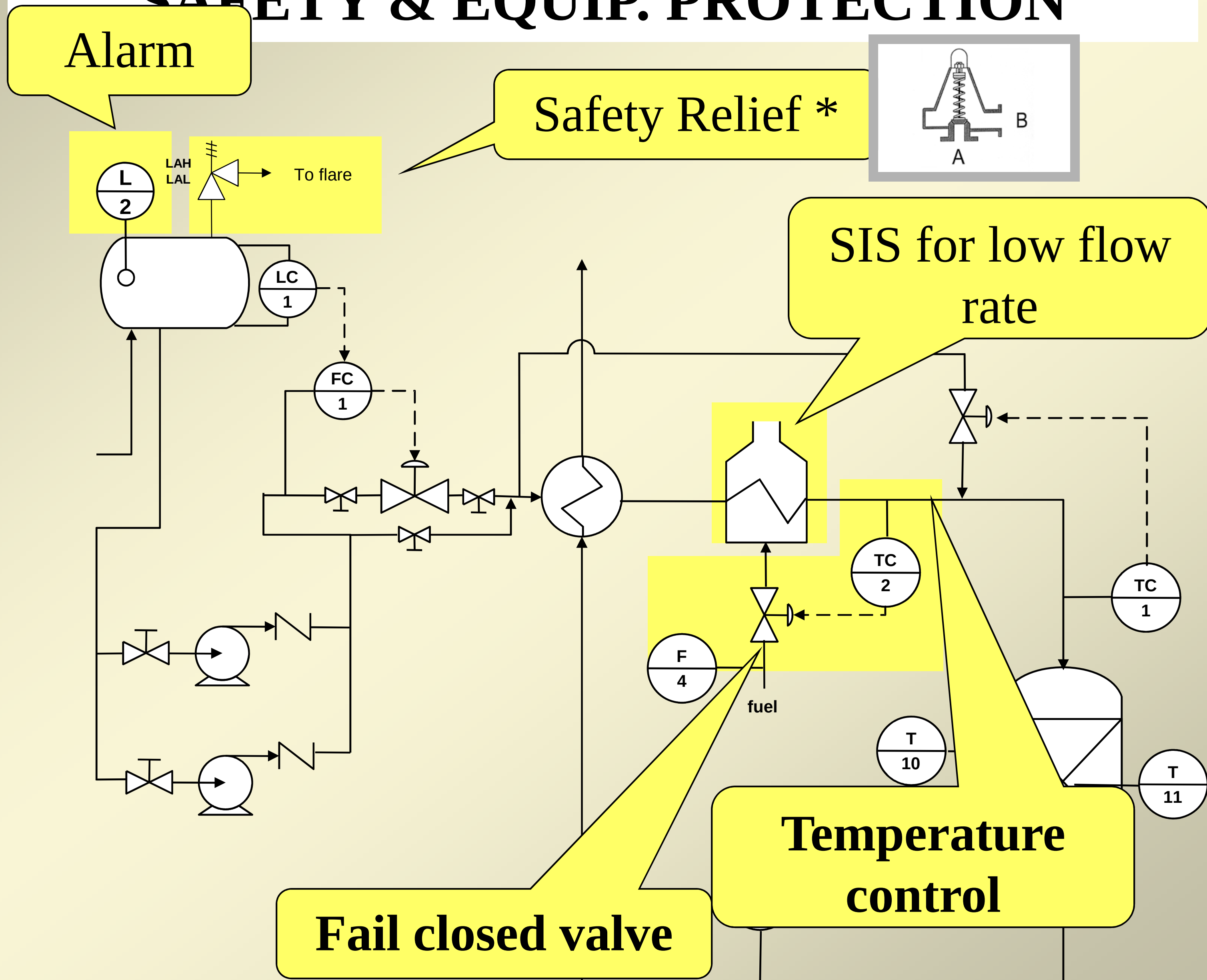
SAFETY & EQUIP. PROTECTION



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SAFETY & EQUIP. PROTECTION

HAZOP method provides a structured manner for safety analysis (using qualitative analysis)

Note the specific location

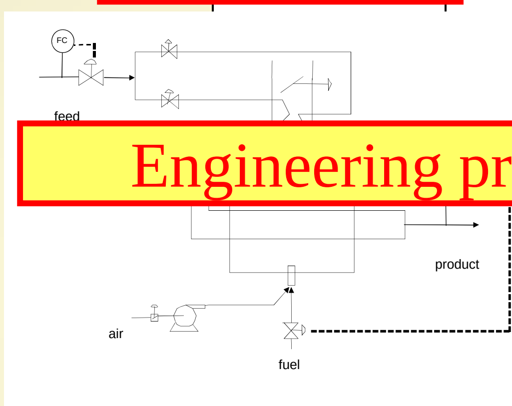
Unit: ________Fired heater____________________

Node:___air pipe after compressor and valve_ Parameter: __Pressure____________________

Guide Word	Deviation	Cause	Consequence	Action
lower	Low pressure in the fuel pipe node	Stoppage of power to motor or turbine turning the compressor	Uncombusted fuel in the fire box – danger of explosion Uncombusted fuel – wasted fuel	SIS based on the rotation of motor shaft *
		Break of coupling between motor and compressor	“	SIS based on rotation of compressor shaft*
		Failure of ...sor, e.g., ...e of blades	“ (plus danger from flying metal)	
		...of air valve due to failure	“	Fail open valve
		Any of the above	“	SIS that measures the flow of air after the pipe and activates the shutdown if the flow if too low
		Closure of air valve due to poor decision by operator	“	Air flow controller with ratio to fuel flow

Principles

Engineering practice



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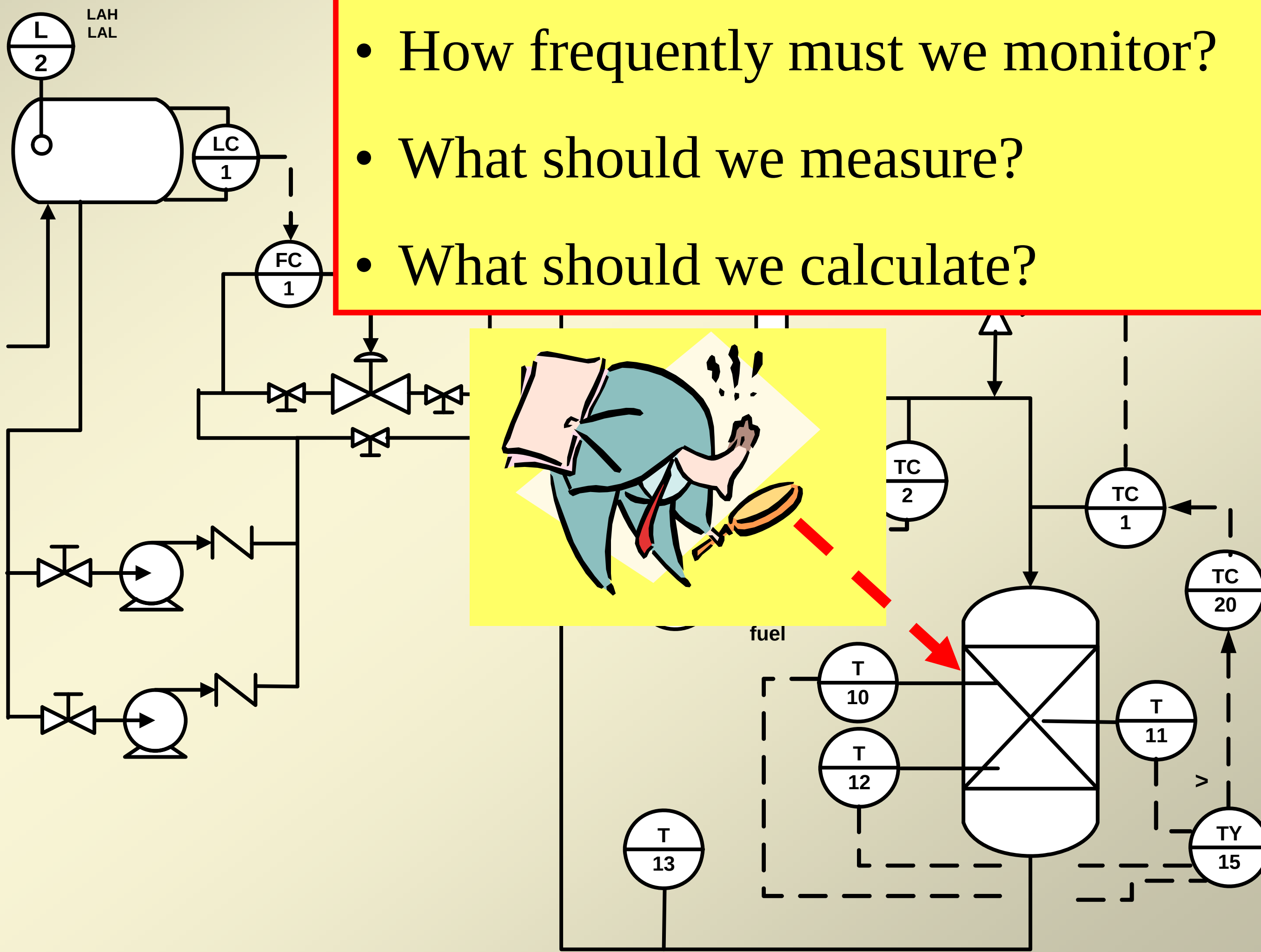
MONITORING & DIAGNOSIS

