Major tasks in safety engineering

Hazard identification

1. Check lists
2. Dow relative ranking
3. HAZOP - hazard and operability

- **Level of protection analysis**
- **Hazard assessment**
  - Fault tree
  - Event tree
  - Consequence analysis
  - Human error analysis
- **Actions to eliminate or mitigate**
  - Apply all engineering sciences

This section covers hazard identification methods, and we will include corrective actions.

We will use our group skills and knowledge of safety layers in applications.

Hazard and Operability: HAZOP

All of these terms! This stupid table! I hate HAZOPS. Why don't we just learn the engineering?

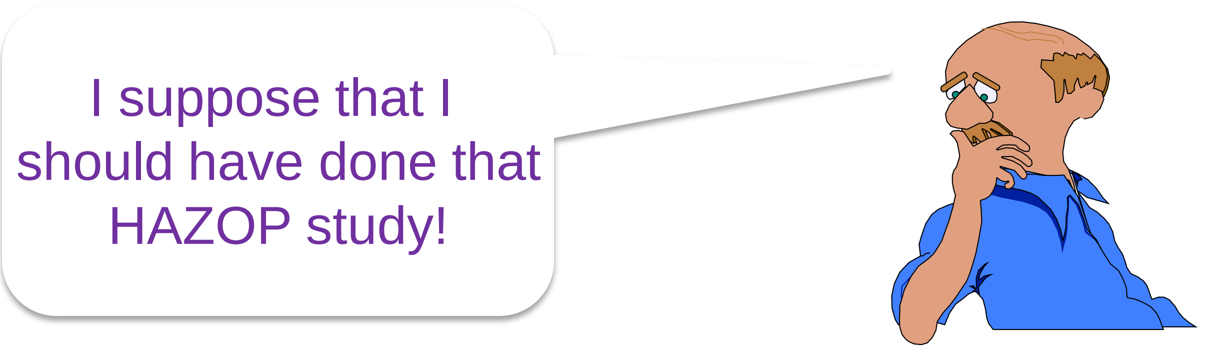
Consequence

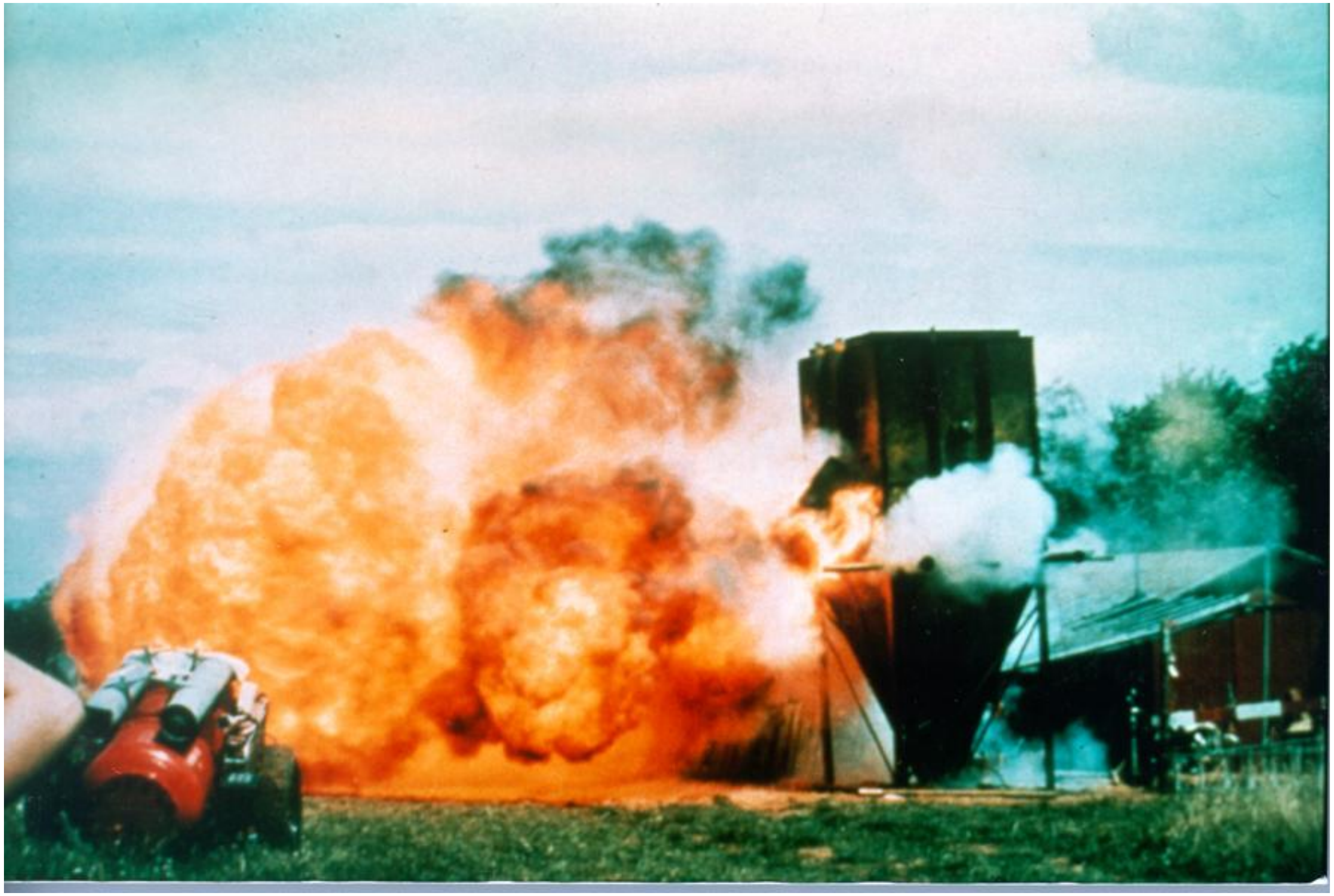
Nodes

Guide words

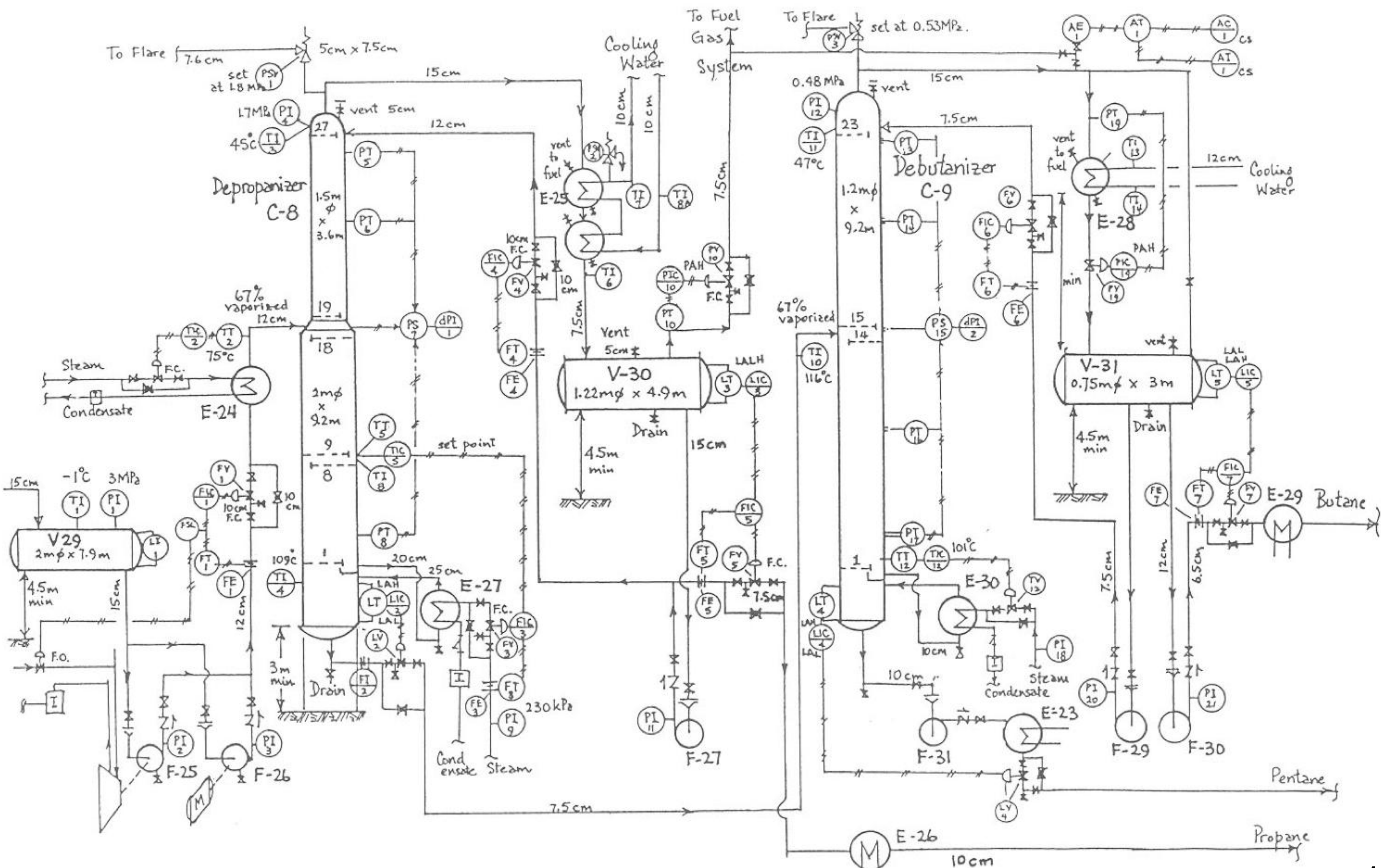
Parameters

Deviation


I suppose that I should have done that HAZOP study!



What can go wrong? Where do we start?



Safety engineering - some terms to know

- Hazard: A hazard introduces the potential for an unsafe condition, possibly leading to an accident.
- Risk is the probability or likelihood of a hazard resulting in an accident
- Incident is an undesired circumstance that produces the potential for an ACCIDENT
- Accident is an undesired circumstance that results in ill health, damage to the environment, or damage to property

Hazard → incident → accident
(includes near misses)

Hazard identification

1. Check lists

- List of hazards identified from previous studies and historical data on operating plants
- Can be tailored to specific materials, equipment, operating procedures, etc.
- Very simple and low cost
- Especially helpful to novice
- But,

  - Does not address new processes, equipment, etc.

  - Past data might not contain infrequent, high consequence accident

Hazard identification
2. Relative ranking

- Based on general information about materials and processes
- Very well defined procedure involving tables and standard data sources. Some judgment, but people should arrive at nearly the same results
- Does not consider important details of specific plant
- Therefore, key applications are

  - Early evaluations of completing projects

  - Insurance evaluations

Hazard identification
2. Relative ranking: Dow Index

- We will use Dow's Fire and Explosion Index - available to all engineers through the AIChE and in Thode Library.
- The resulting Index value can be used to estimate the degree of hazard (below from Crowl and Louvar, 1990)

Dow Index	Degree of Hazard
1 - 60	light
61-96	moderate
97-127	intermediate
128-158	heavy
159 up	severe

Hazard identification
2. Relative ranking: Dow Index

- Further calculations can be performed to estimate potential property loss (max cost per accident) and business interruption (days downtime per accident)

- Uses

  - Evaluation by insurance companies

  - Quick estimate of the hazard, especially when company does not have prior experience

