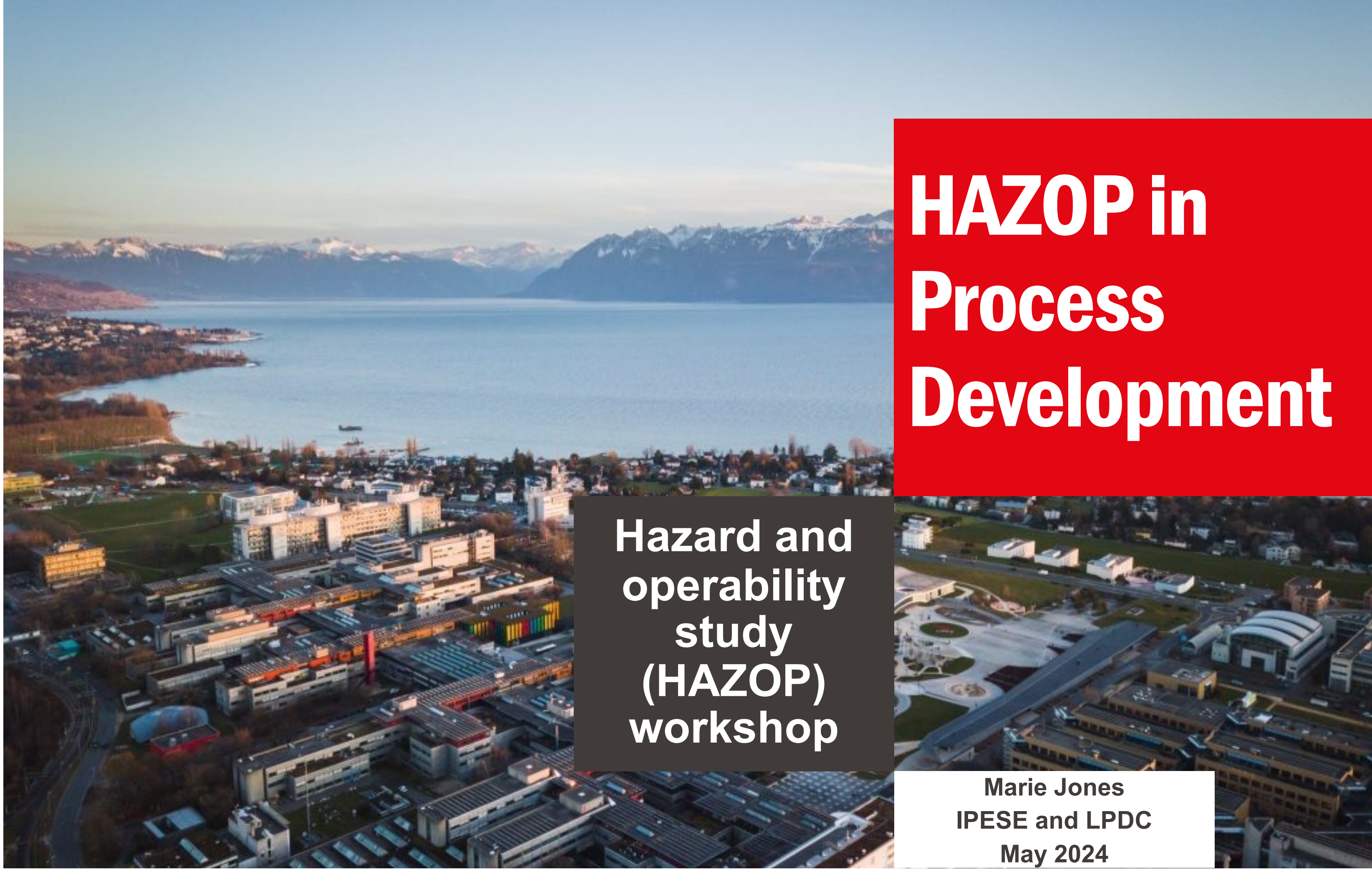
EPFL

IPESE
Industrial Process and Energy Systems Engineering



HAZOP in Process Development

Hazard and operability study (HAZOP) workshop

Marie Jones
IPESE and LPDC
May 2024

École polytechnique fédérale de Lausanne

Outline

- Introduction
- Vocabulary and definitions
- HAZOP methodology
- Hands-on exercise
- Process control
- Standard Operating Procedures
- How to do HAZOP for your project?

HAZOP motivation

Fertilizer
Germany, 1921

Mercury
Japan, 1932

Fertilizer
United States, 1947

Hydrocarbons
England, 1974

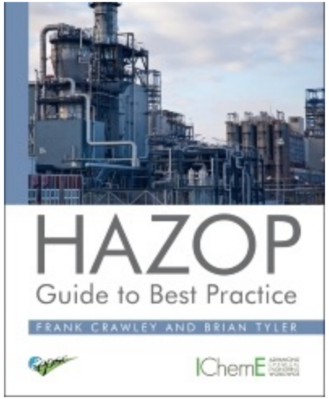
Pesticides
India (Bhopal), 1984

Flurry of activity to
establish protocols

Fukushima,
2011

Fertilizer
Beirut, 2020

- "Safety of chemical processes" course
  - Importance of risk assessment
  - Learn from past incidents
- HAZOP (Hazard and operability study)
  - Qualitative and systematic analysis
  - Brainstorming predictive method → identify unforeseen events
  - Complies with standards (Seveso Directive)



HAZOP motivation

Fertilizer
Germany, 1921

Mercury
Japan, 1932

United States, 1947

Hydrocarbons
England, 1974

India (Bhopal), 1984

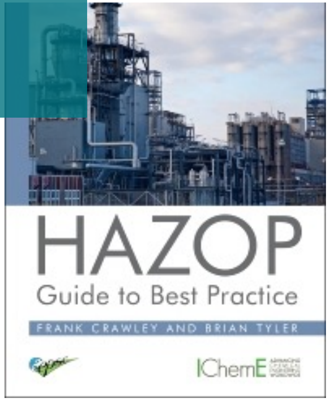
Flurry of activity to

Fukushima,
2011

Fertilizer
Beirut, 2020

Engineers' responsibility to **assess consequences** of processes and develop **risk mitigations** in compliance with international standards

- "Safety of chemical processes"
  - Importance of risk assessment
  - Learn from past incidents
- HAZOP (Hazard and operability study)
  - Qualitative and systematic analysis
  - Brainstorming predictive method → identify unforeseen events
  - Complies with standards (Seveso Directive)



Specific HAZOP vocabulary

- **Node** – plant section, area of interest
- **Design intent** – refers to equipment, materials, conditions and changes
- **Parameter** – Measurable and controllable variable of the system
- **Deviation** – difference from normal operating conditions
- **Guide words** – list of words used to qualify deviations
- **Cause** – reason leading to deviated state
- **Consequence** – possible outcome of deviation
- **Safeguards** – possible pro- and re-active implementations
- **Recommendations/actions** – suggestions for changes

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

EPFL

HAZOP procedure

A
G
I
R

Team

- Chairman
- Scribe
- Process engineer
- Operator

Preparation

- Data collection
- Scope definition

P&ID nodes

- Split P&ID into nodes

Reporting

F. Crawley, B. Tyler, and O’Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

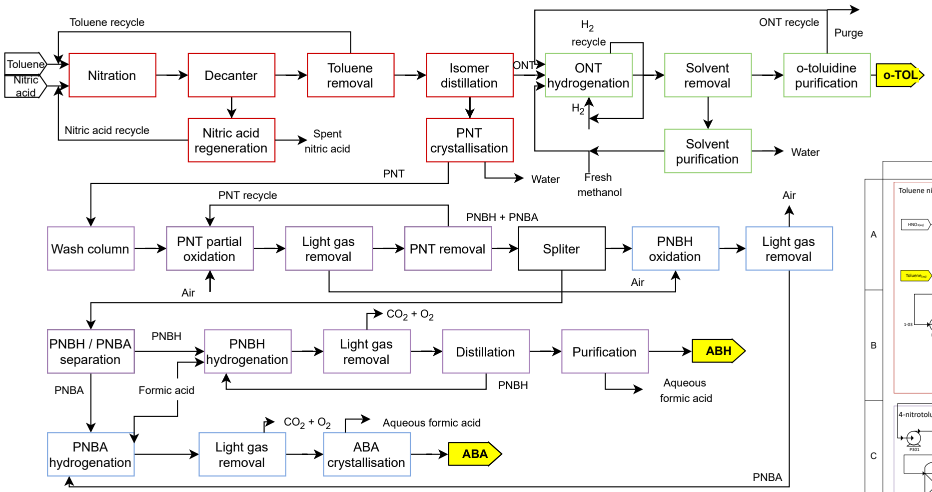
HAZOP procedure

- For each *node*:
  1. Define *design intent*
  2. Choose a *parameter*
  3. Work through the *guide words*
  4. Is the deviation (*guide word* + *parameter*) meaningful?
  5. Identify possible *causes* and *consequences*
  6. Identify existing *safeguards*
  7. Make *recommendations* if necessary
  8. Assign responsible person for follow up