- What is important?
- How frequently must we monitor?
- What should we measure?
- What should we calculate?



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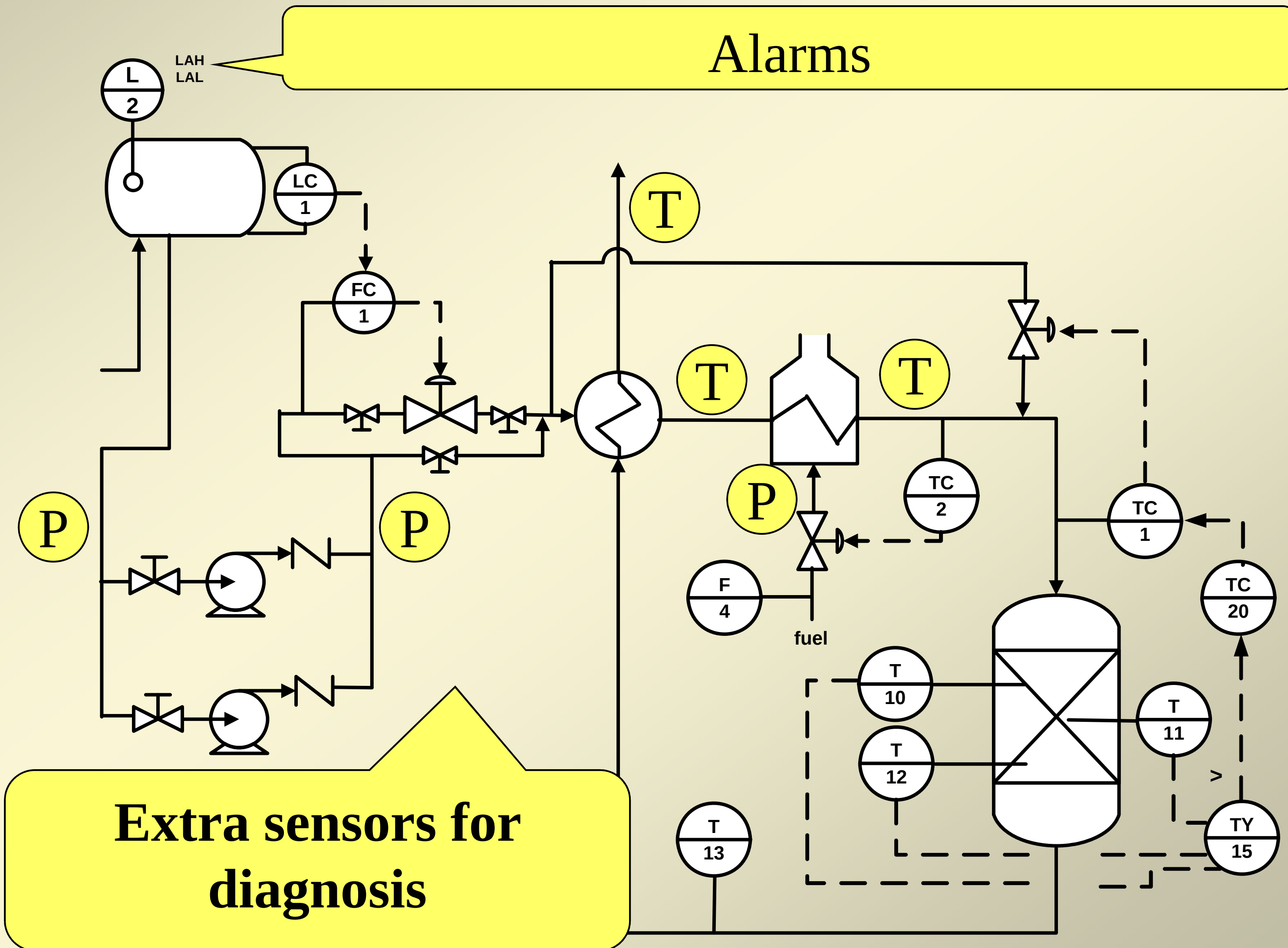
MONITORING & DIAGNOSIS

Rapid decisions – made by operating personnel



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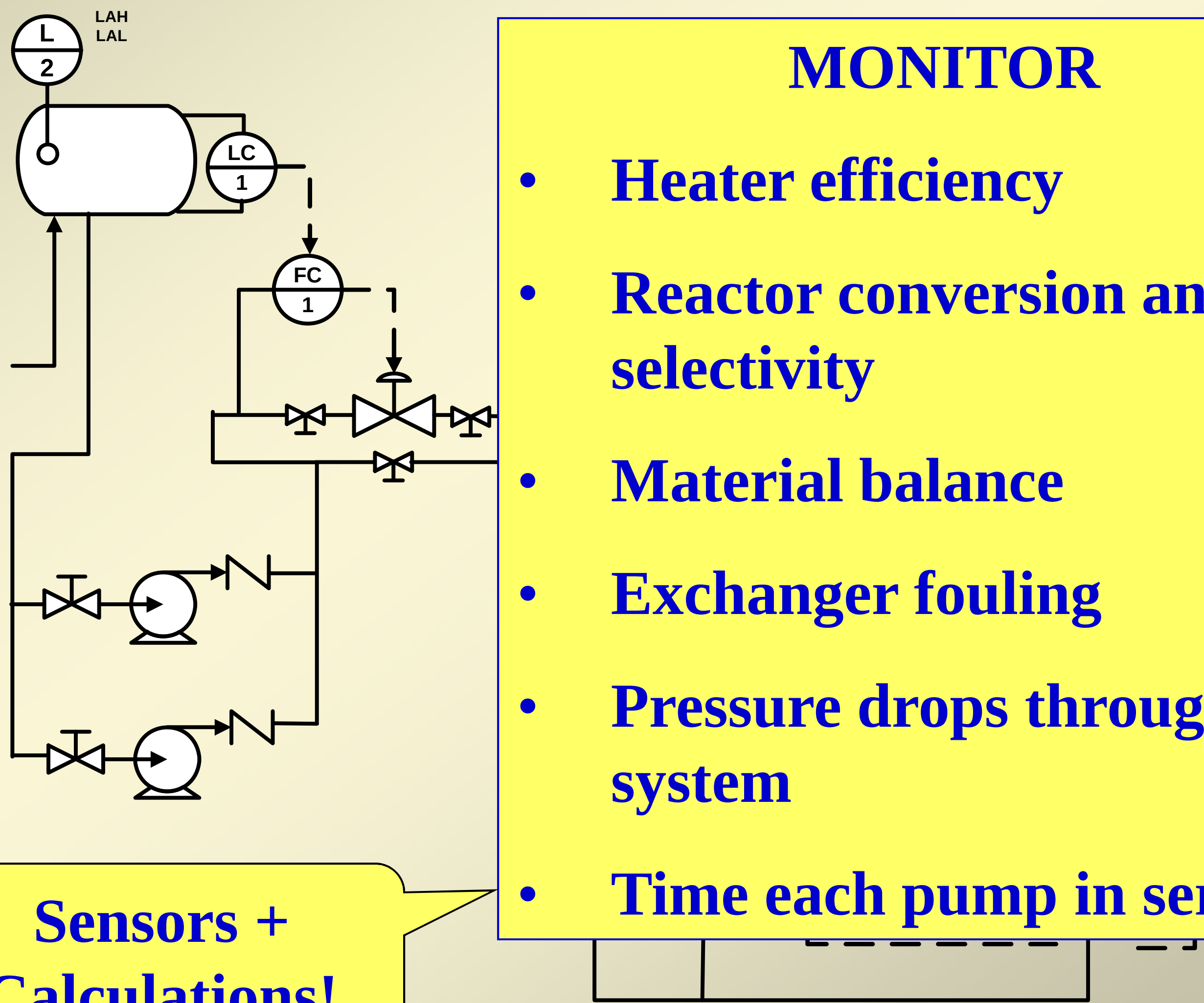
MONITORING & DIAGNOSIS