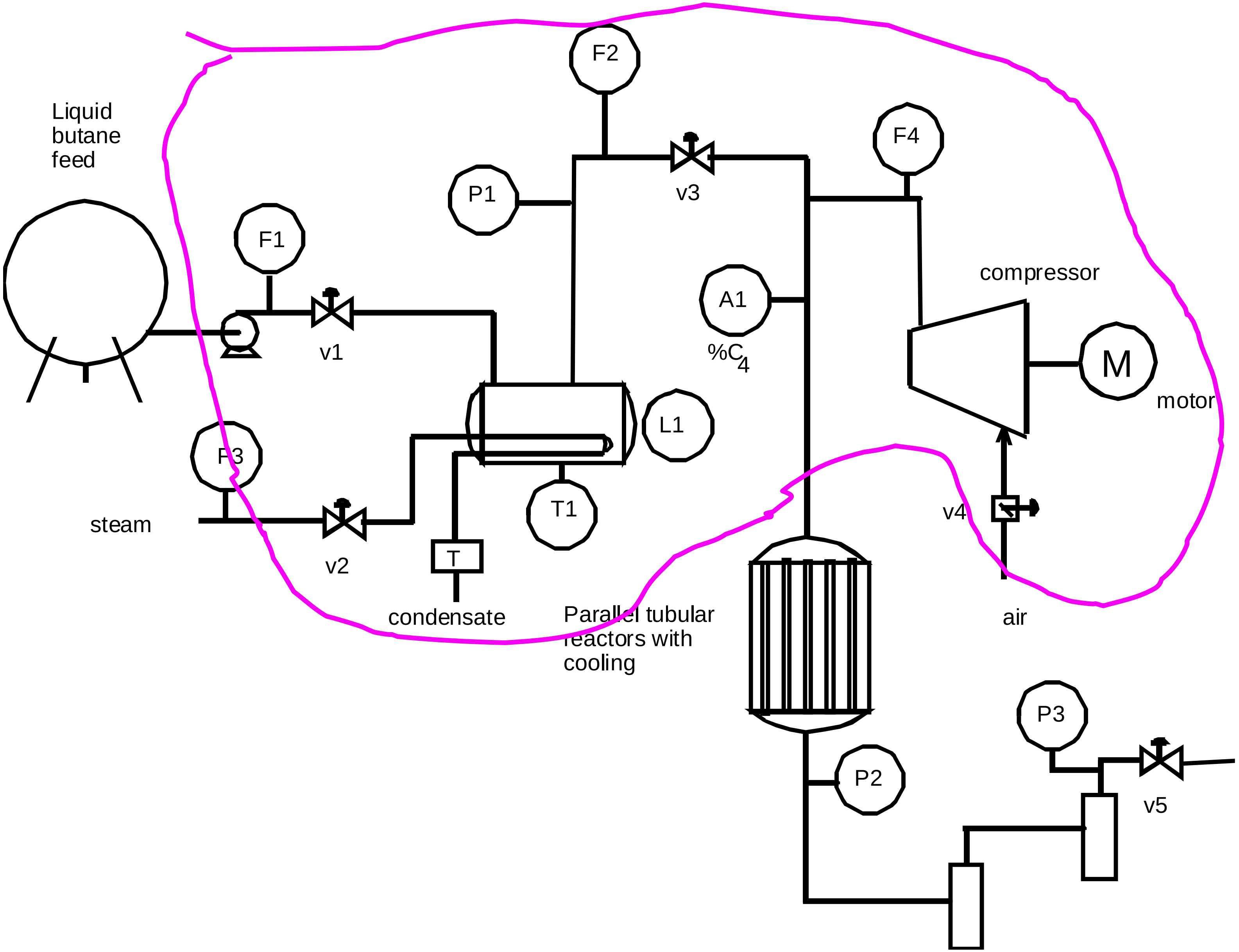
  - Note that process and equipment technology is not included in evaluation

Hazard identification
2. Relative ranking: Dow Index

Class Example: Bartek Feed Vapourizer

Plant:	Bartek Maleic Anhydride
Unit:	Butane vapourizer and air blower
	(not including butane storage or reactor)
Materials:	Butane and air
Operating mode:	Normal continuous operation

Hazard identification
2. Relative ranking: Dow Index



Hazard identification
2. Relative ranking: Dow Index

For this example, the index a value at the upper bound of "light risk".

DOW INDEX for Bartek Vaporizer process

Material Factor for Butane: MF = 21 (Dow Index Table)

GENERAL PROCESS HAZARDS	
BASE FACTOR	1.0 (if T > 140 F, see page 14)
A. Exothermic reaction	0 (not a reactor)
B. Endothermic reaction	0 (not a reactor)
C. Material handling	0 (not in this unit)
D. Enclosed unit	0
E. Access	0
F. Drainage	0 (not known)
F1 =	1.0 (sum of above)
SPECIAL PROCESS HAZARDS	
BASE FACTOR	1.0
A. toxic materials	0.0 = 0.20 * N_h = 0.20*0.0 (N_h = 0.0, short exposure under fire conditions has no toxic hazard)
B. sub-atmospheric pressure	0
C. operation in near flammable range	
1. tank farms	0
2. upset	0
3. always in flammable range	0.80 (after mix point)
D. Dust	0
E. pressure	0.25 (safety relief at 70 psig, see Figure 2, page 22)
F. low temperature	0
G.. Quantity of flammable material	
1. In process	0.10 (30 gal of butane is below lowest value of x coordinate, BTU = .0029 x 10^9)
2. In storage	0
3. solids	0
H. corrosion and erosion	0 (don't have all data, no sight glass on vaporizer)
I. Leakage	0.10 (pump)
J. Fired Heaters	0
K. Hot Oil System	0.0
L. Rotating Equipment	0.50 (compressor)
F2	2.75
F3 = (F1) (F2)	F3 = (1.0) (2.75) = 2.75
Fire and Explosion Index	(F3) (MF) =(2.75) (21) = 57.8

See lecture notes for larger version of table.

Hazard identification
3. Hazard and Operability: HAZOP

- HAZOP is a formal and systematic procedure for evaluating a process

  - It is time consuming and expensive

- HAZOP is basically for safety

  - Hazards are the main concern

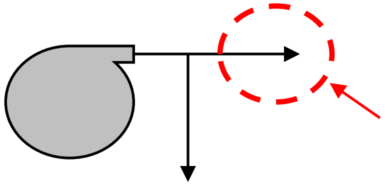
  - Operability problems degrade plant performance (product quality, production rate, profit), so they are considered as well

- Considerable engineering insight is required - engineers working independently could (would) develop different results

Hazard identification
3. Hazard and Operability: HAZOP

HAZOP keeps all team members focused on the same topic and enables them to work as a team:

1 + 1 + 1 = 5

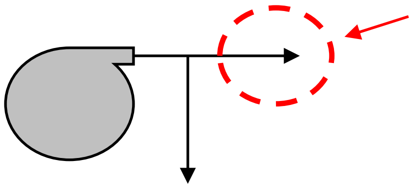


Node: Concentrate on one location in the process

Parameter: Consider each process variable individually
(F, T, L, P, composition, operator action, corrosion, etc.)

Guide word: Pose a series of standard questions about deviations from normal conditions. We assume that we are able to find/operate at a safe "normal" operating point.

Hazard identification
3. Hazard and Operability: HAZOP



Node: Pipe after pump and splitter

e.g. 4.1 m^3/s of 92% ammonia at 20°C; a pressure of 3.5 atm, from a pump to a heat exchanger.