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

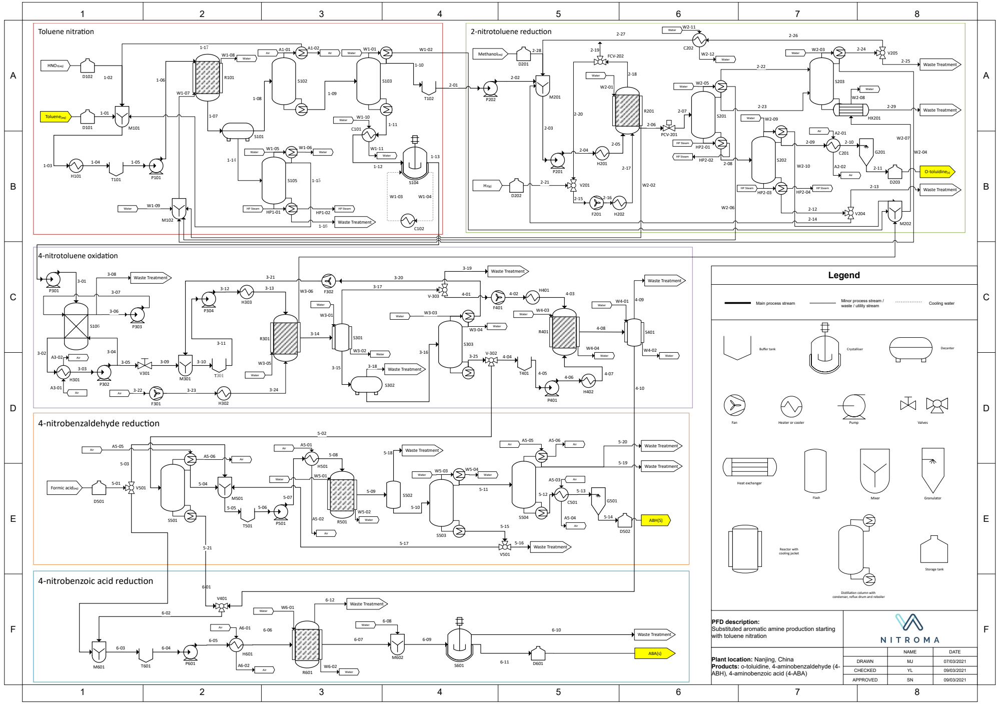
Chemical process representation

Marie JONES



Block Flow Diagram (**BFD**)

➔ Process steps



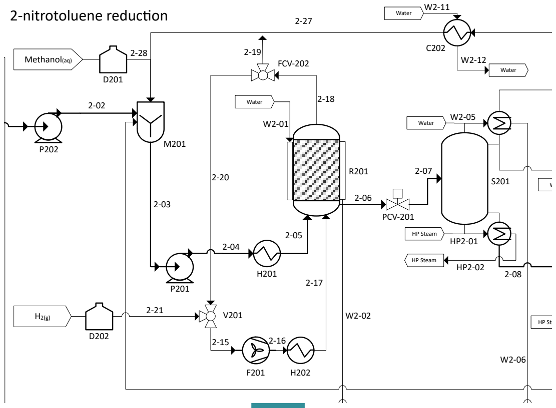
Process Flow Diagram (**PFD**)