Longer-term decisions – made by engineers



MONITOR

- Heater efficiency
- Reactor conversion and selectivity
- Material balance
- Exchanger fouling
- Pressure drops through system
- Time each pump in service

Sensors + Calculations!

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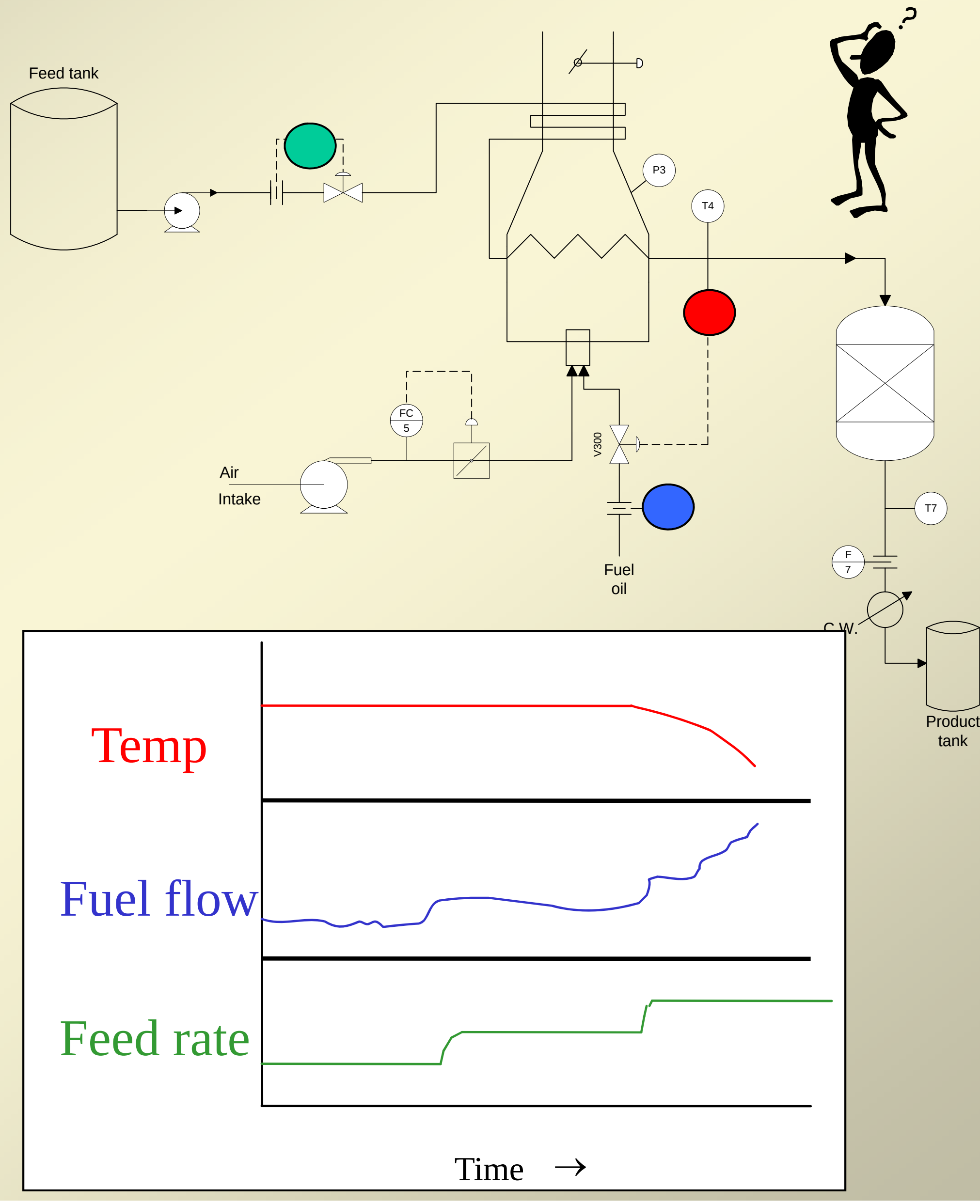
MONITORING & DIAGNOSIS

Systematic Problem Solving Method!

Process Trouble Shooting

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate



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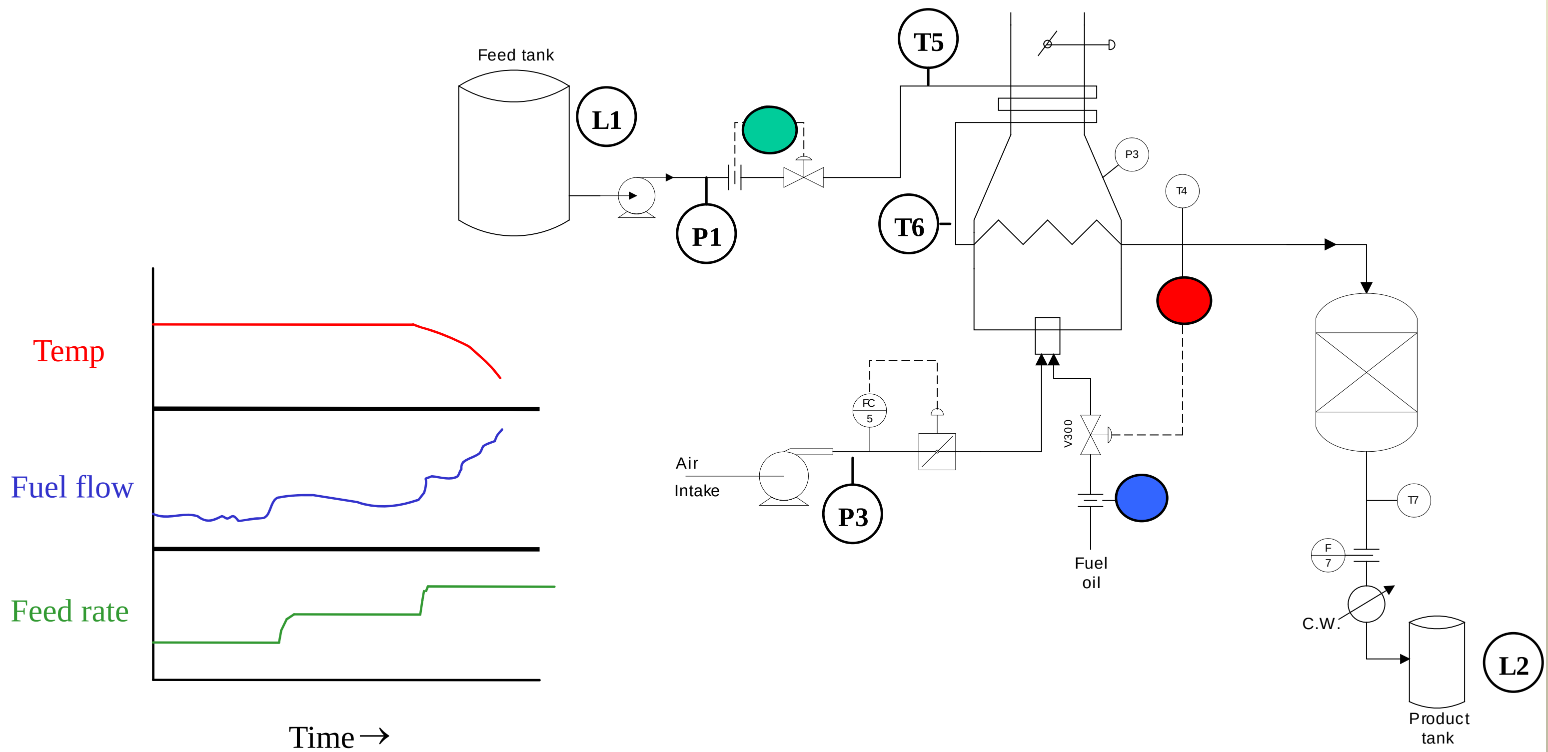
MONITORING & DIAGNOSIS