Parameter*: Flow rate

Guide word: Less (i.e. less than normal value)

- *Deviation*: less flow than normal
- *Cause*: of deviation, can be more than one
- *Consequence*: of the deviation/cause
- Action: initial idea for correction / prevention / mitigation

All group members focus on the same issue simultaneously

* For an expanded list of parameters and associated guide words, see Wells (1996)

Hazard identification
3. Hazard and Operability: HAZOP

Typical guidewords used for processes

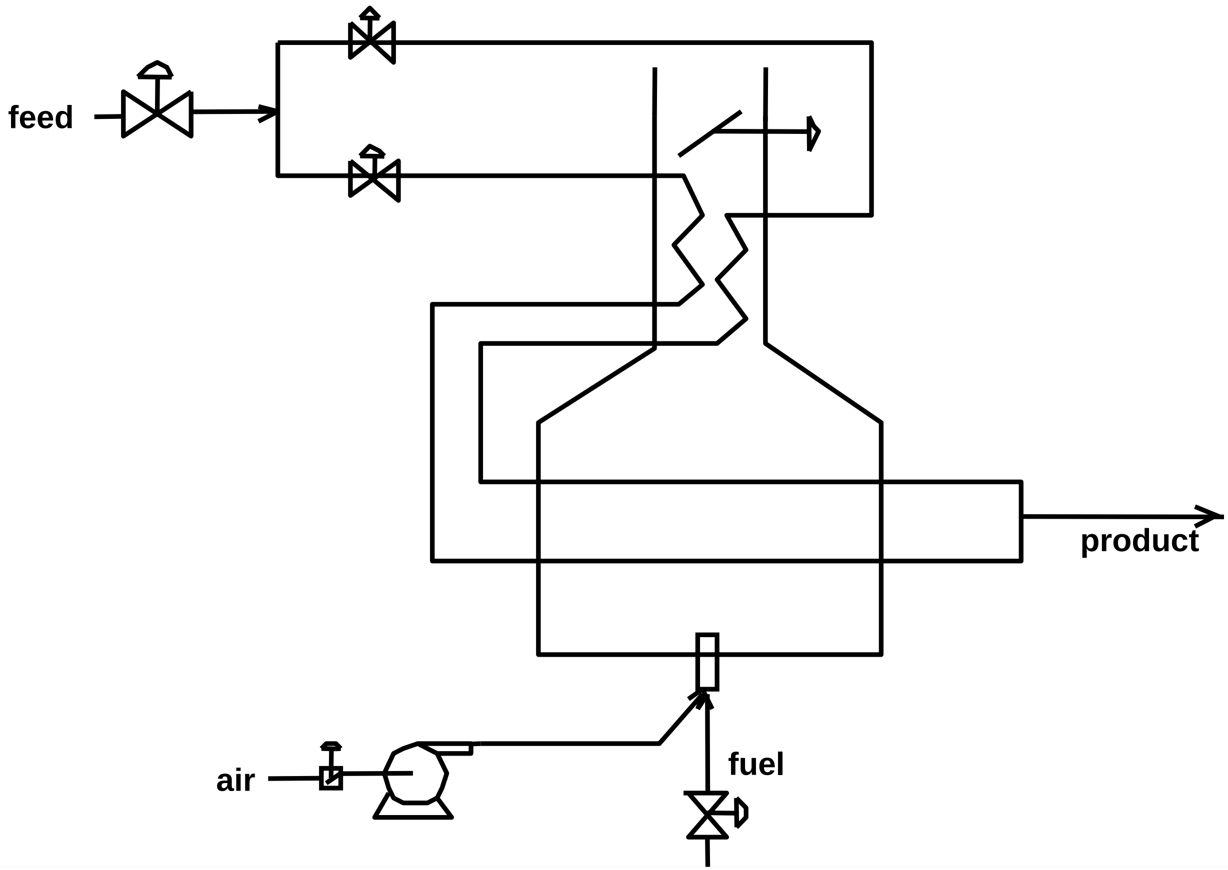
Guide word	Explanation
NO or NOT or NONE	Negation of the design intent
MORE LESS	Quantitative increase Quantitative decrease
AS WELL AS PART OF	Qualitative increase e.g., extra activity occurs Qualitative decrease
REVERSE	Opposite of the intention
OTHER THAN	Substitution
SOONER/LATER THAN	Activity occurring a time other than intended

Selected parameters with applicable guide words (see Wells, 1996, p. 95-6)

Flow (no, more, less, reverse)
Temperature (higher, lower)
Pressure (higher, lower)
Level (none, higher, lower)
Composition (none, more, less, as well as, other than)
Action (sooner, later, insufficient, longer, shorter)

Hazard identification
3. Hazard and Operability: HAZOP

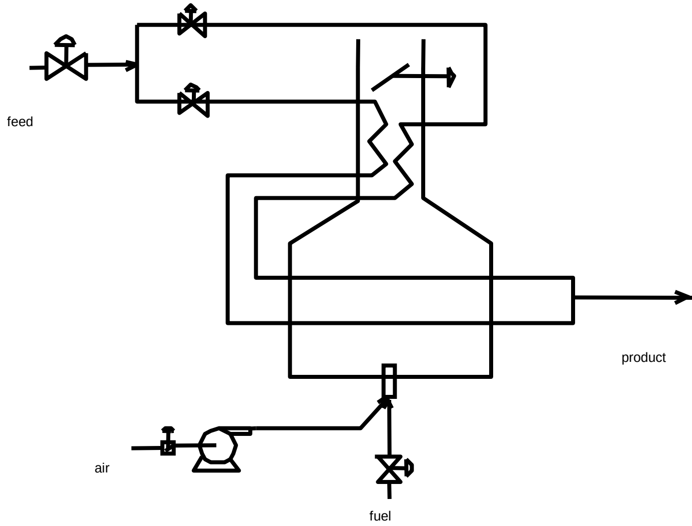
Fired heaters are used in process plants and have many potential hazards. Let's perform a HAZOP study!



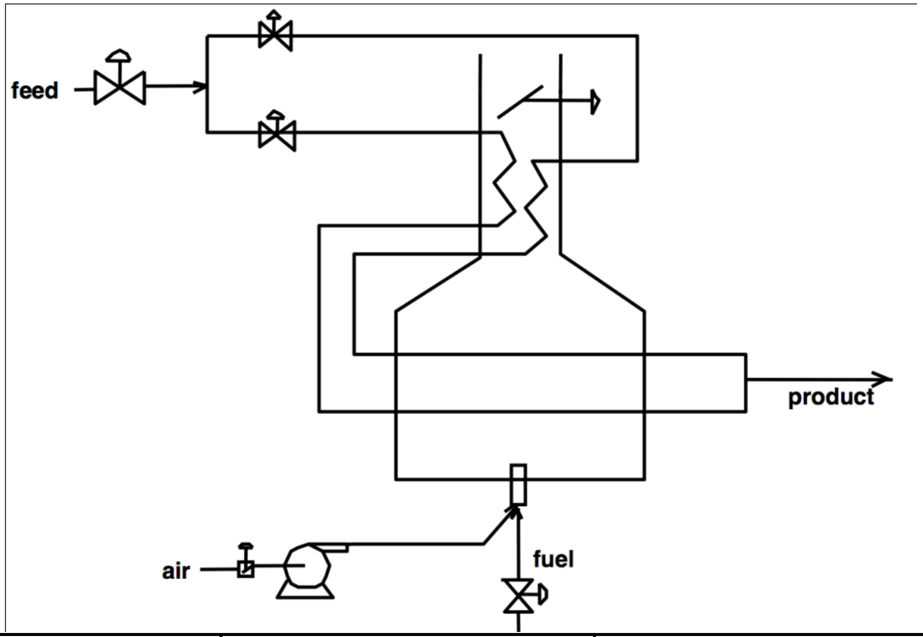
Consider how we normally raise the temperature of a stream