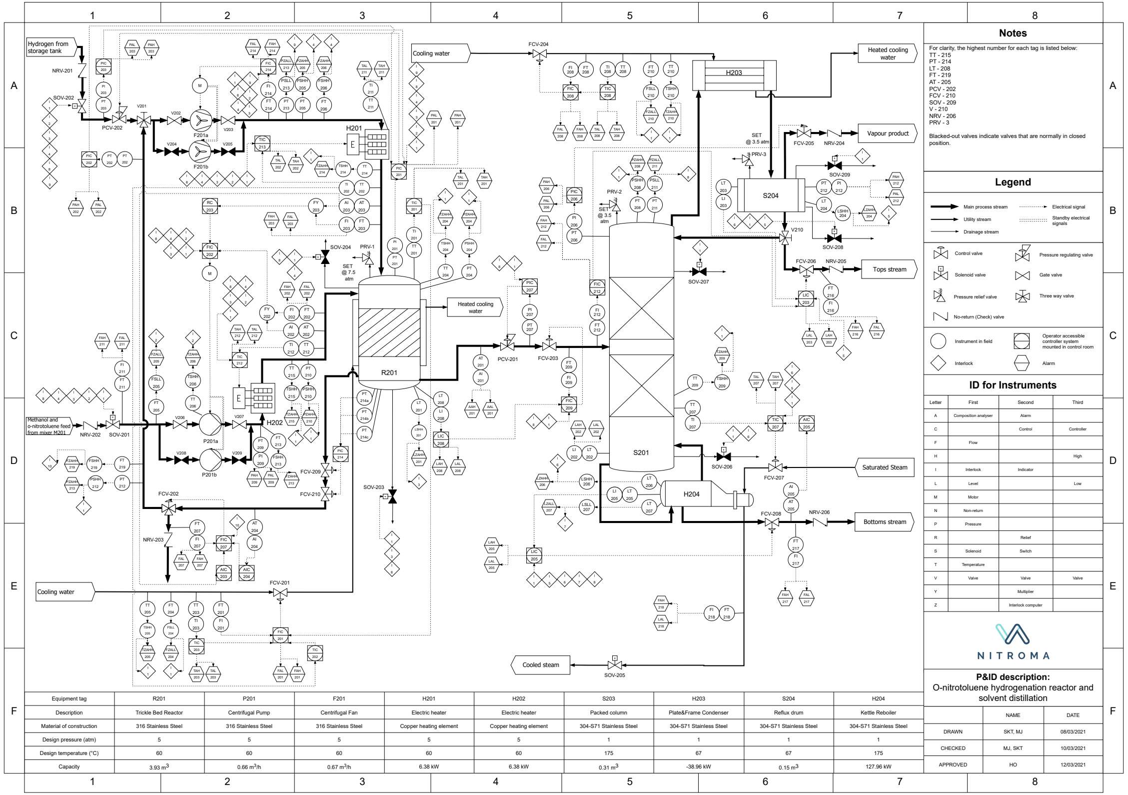
➔ Process equipment

Final year design project, Team 8, Imperial College London, March 2021

Marie JONES

Chemical process representation





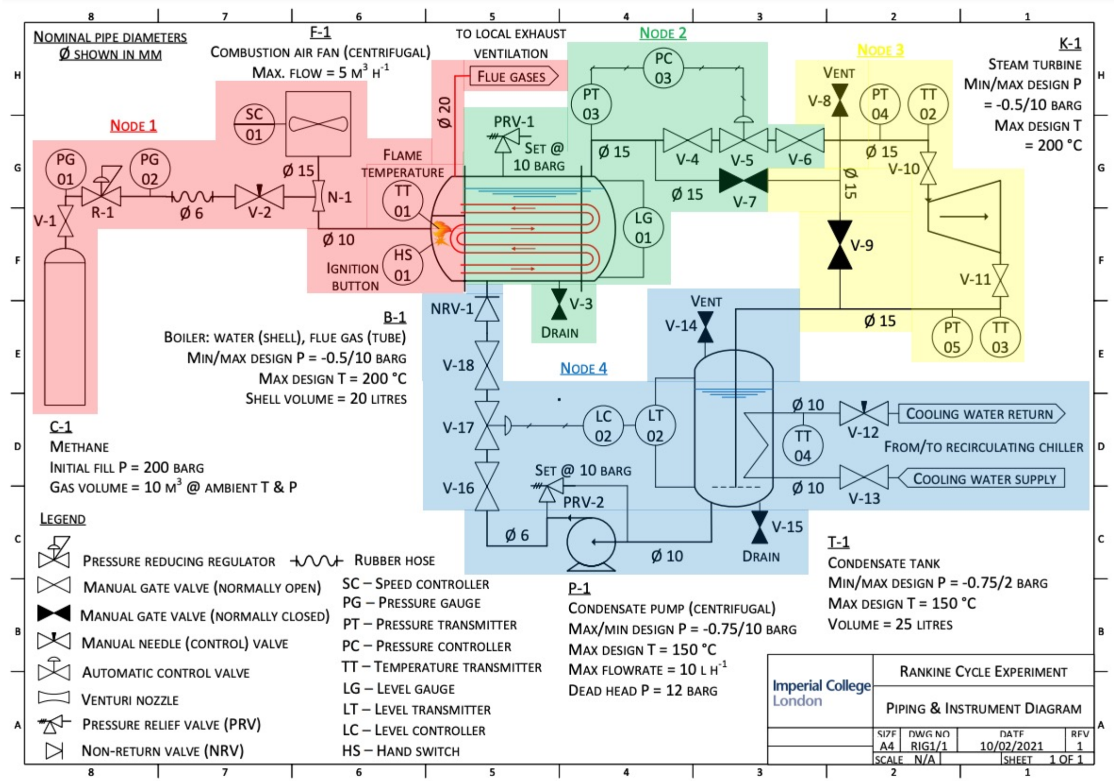
Equipment tag	R201	P201	F201	H201	H202	S203	H203	S204	H204
Description	Trickle Bed Reactor	Centrifugal Pump	Centrifugal Fan	Electric heater	Electric heater	Packed column	Plate&Frame Condenser	Reflux drum	Kettle Reboiler
Material of construction	316 Stainless Steel	316 Stainless Steel	316 Stainless Steel	Copper heating element	Copper heating element	304-S71 Stainless Steel	304-S71 Stainless Steel	304-S71 Stainless Steel	304-S71 Stainless Steel
Design pressure (atm)	5	5	5	5	5	1	1	1	1
Design temperature (°C)	60	60	60	60	60	175	67	67	175
Capacity	3.93 m^3	0.66 m^3/h	0.67 m^3/h	6.38 kW	6.38 kW	0.31 m^3	-38.96 kW	0.15 m^3	127.96 kW

Process & Instrumentation Diagram (**P&ID**)

➔ Sensors, control loops, valves

Final year design project, Team 8, Imperial College London, March 2021

Node identification



- Design intent node1: Mix methane from C-1 and air from F-1 at equivalence ratio of one (9.8 vol% methane) at maximum rated burner heat output of 5 kW. Flue gases are extracted by local exhaust ventilation (LEV).

C. Tighe, *HAZOP Workshop,* Imperial College London. March 2021.

Possible parameters

- Process variable → **Degree of Freedom**
- Measurable with sensor
- Controllable with actuator

Flow	Transfer	Phase	Signal
Pressure	Viscosity	Speed	Start/stop
Temperature	Reaction	Particle size	Operate
Level	Addition	Measure	Maintain
Composition	Monitoring	Control	Diagnostics
Mixing	Separation	pH	Services
Stirring	Time	Sequence	Communication

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

Standard Guide Words

Guide word	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in parameter
Less (less of, lower)	Quantitative decrease in parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intent occurs
Other than	Another/unsusual activity takes place

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

Principal Deviations – Continuous process

Parameter	Possible guide words
Flow	None, more of, less of, reverse, as well as
Temperature	Higher, lower
Pressure	Higher, lower, reverse
Level	Higher, lower, non
Mixing	Less, more, none
Reaction	Higher (rate), lower (rate), none, reverse, other than, as well as, part of
Phase	Other, reverse, as well as
Composition	Part of, as well as, other than

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

Typical safeguards

Safeguard	Function
High/low alarm	Activates alarm in control room when parameter high/low
High/low trip	Performs automated action when parameter high/low
Emergency shutdown	Initiates emergency shutdown
Interlock	Connection between actuators (valve A cannot open until valve B is closed)
Locked open/closed	Valves have a lock on them to prevent unauthorised operation
Safety relief valve	Opens at a set pressure, closes again when pressure reduces
Bursting disc	Permanently opens at set pressure
Zoning	Isolation of particularly hazardous units with local safeguards
Containment	Bund around vessel to contain spillage
Testing/maintenance	Routine for critical equipment
Monitoring	Routine for critical parameters (ex: corrosion)
Inerting	Removal of oxygen to prevent fire/explosion

F. Crawley, B. Tyler, and O'Reilly for Higher Education, *HAZOP: Guide to Best Practice, 3rd Edition*. 2015.

EPFL

Reporting

Node ID	1
Design Intent	Mix methane from C-1 and air from F-1 at equivalence ratio of one (9.8 vol% methane) at maximum rated burner heat output of 5 kW. Flue gases are extracted by local exhaust ventilation (LEV). Parameters under normal operation are as follows:

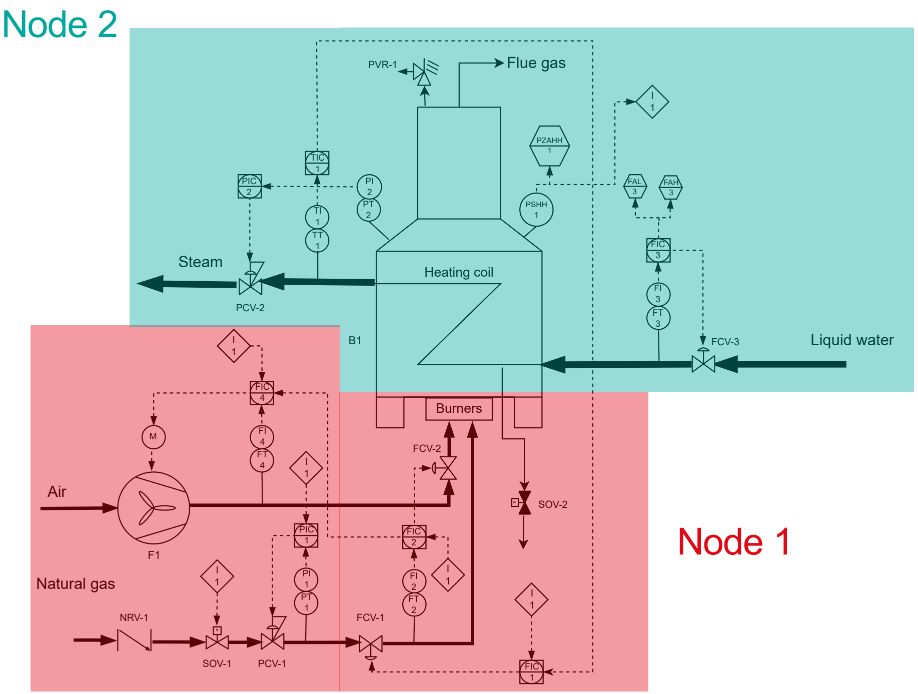
Row ID	Parameter	Deviation	Causes	Consequences	Existing Safeguards	Recommendations
1.1	Flow	No	F-1 fails (spurious failure)	C1: Misdirected flow of methane through F-1 to local area, potential for unconfined explosion leading to personal injury C2: Get flame out (no combustion occurring) in B-1 due to no air supply, uncombusted methane vented to exhaust, potential for unconfined explosion leading to personnel injury (area not located in P&ID)	SG1: Operator could close V-1 and stop supply of methane SG2: Exhaust ventilation should remove methane	R1: Provide a non-return valve downstream of F-1 to prevent reverse flow. R2: Ensure exhaust ventilation is appropriately rated. R3: Provide a low temperature trip that isolates the flue gas supply on loss of combustion in B-1
			V-1 closed in error (or broken but must stop process)		SG1: Pressure gauge (PG01 gives operator indication that V-1 has been closed in error) SG2: TT-01 will detect low T in B-1	
1.2	Flow	No	V-2 closed in error	C1: Get flame out (no combustion occuring) in B-1 due to no fuel supply	SG1: TT-01 will detect low T in B-1 --> indicate that the operator has to take action	R1: Install regular alarm for low pressure PAL01 linked to pressure transmitter R2: Install executive alarm PZALL to trigger interlock stopping process
			R-1 set point too low in error		SG1: Pressure gauge (PG02 gives operator indication that R-1 has been closed in error) SG2: TT-01 will detect low T in B-1	
1.3	Pressure /level	Less	C-1 underfilled	C1: Insufficient pressure and flow of methane C2: get flame out (no combustion occuring)	SG1: Pressure gauge PG01 and PG02	SG1: Level indicator on C-1 SG2: Regular alarm Low and executive alarm LL