Hypothesis	Initial information	Diagnostic Action
T sensor drift	Neutral	Check with temperature at exit of reactor
Fuel valve is stuck open	Disprove (Temperature would increase)	Place flow controller in manual and make small change to controller output
Feed rate causing T decrease (TC too slow)	Disprove (previous changes were controlled)	________________



FISHBONE DIAGRAM FOR MONITORING & DIAGNOSIS

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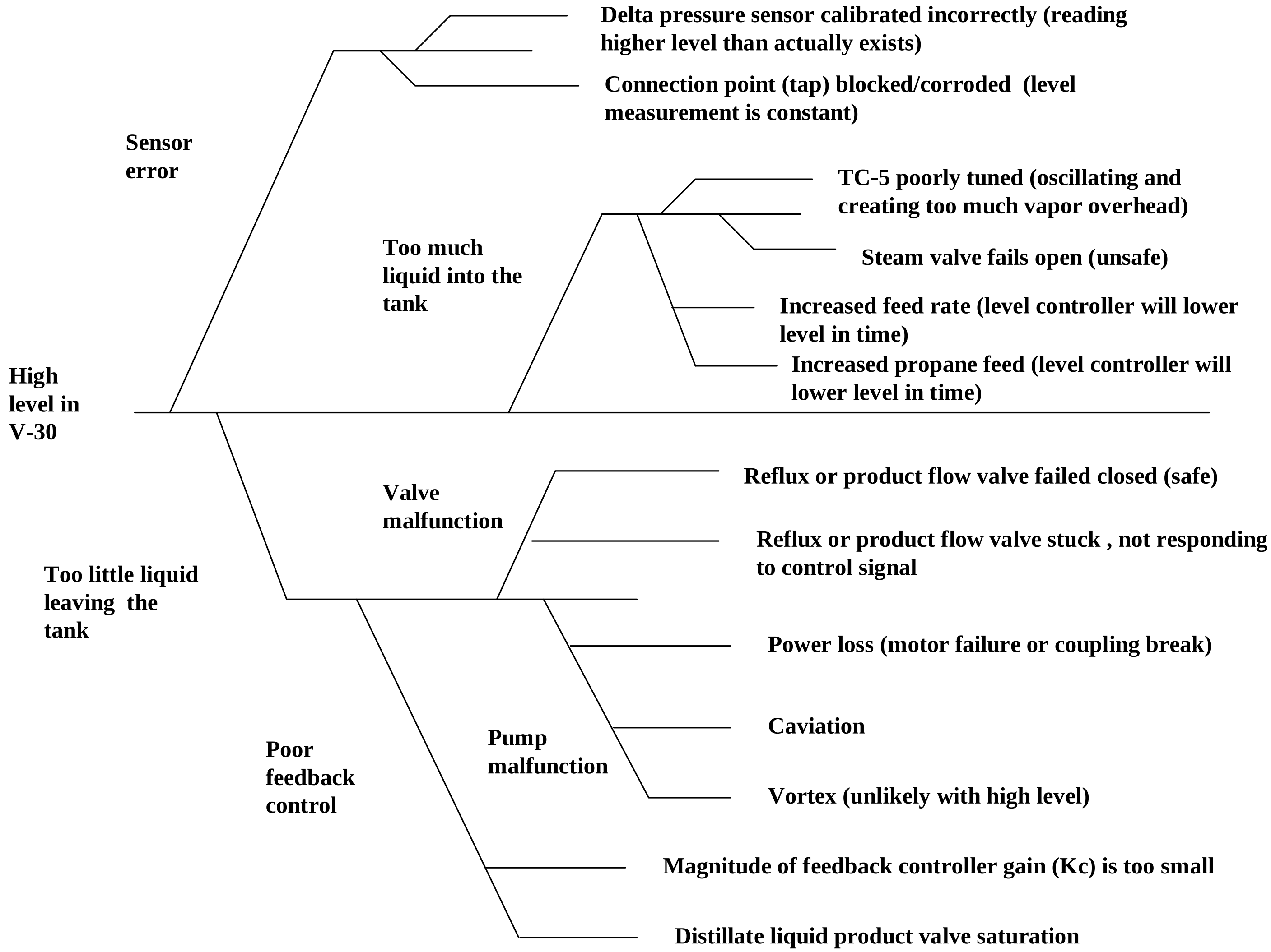
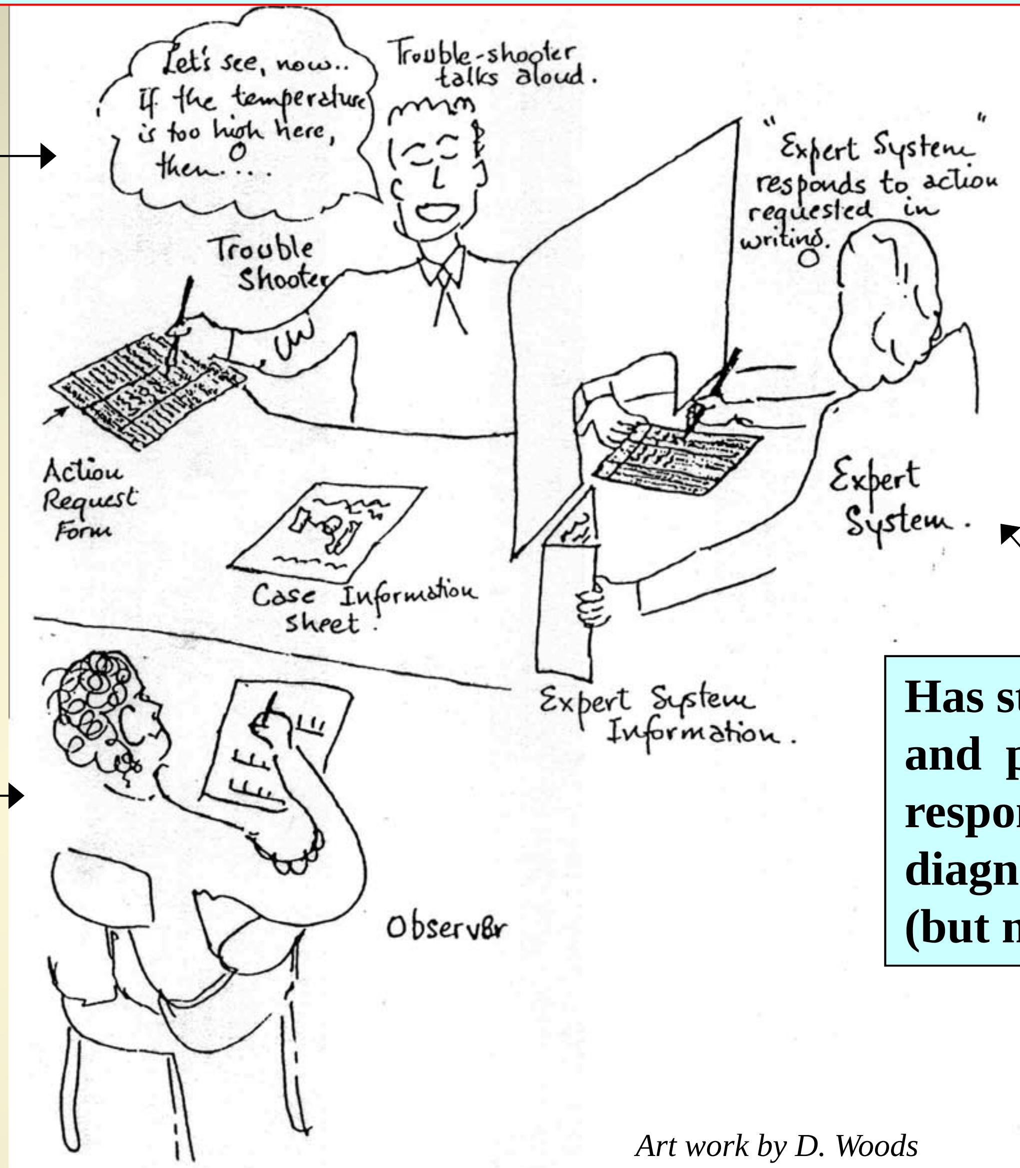