Class example: fired heater

1. Discuss the first entry in the HAZOP form
2. Complete an entry for another guide word for the parameter
3. Complete an entry for a different parameter for the same node
4. Complete an entry for a different node/ parameter/guide word



HAZOP FORM



Unit: <u>Fired Heater</u>

Node: <u>Feed pipe</u>
(after feed valve, before split)

↑

Location (line or vessel)
or procedure (start up)

Parameter: <u>Flow</u>

↑

Process variables

Guide Word	Deviation	Cause	Consequence	Action
Select from official list of words to ensure systematic consideration of possibilities	applying guide word to this parameter	process engineering	process engineering	preliminary result which should be reconsidered when time is available
no	no feed flow	1. feed pump stops	damage to pipes in radiant section, possible pipe failure	1. automatic startup of backup pump on low feed pressure

Include existing “safeguards”

		2. feed valve closed	“	2. fail open valve
		3. feed flow meter indicates false high flow (controller closes valve)	“	3. redundant flow meters
		4. pipe blockage	“	4. a) test flow before startup 4. b) place filter in pipe
		5. Catastrophic failure of pipe	5.a) damage to pipes in radiant section b) pollution and hazard for oil release to plant environment	Install remotely activated block valves at feed tanks to allow operators to stop flow
				For 1-5, SIS to stop fuel flow on **LOW or NO** feed flow, using separate feed flow sensor

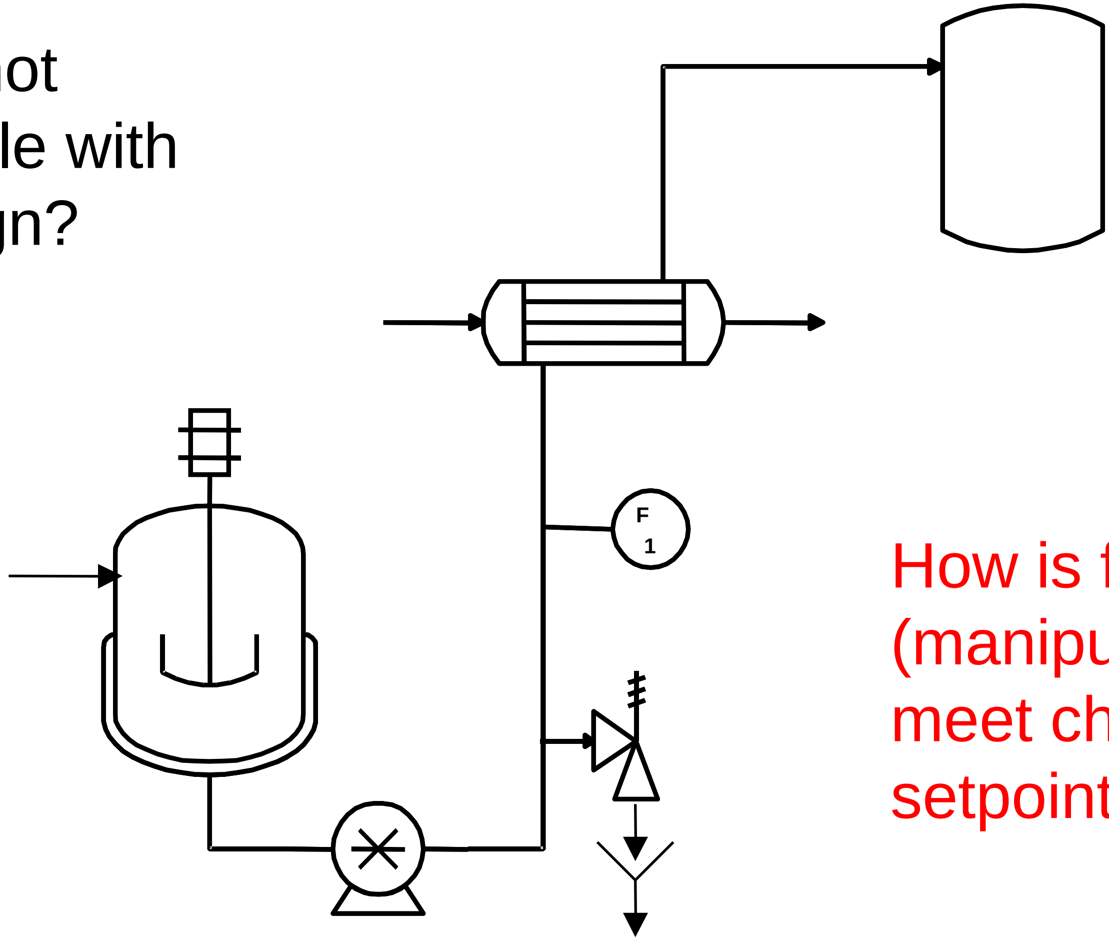
Hazard identification
3. Hazard and Operability: HAZOP

We have seen examples of safety – where is the “Operability”?

- When equipment fails, the likelihood of personal injury is high
- Identifying the cause of unsafe conditions, we can respond with improved equipment reliability, including maintenance
- Some parameter-guideword combinations will lead to conditions that are safe, but result is significant economic loss. These will require responses.

Hazard identification
3. Hazard and Operability: HAZOP

What is not acceptable with this design?