Hands-on exercise

1. Nominate chairman, scribe and reporter in your team
2. Divide process in nodes and determine design intent
3. Come up with 3 deviations for your assigned node
4. For each deviation, identify causes, consequences and safeguards
5. Make recommendations

EPFL

The process



Legend

- Main process stream
- Electrical signal
- Utility stream
- Drainage stream
- Control valve
- Pressure regulating valve
- Solenoid valve
- Gate valve (normaly opened)
- Pressure relief valve
- Three way valve
- No-return (Check) valve
- Valve (normaly closed)
- Instrument in field
- Controller system
- Interlock
- Alarm

ID for Instruments

Letter	First	Second	Third
A		Alarm	
C		Control	Controller
F	Flow		
H			High
I	Interlock	Indicator	
L	Level		Low
M	Motor		
N	Non-return		
P	Pressure		
R		Relief	
S	Solenoid	Switch	
T	Temperature		
V	Valve	Valve	Valve
Y		Multiplier	
Z		Interlock	

Equipment tag	B1	F1
Description	Boiler	Centrifugal Fan
Material of construction	316 Stainless Steel	316 Stainless Steel
Design pressure (atm)	10	5
Design temperature (°C)	200	60
Capacity	1 m^3/h	10 m^3/h

EPFL

P&ID description:

Steam production with natural gas boiler

Drawn by MJ - 05/05/2022

Process control

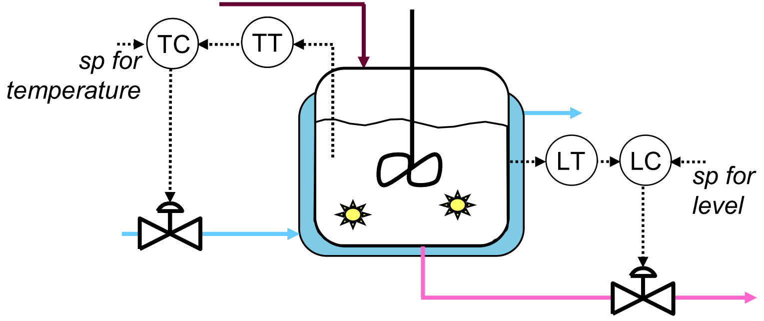
From qualitative approach to process operation

Marie JONES

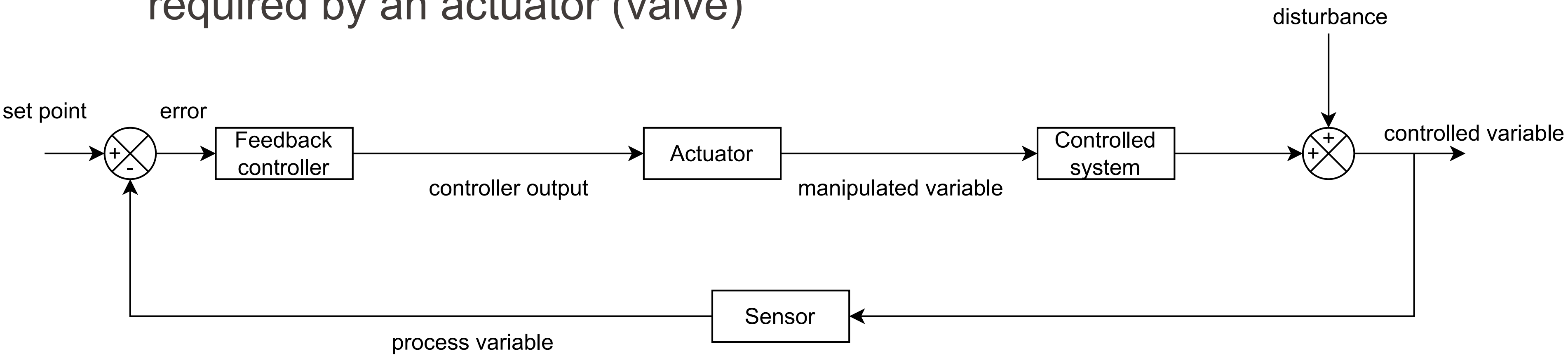
Goals of process control

- Recap from Bachelor course ”Chemical process control”
- **Control makes it possible to operate a process**
- Addresses operability, safety and product quality
- Ensures **optimal** process operation →converged state in Aspen
- Material and energy (P and T) flows management
- Implications for plant’s life expectancy
- Introduces safeguards in case of failure

Process unit control



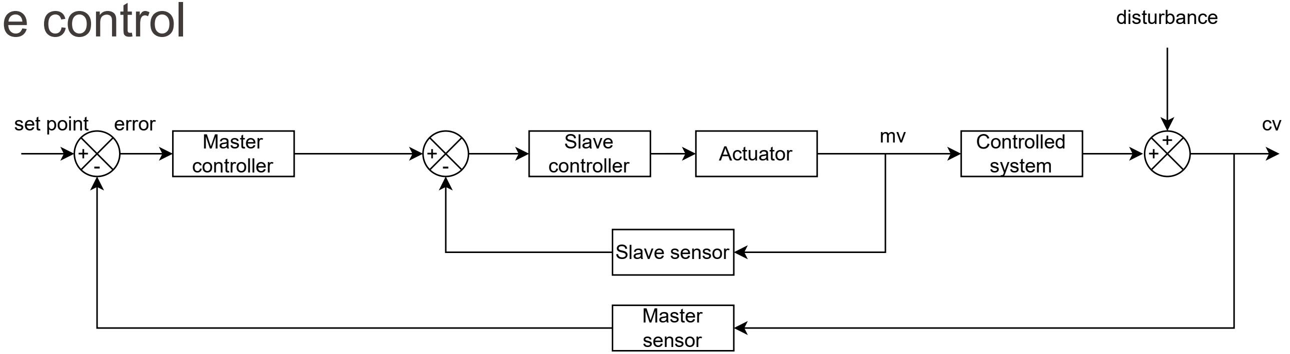
- **Feedback control:** Using a measured variable compared to a setpoint to adjust the response required by an actuator (valve)