Student "Triad" Groups for Trouble Shooting Tutorials

Applies the method and verbalizes thinking process

Monitors the TS'ers method and provides feedback after exercise



Art work by D. Woods

Has studied the case and provides responses to diagnostic actions (but no hints)

INSTRUCTOR'S EXPERIENCES

- **Any problem-based teaching style will likely satisfy needs**
- **Heavy load to develop**
- **Operability involves generic topics that are applicable to essentially any process (would have to be modified for product design). See sample projects from previous years.**

- Ammonia reactor and separation loop
- Milk powder evaporators and fluid bed drier
- Municipal water purification plant
- Desalination plant by reverse osmosis
- Ice cream production
- Penicillin production (reactor and separation)
- Refrigeration and cooling tower plant
- Boiler feed water treatment and storage
- Kraft pulp digester
- Wine production

STUDENTS' EXPERIENCES

The Good

- Students enjoyed the problem solving tasks (HAZOP and Trouble Shooting)
- Defined diverse projects & found good operability issues

The Bad

- Difficulty recognizing causes of variability and uncertainty
- Challenge to "work backwards": effect $\longrightarrow$ cause
- Needed to build experience with qualitative process analysis

The Ugly   To much work!

A PROPOSAL FOR Ch.E. INSTRUCTORS

- Integrate **Robust design/process operability** in the capstone design course
- No instructor has experience with all issues
- Limited educational material is available that is accessible to undergraduates

Proposal to establish a portal for robust design/ process operability, with educational materials for public use

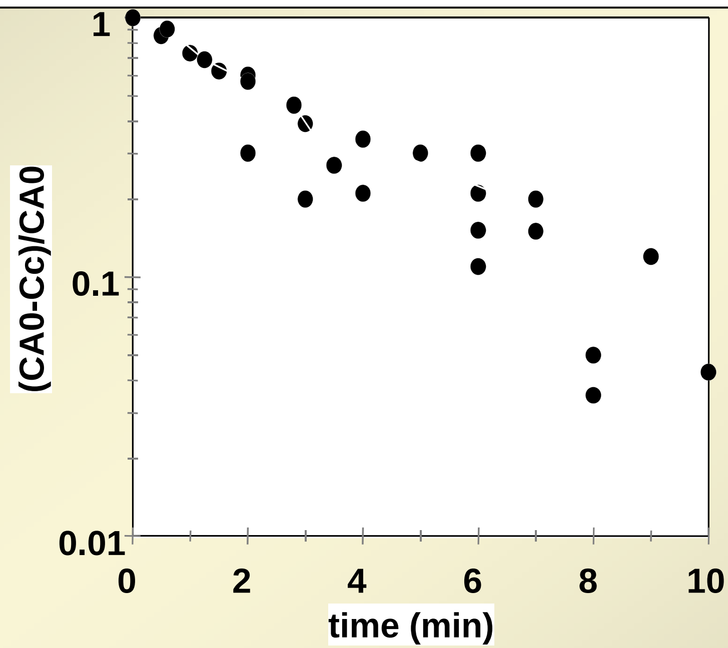
Expanded copy of white paper and power point lessons are available at

www.pc-education.mcmaster.ca/

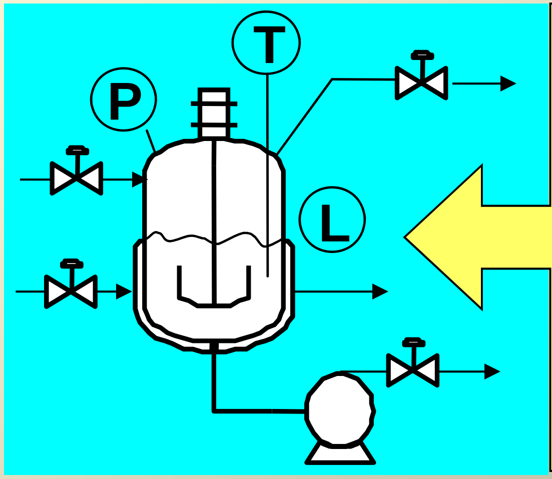
A RECOMMENDATION FOR PRIOR COURSES

- **Typical courses need to introduce causes of variability and uncertainty.**
- **Solutions should ensure operability (at least in s-s)**