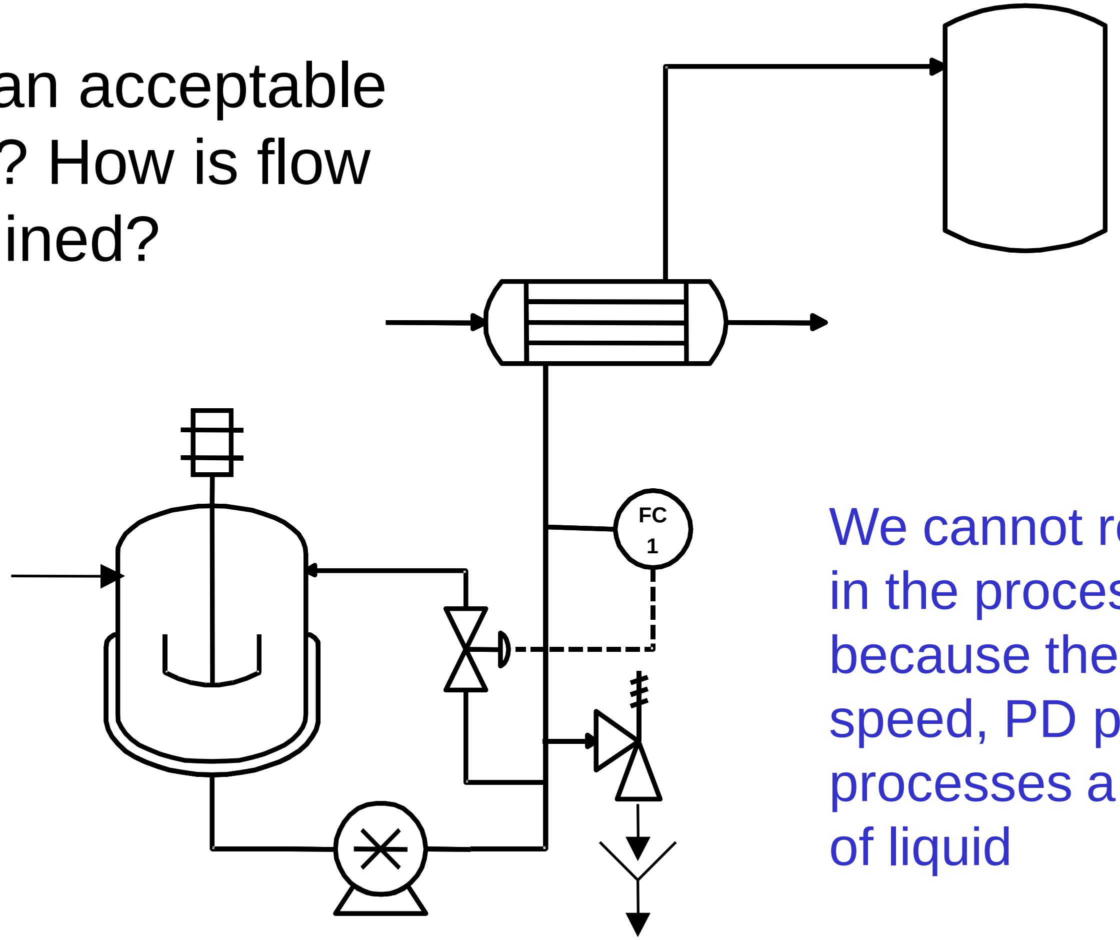


Constant speed PD pump

How is flow adjusted (manipulated to meet changing setpoints?

Hazard identification
3. Hazard and Operability: HAZOP

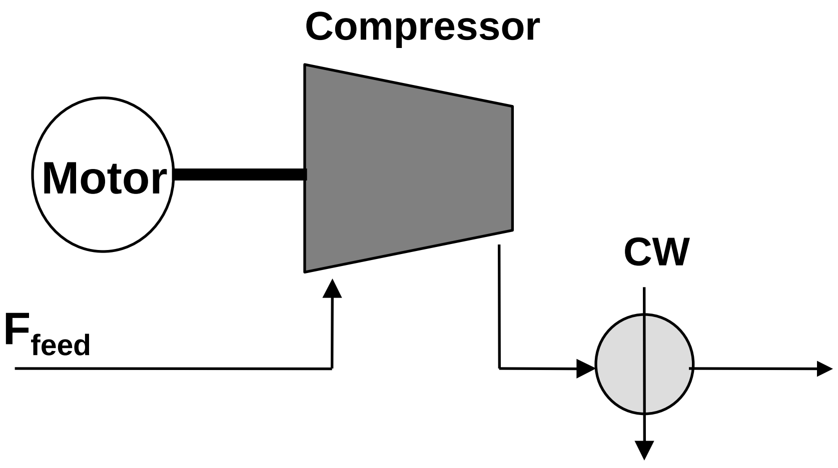
Is this an acceptable design? How is flow determined?

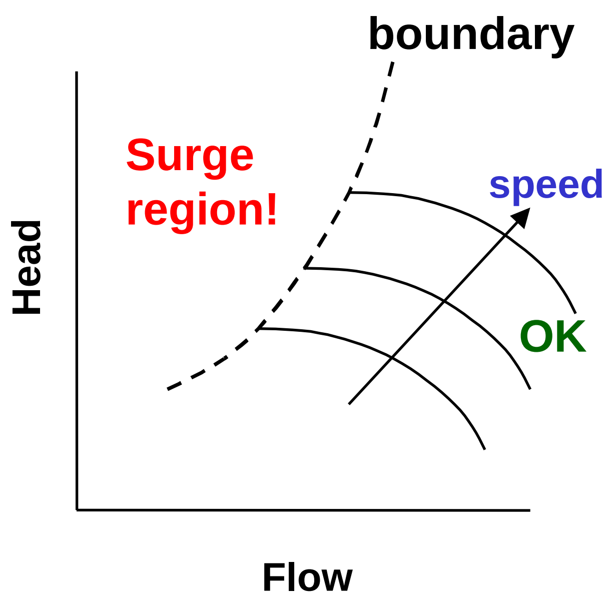


Constant speed PD pump

We cannot regulate a valve in the process stream because the constant speed, PD pump processes a fixed volume of liquid

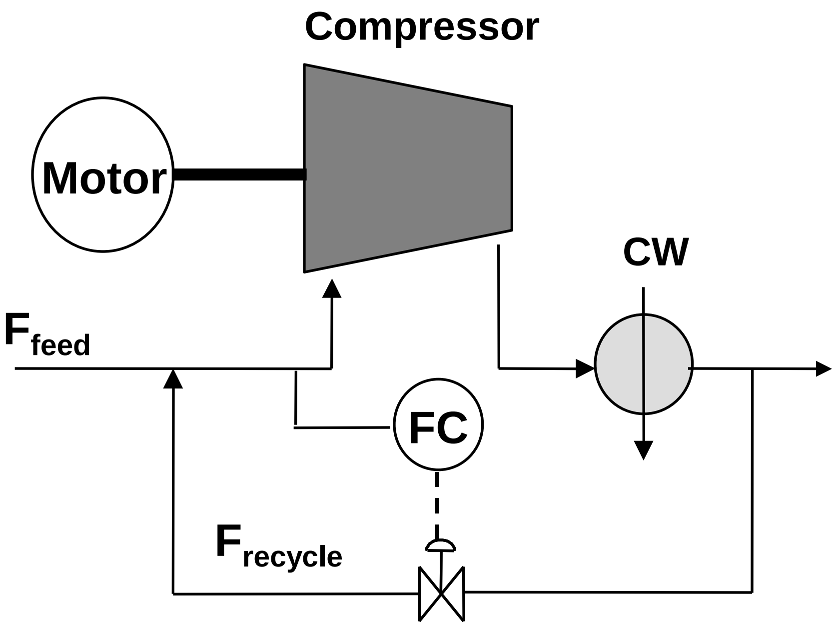
Hazard identification
3. Hazard and Operability: HAZOP