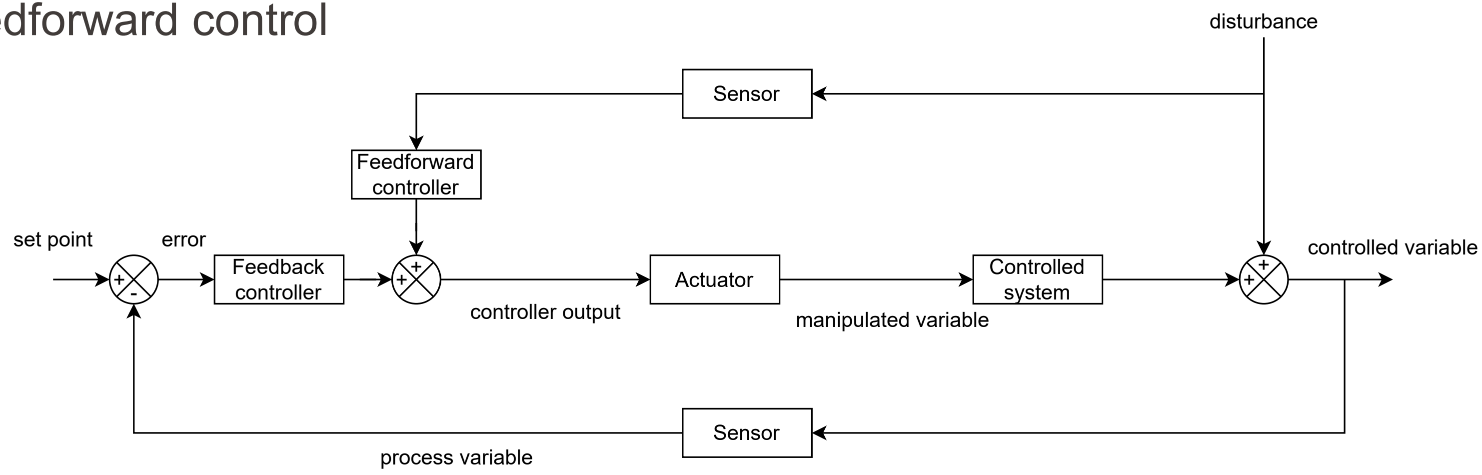
N. Thornhill, “Process Dynamics and Control,” Imperial College London, Sep. 2009.

Process-wide control

- Cascade control



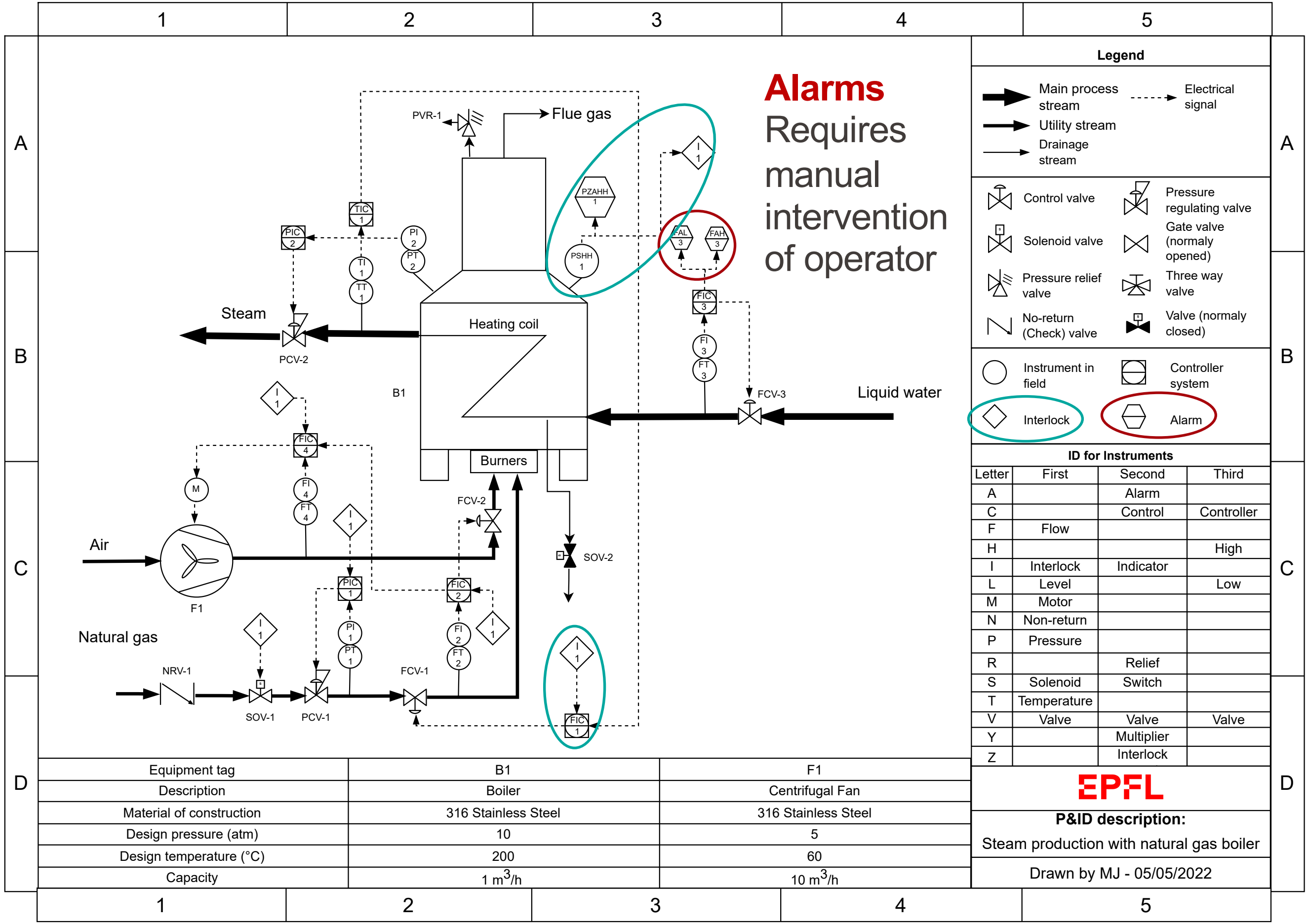
- Feedforward control



P&ID: Alarms and interlocks

Interlock

- Brings automatically process in fail-safe mode
- Sensor network independent from control loops
- Connected to executive alarms



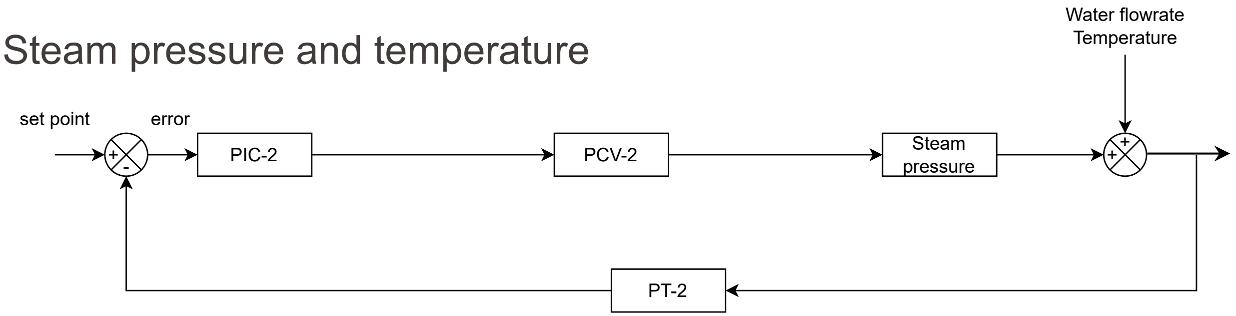
ID for Instruments

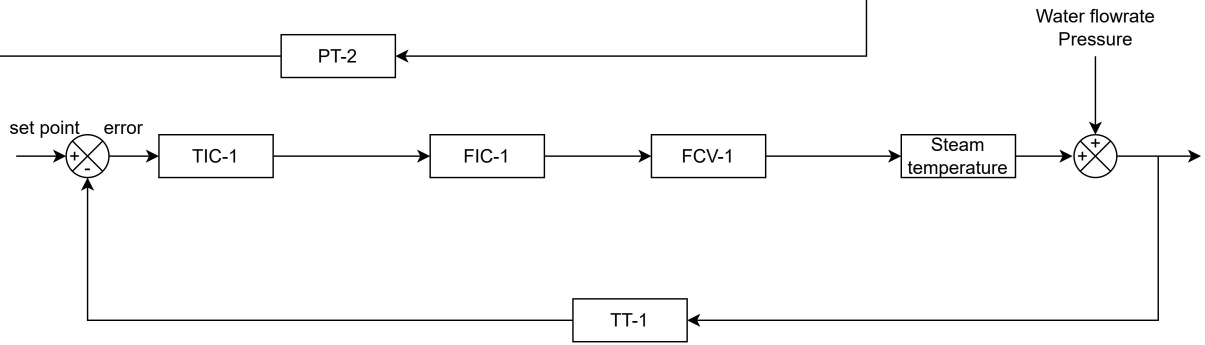
Letter	First	Second	Third
A		Alarm	
C		Control	Controller
F	Flow		
H			High
I	Interlock	Indicator	
L	Level		Low
M	Motor		
N	Non-return		
P	Pressure		
R		Relief	
S	Solenoid	Switch	
T	Temperature		
V	Valve	Valve	Valve
Y		Multiplier	
Z		Interlock	