Uncertainty in Rxn kinetics



Variability in production rate: 70-110% of base design



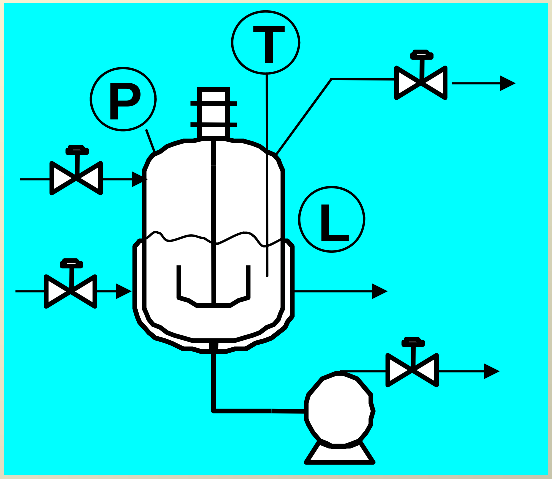
Determine the reactor volume

A RECOMMENDATION FOR PRIOR COURSES

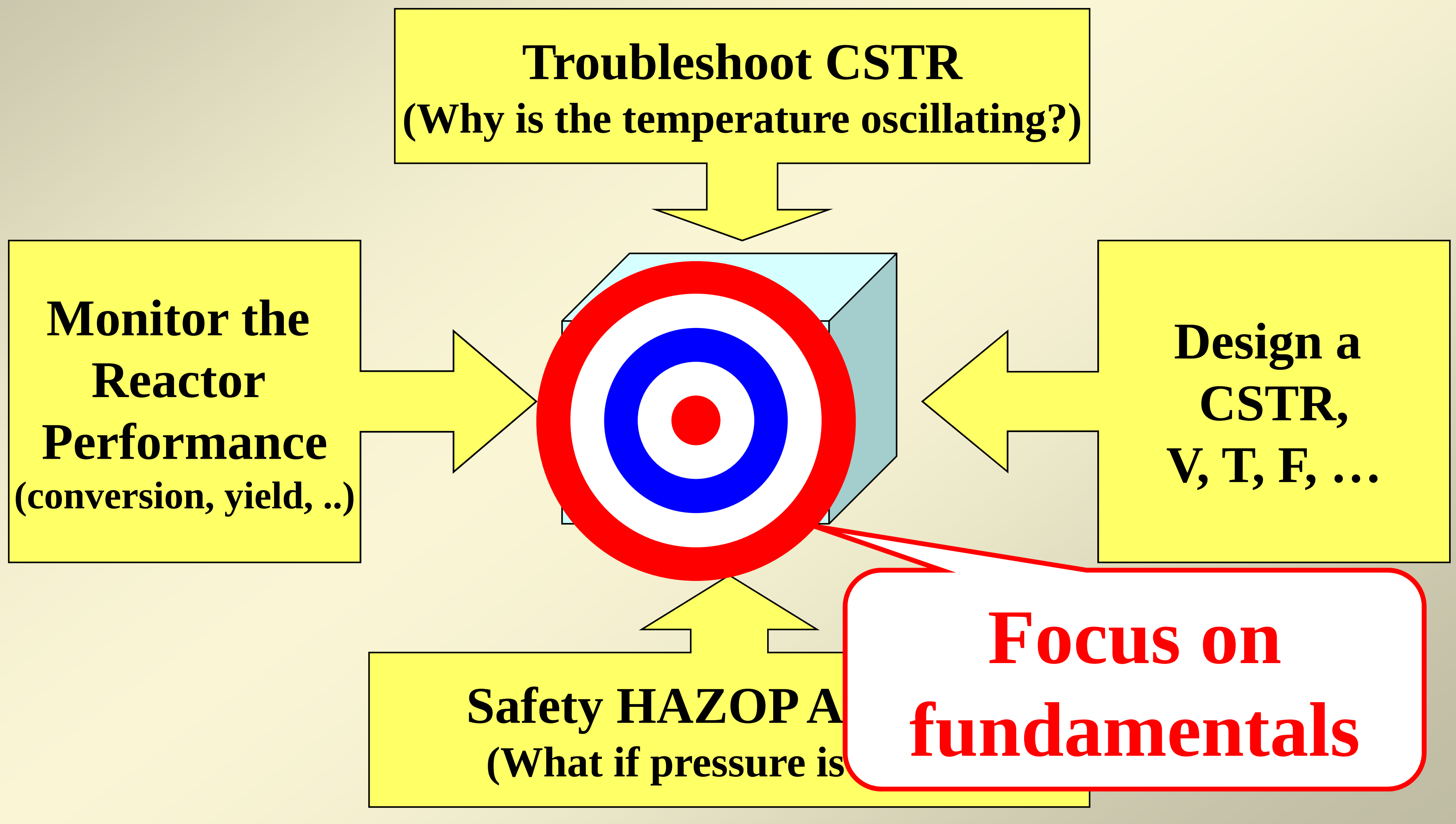
- **Courses need to indicate that processes are changed to achieve desired conditions.**
- **Engineers should be able to analyze the process qualitatively**

We want to increase the feed flow rate by 10% and maintain the conversion unchanged.

What do we do?



NO NEW PRINCIPLES, but Applications, Problem Solving, and Integration are Unique



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OPERABILITY IN UNDERGRADUATE EDUCATION

We would appreciate comments, criticism, suggestions at any time, now or by email.

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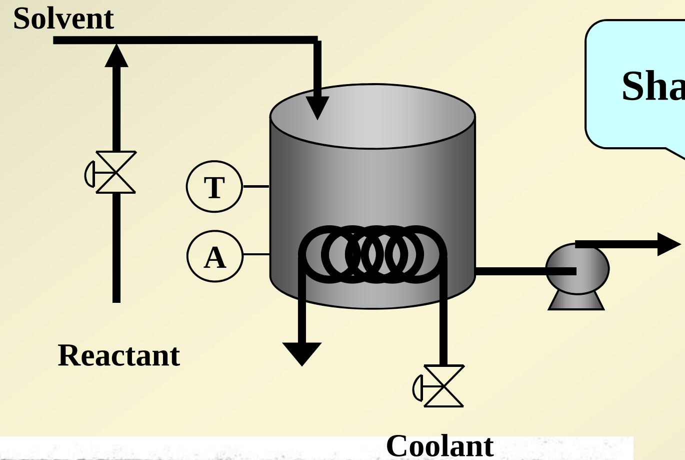
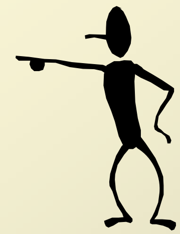
OPERATING WIDOW

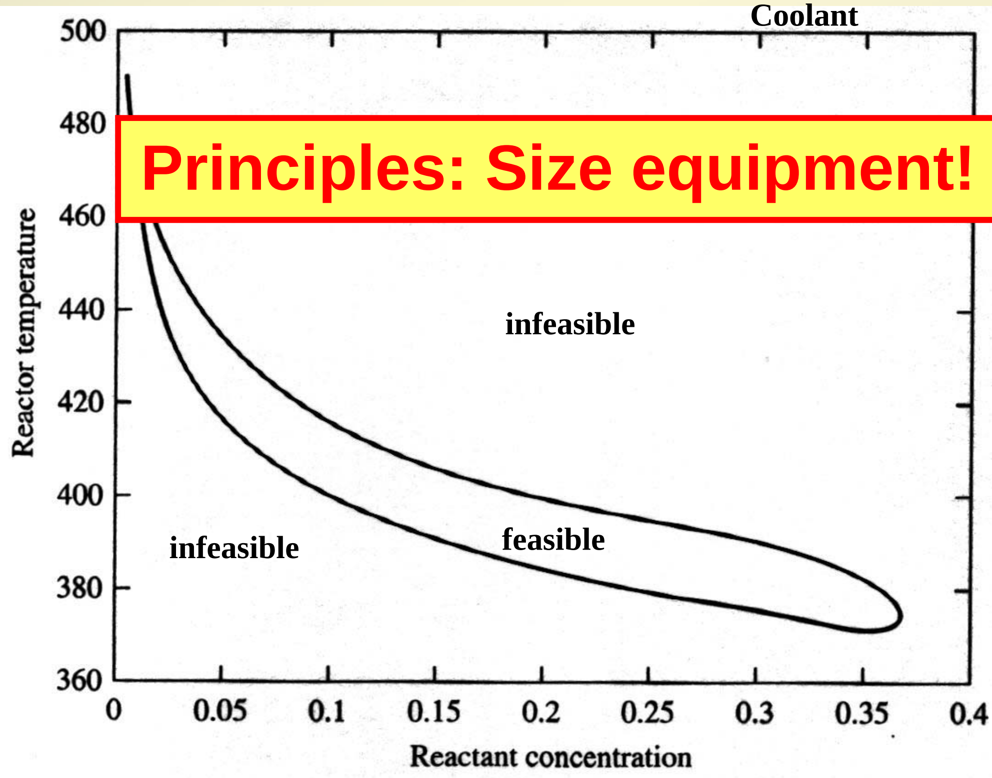
$$A \rightarrow B$$

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



Shape of op. Window?





Principles: Size equipment!

- **Depends of variability**
- **Depends on flexibility**
- **Not rectangular!**

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RELIABILITY

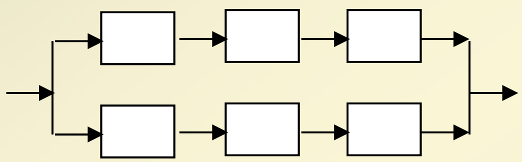
Probability that the process will perform its function properly (one "path" must function)

No redundancy

A) 

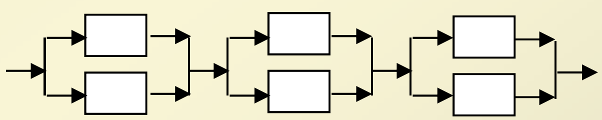
$$R_A = (0.90)^3 = 0.729$$

System-level redundancy

B) 

$$R_B = 1 - \left[1 - (0.90)^3\right]^2 = 0.927$$

Module-level redundancy

C) 

$$R_C = \left\{1 - \left[1 - 0.90\right]^2\right\}^3 = 0.970$$

Increased reliability with increased complexity and cost. We have added <u>redundancy</u> with parallel paths.