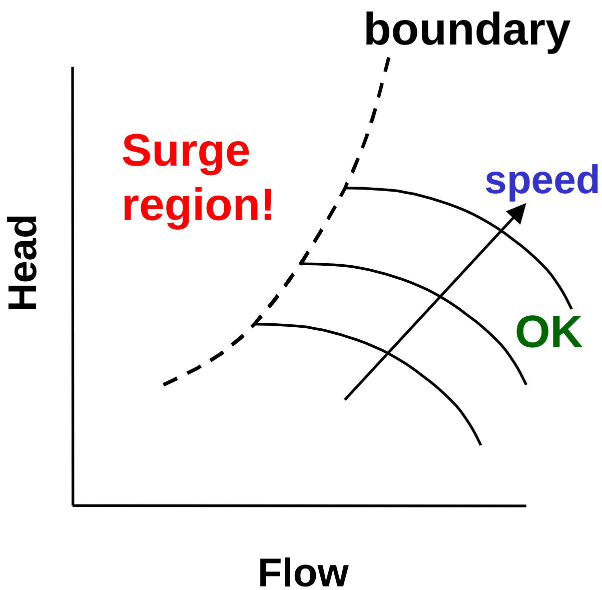




Exceeding the operating window of the equipment could lead to unsafe conditions.

Hazard identification
3. Hazard and Operability: HAZOP



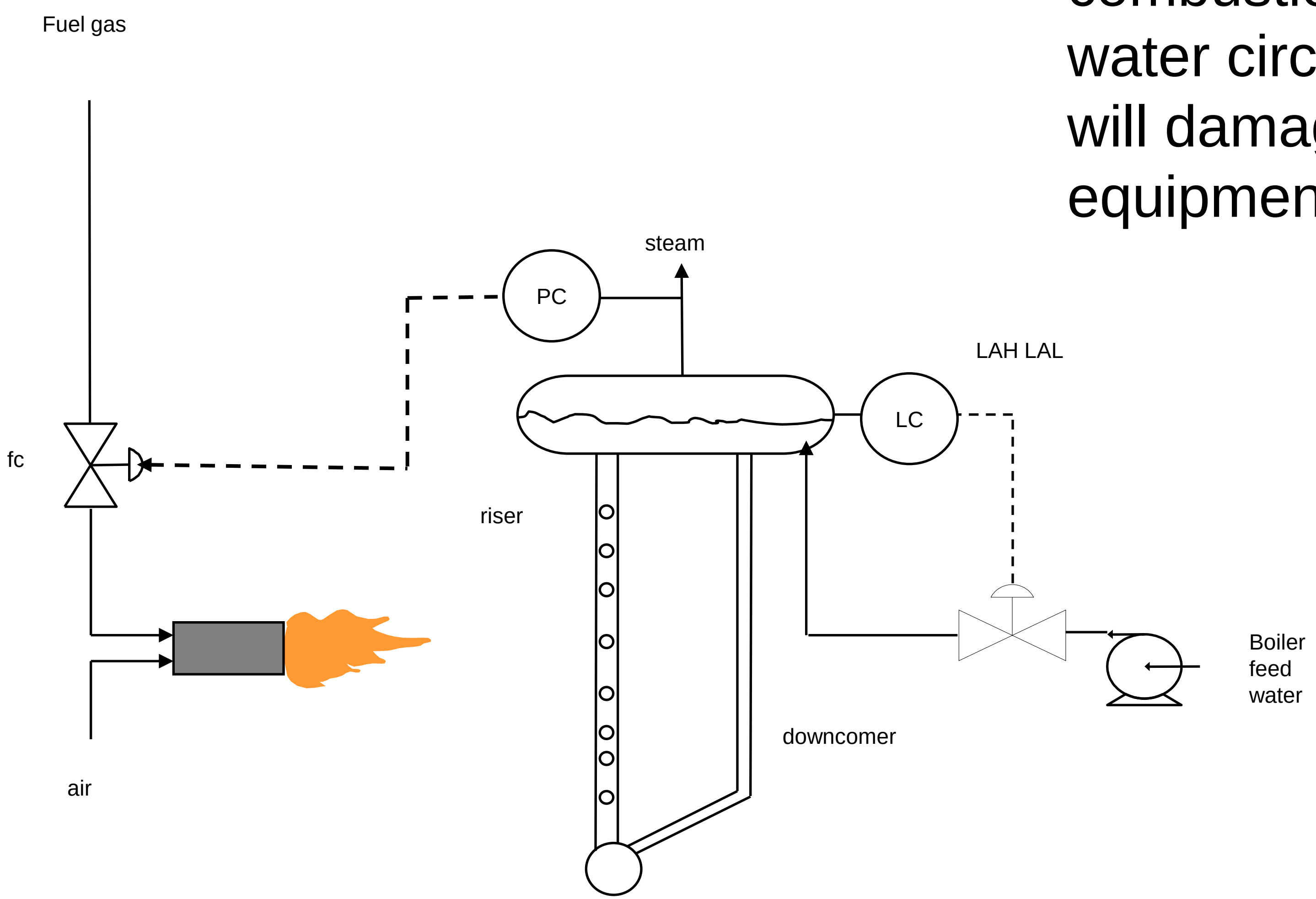


Why recycle after the exit cooling?