Equipment tag	B1	F1
Description	Boiler	Centrifugal Fan
Material of construction	316 Stainless Steel	316 Stainless Steel
Design pressure (atm)	10	5
Design temperature (°C)	200	60
Capacity	1 m^3/h	10 m^3/h

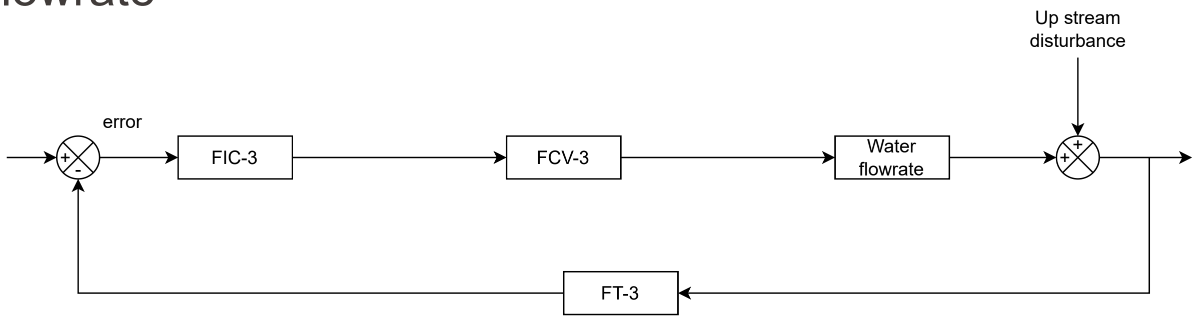
Examples

- Steam pressure and temperature





- Water flowrate



Marie JONES

Standard Operating Procedures

1. Introduction
2. Start-up
3. Shutdown

Marie JONES

Procedure overview

- Standard operating procedures for start-up and shutdown:
  - Gantt chart of steps with estimated duration

Time

Actions

Mode	Startup	Duration (min)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375	390	405	420
Step	Procedure																														
Preliminary Preparations																															
1	Preliminary inspection of plant sub-section	60																													
2	Remove shutdown blinds and install running blinds	30																													
Auxiliary Equipment and Utilities Start-up																															
3	Testing of electrical appliances and controls	15																													
4	Preparation of cooling water system	10																													
5	Preparation of steam system	10																													
6	Start-up fan F201 and electric heaters H201 and H203	5																													
Elimination of Air and leak prevention																															
7	Purge of units with nitrogen	60																													
8	Pressurisation of units	15																													
9	Tightness testing and bolt tightening	45																													
Initiation of onstream units																															
10	Opening hydrogen feed line	5																													
11	Pressurisation and heating of R201 to 5 atm, 60°C	10																													
12	Open hydrogen recycle purge	5																													
13	Introduce set amount of methanol into column S201	5																													
14	Allow level in the reboiler and condenser to build-up	15																													
15	Turn on pump P201	5																													
16	Gradually open liquid feed line to reactor and distillation column	60																													
17	Open valves on distillation products take-off lines	5																													
Downstream Preparations																															
18	Start-up of downstream units	210																													

Safe ups and downs for process units: a collection of booklets describing hazards and how to manage them, 6th ed, (Eds.: BP International, Institution of Chemical Engineers (Great Britain)), OCLC: ocm71751104, Institution of Chemical Engineers, Rugby, 2006, 69 pp.

Manual action checklist

- Standard operating procedures for start-up and shutdown:
  - Gantt chart of steps with estimated duration
  - Checklist for operators (valves, pumps, etc…) → for each step in procedure

Checklist 1.1 – Gas Feed Start Procedure

Step	Floor	Valve	Grid	Open	Closed	Purpose	Checked	Comments
4.1.1	4 (CR)	SOV424	D16		X	Prevent gas recycles from mixing		
4.1.2	1	Unlabelled 2.	D16	X		Allow flow of gasses from analyser		
4.1.3	1	V185	M20		X	Prevent drainage from K103		
4.1.4	1	V171	L19	X		Allow flow into K101		
4.1.5	4	V409	D16		X	Prevent venting of N2 recycle		

Pilot plant project, Chemical Engineering Department, Imperial College, Nov 2018

EPFL

Start-up and Shutdown

Marie JONES

Start-up

1. Preliminary preparations
2. Auxiliary equipment and utilities start-up
3. Elimination of air and leak prevention
4. Initiation of onstream units
5. Downstream preparations

Shutdown

1. Cooling and depressurising units
2. Pumping out of process fluids
3. Purging residual materials and water disposal
4. Blinding and opening
5. Inspection for entering
6. Shutdown downstream units

How to do HAZOP for your project?

HAZOP is ONLY for the final report!