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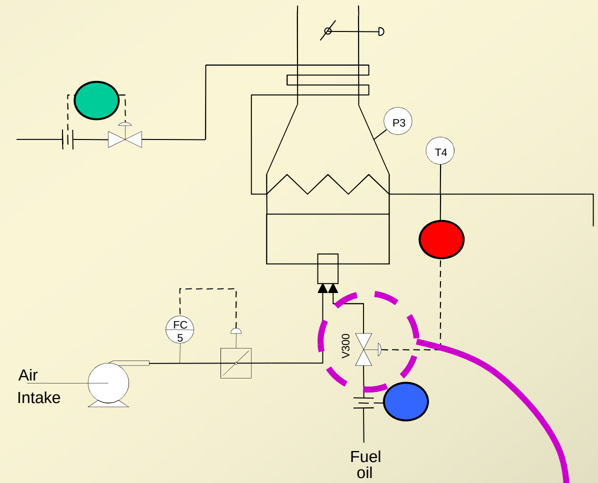
SAFETY & EQUIP. PROTECTION

Learning goals are process principles of SIS: measurements, logic and actions



F100

F210

T305

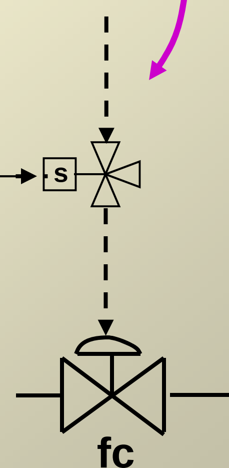
.....

Feed flow > min
Air flow > min
Temp < max
•
•

Fuel valve

Stack damper

....



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OPERATION DURING TRANSITIONS

Special equipment and procedures (controls) are required during transition.

Steady-state processes

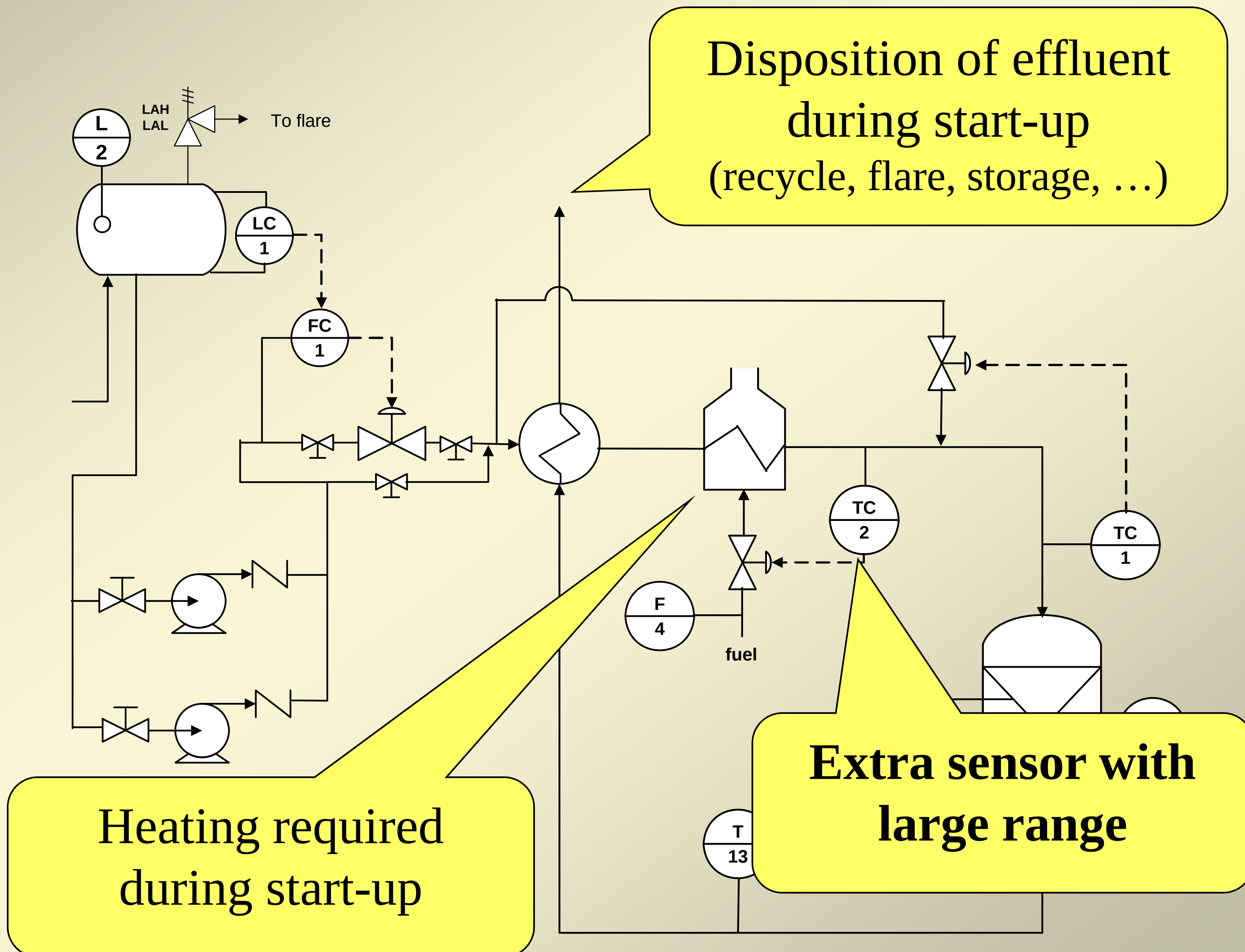
- Start-up and shutdown
- Regeneration
- Short runs with frequent switches
- Load following (highly variable demand)

Unsteady-state processes

- Batch

Equipment capacity must satisfy peak demand, not daily or batch average!

OPERATION DURING TRANSITIONS



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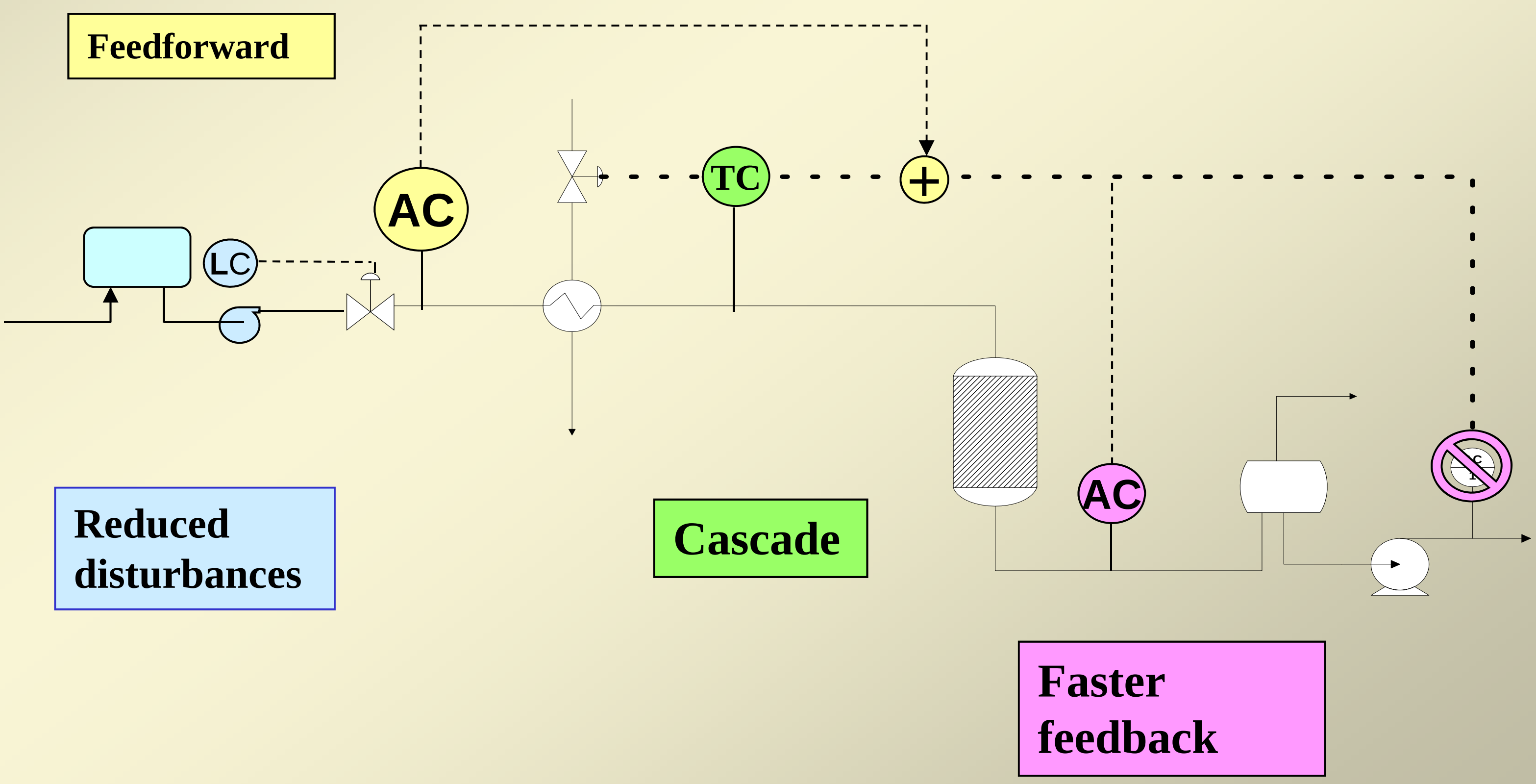
DYNAMIC PERFORMANCE