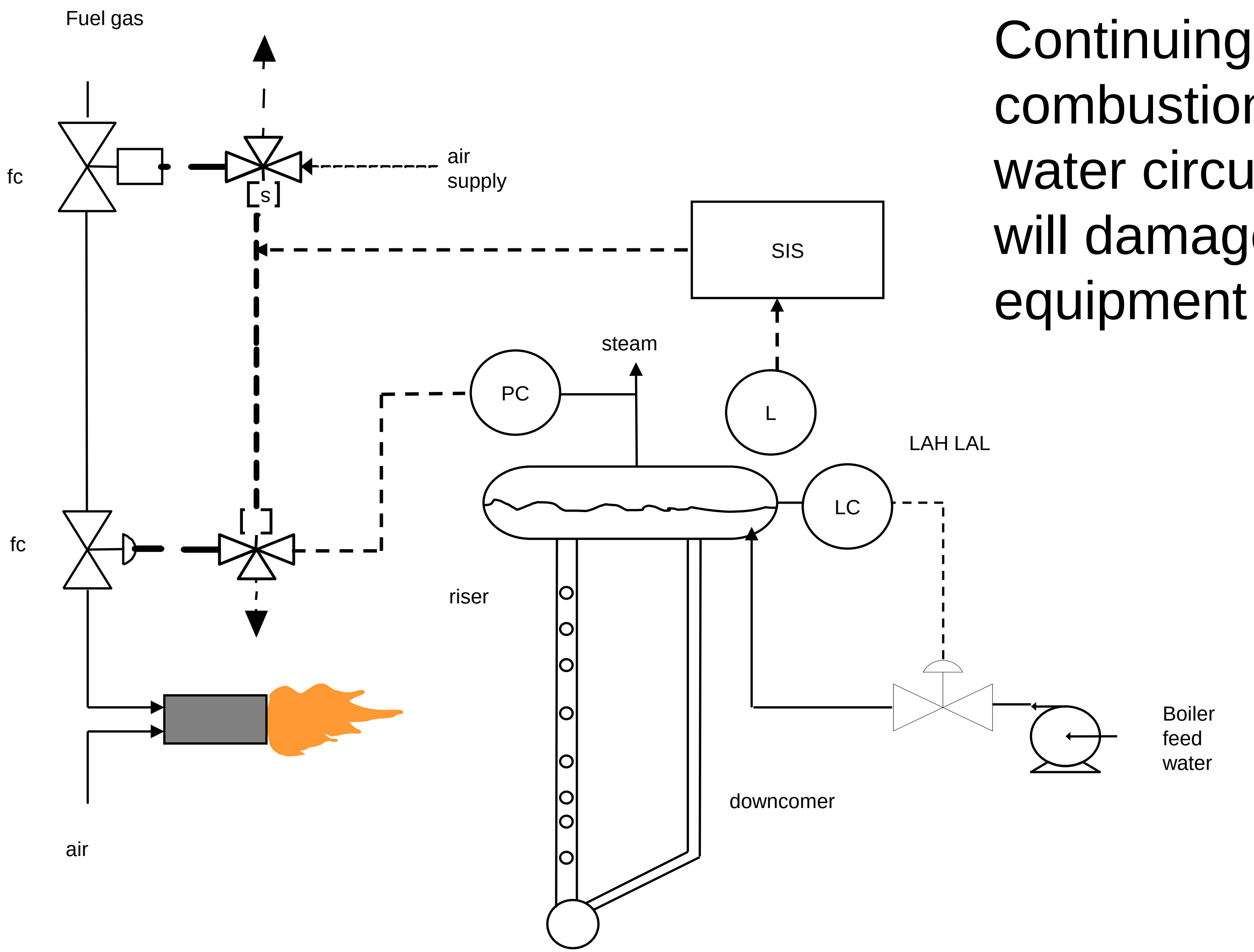
What else is missing at the compressor's feed point?

Hazard identification
3. Hazard and Operability: HAZOP

Continuing fuel combustion w/o water circulation will damage equipment



Hazard identification
3. Hazard and Operability: HAZOP



Continuing fuel combustion w/o water circulation will damage equipment

HAZOP - Process applications

- Thorough review at or near the completion of a new process design
  - Equipment and operating details known
  - Can uncover major process changes

- Review of existing processes (periodic update)
  - Safe operation for years does not indicate that no Hazards exist

- Review of changes to an existing process that had been “HAZOPed” - Important part of Change Management
  - No consistency on what type of changes require formal HAZOP

Managing the HAZOP process

- The HAZOP group should contain people with different skills and knowledge
  - operations, design, equipment, maintenance, quality control, ..
  - do not forget operators!!!
- The team should understand the plant well
- Documents should be prepared and distributed before the meeting
- The HAZOP leader should be expert in the HAZOP process
- Results must be recorded and retained

Hazard identification
3. Hazard and Operability: HAZOP

- At the conclusion, every item should be evaluated for further study

  - the need for and priority of future effort is decided
  - every item should be evaluated for
    + severity,
    + likelihood, and
    + cost (H/M/L or weightings 1-10)
  - columns for the three factors above can be added to the standard HAZOP form (See Wells, 1996, p. 104-5)

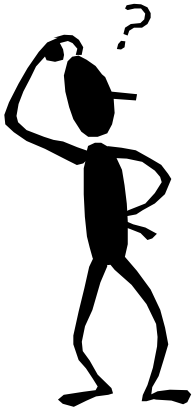
- For all significant items, a Hazard Assessment is performed (one or more of methods below)
  - Fault Tree
  - Event Tree
  - FMEA (failure mode and effects analysis)
  - Consequence Analysis
  - Human Error Analysis

HAZOP - Some words of caution

- Recommendations are based on
(likelihood x consequence x action cost)
  - Do not "gold plate" the plant for very unlikely scenarios
  - airplane hitting a plant is very unlikely; however, a nuclear power plant has large consequence

- Very complex systems are prone to failure, this includes safety systems
  - remember about alarm proliferation ("crying wolf") - this can happen with other aspects of safety

Hazard identification
3. Hazard and Operability: HAZOP



You are responsible for the safety team.

Without HAZOP

How will you document that you have performed and implemented a professional safety study?

Without HAZOP

How will you focus all members of a team on the key issues in a systematic manner?

REFERENCES

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AIChE, Guidelines for Engineering Design for Process Safety, American Institute of Chemical Engineers, New York, 1993

AIChE, Guidelines for Consequence Analysis of Chemical Processes, American Institute of Chemical Engineers, New York, 1999

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Wells, G., Hazard Identification and Risk Assessment, Institute of Chemical Engineers, Gulf Publishing, Houston, 1996 (ISBN 0-85295-353-4)

Some WEB sites

http://slp.icheme.org/chemicals.html (safety-related data bases)

http://tis.eh.doe.gov/techstds/standard/hdbk1100/hdbk1100.pdf - USA DOE Safety Handbook

www.lihoutech.com/hzp1frm.htm - About one chapter on HAZOP from company that provides HAZOP software

http://ed.icheme.org/chemengs.html - Good source of general information on chemical engineering, follow key words for safety and risk. By IChemE in the UK