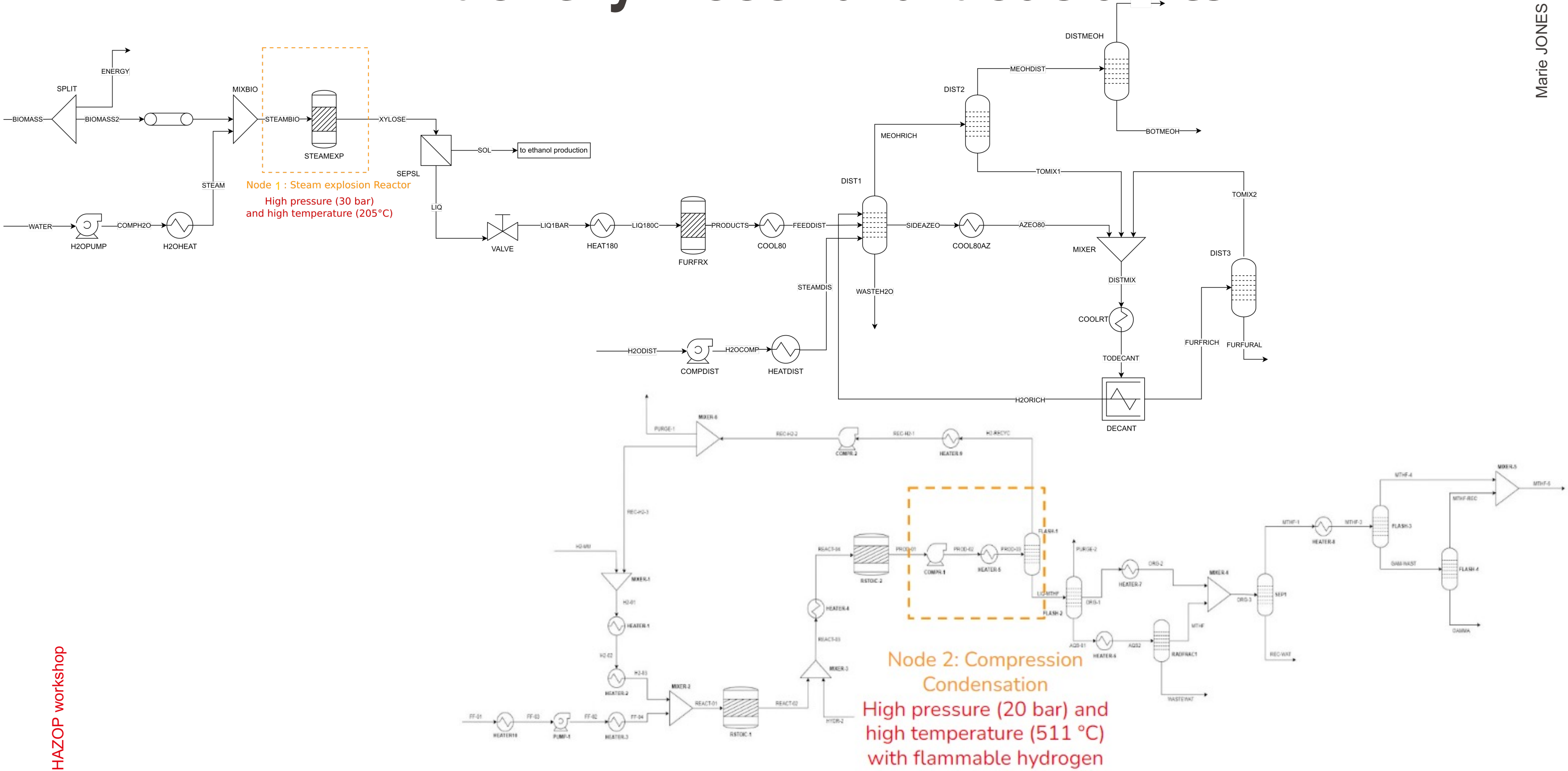
Objectives for your report

1. Identify most hazardous units in your whole process
2. Choose **one unit** (reactor or separation including auxiliaries) to study in detail and justify why
3. Come up with 2 control loops
4. Draw a P&ID for your section and add control loops
5. Do the HAZOP for your section
6. Implement on your P&ID the alarms you recommended