Rapid compensation for disturbances and timely changes to set points – the process side of process control



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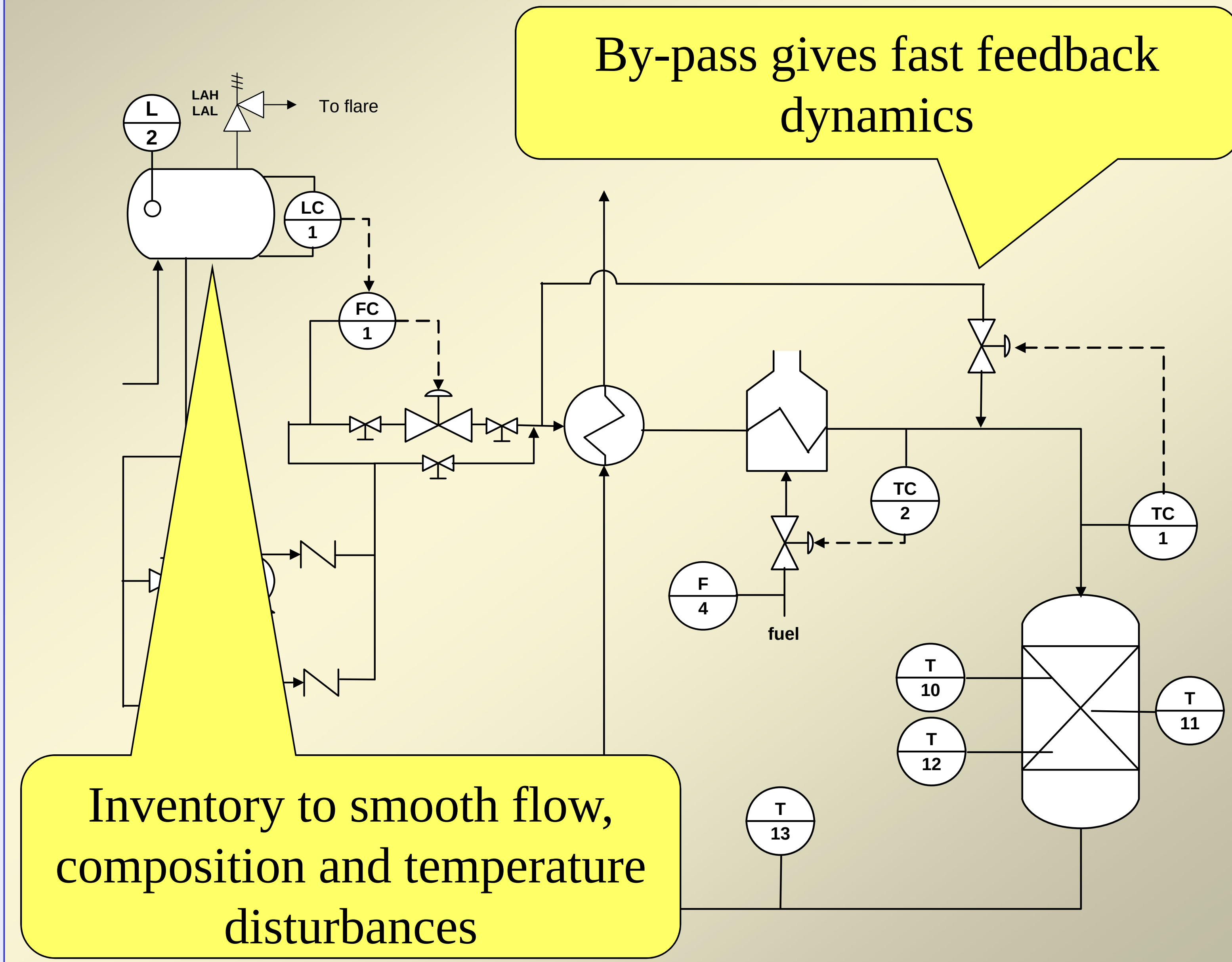

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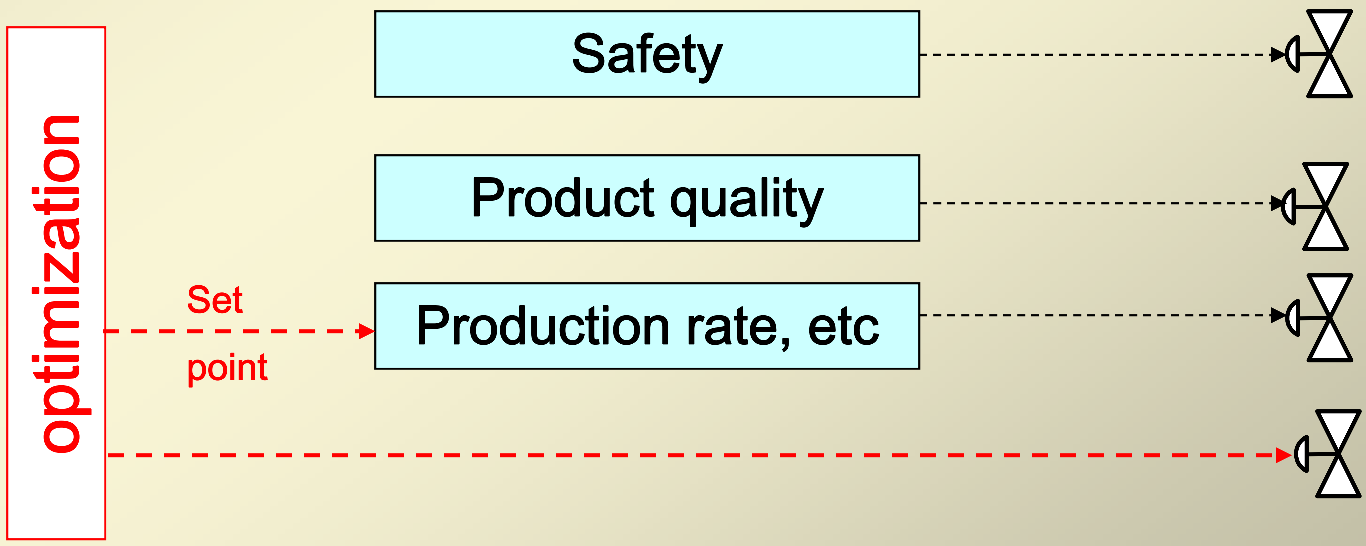
EFFICIENCY & PROFIT

With safe, smooth operation making consistently high product quality, is there more to do? **YES!**

Operability requires extra capacity for extreme situations. We can take advantage during most times to increase profit.



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