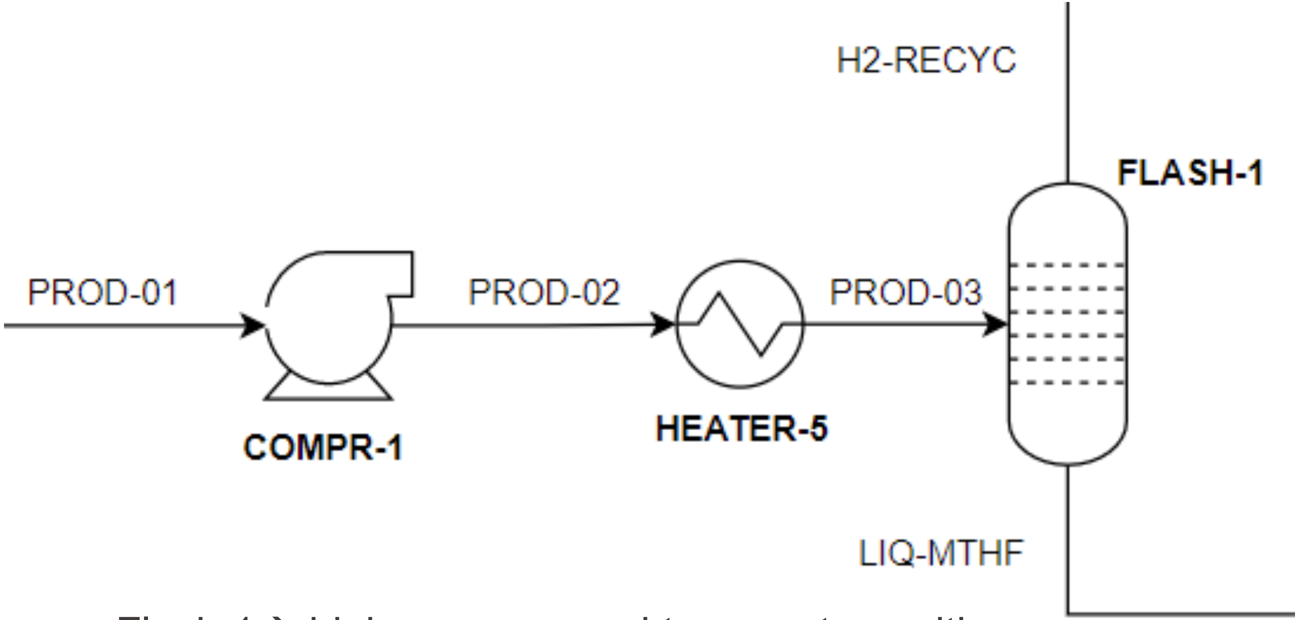
EPFL

1. Identify most hazardous units

Marie JONES



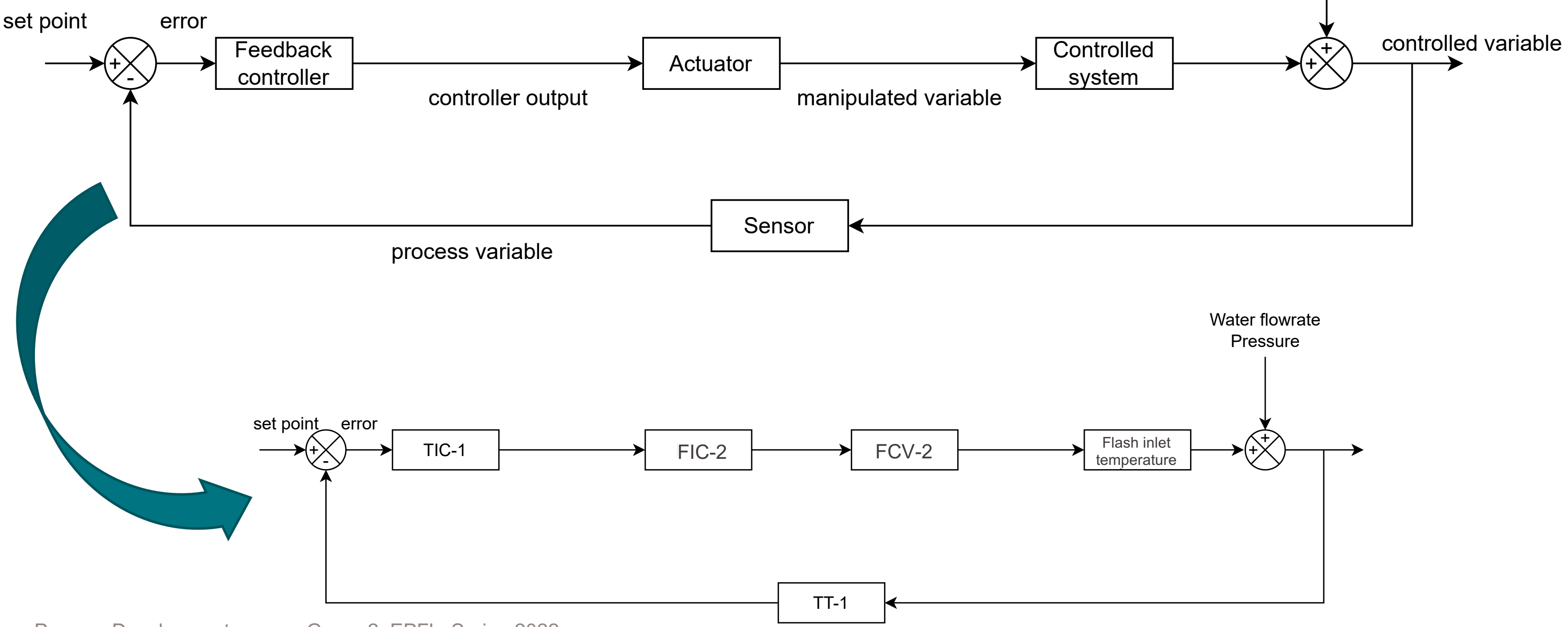
2. Choose one unit to study in detail



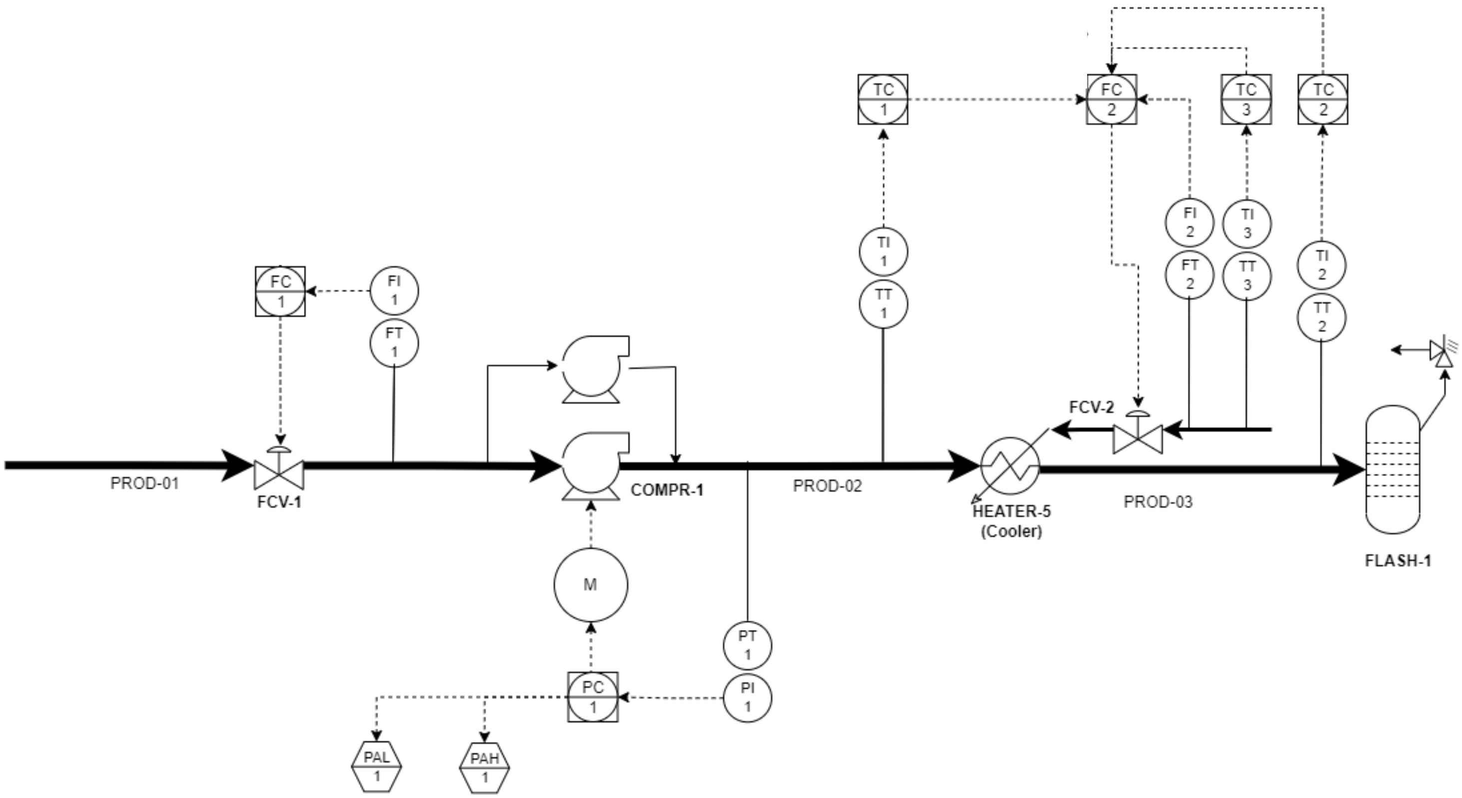
- Focus on Flash 1→ high pressure and temperature with flammable hydrogen
- Include auxiliaries: pump, heaters and coolers

3. Design control loops for your section

1. Build block diagram with words
2. Think of the physical equivalent to the word
3. Give it a label and replace it in your block diagram



4. Draw the P&ID



Marie JONES

5. Do the HAZOP review

Node ID	**2**
Design Intent	A mix of hydrogen and MTHF both in vapor phase are compressed and decantation to further separate MTHF, which will be liquid and hydrogen, which still be in vapor phase

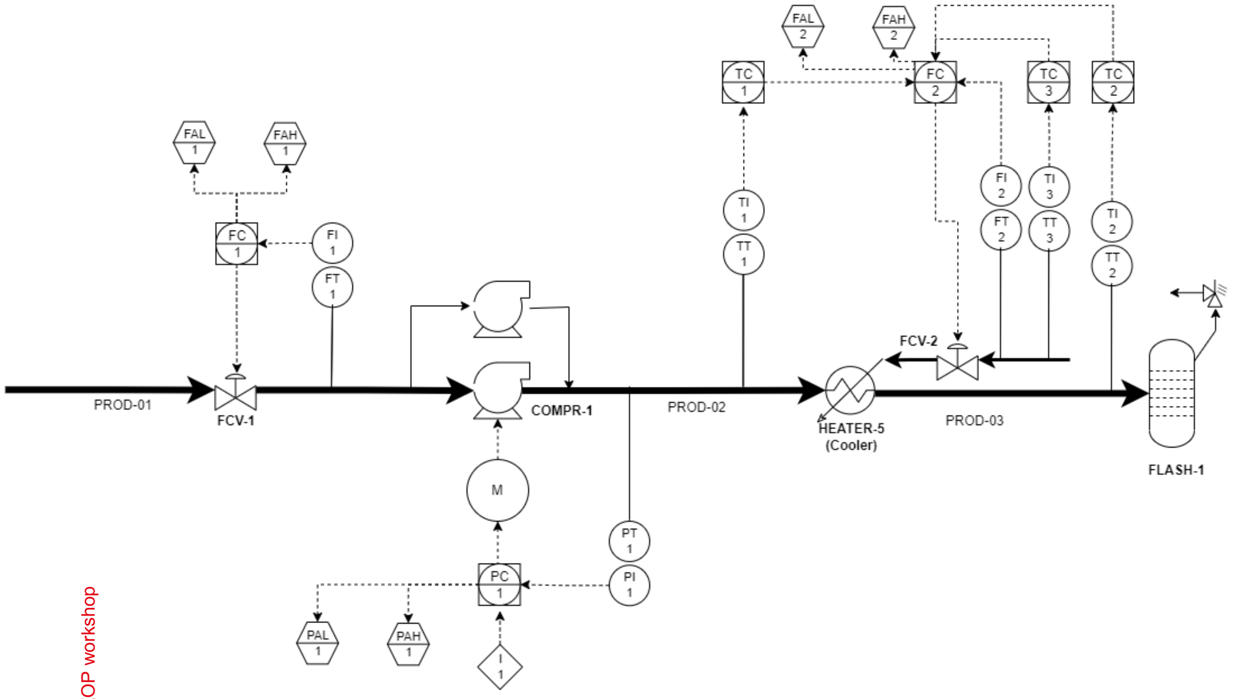
Row ID	Parameter	Deviation	Causes	Consequences	Existing Safeguards
1,1	Pressure	More	Incorrect set point of FCV-1 because incorrect reading of FT-1 Compressor's motor runaway	C1: Overpressure the line leading to rupture of piping and explosion C2: Potential for unconfined explosion leading to personal injury C3: Overpressure of HEATER-5 C4: Overpressure in the FLASH-1 column leading to the condensation of hydrogen in MTHF stream	SG1: PT-1 will detect rise in pressure and PC-1 will change the settings of the compressor's motor SG2: Operator could close FCV-1 to stop supply of vapor phase SG3: High pressure alarm PAH1 SG4: Intelock in case of high pressure
1,2	Temperature	More	Incorrect set point of FCV-1 because incorrect reading of FT-1 Less water flow due to failure in FCV-2 Not enough cold water in HEATER-5 Overpressure in the stream PROD-02	C1: Overpressure of steam leading to heating coil rupture C2: Overheating of HEATER-5 because of loss of cold water flow C4: Potential for explosion leading to personal injury C5: Too much MTHF could be in vapor phase and go in the further hyrogen recycling loop	SG1: TT-1 will detect a high temperature in PROD-02 and the operator could open FCV-2 for a higher flux of cooling water SG2: TT-2 will detect a high temperature in the inlet stream to the flash and the operator could open FCV-2 for a higher flux of cooling water SG3: TT-3 would measure if the cooling water is at the good temperature and the operator could close or open FCV-2 to modulate the flux SG4: Alarms on FC2 for too high and too low flow
1,3	Pressure	Less	Incorrect set point of FCV-1 because incorrect reading of FT-1 Compressor's motor deficiency	C1: Not enough MTHF will be in liquid phase for the separation in Flash4 C2: Presence of hydrogen in the decantation and purification parts of the process	SG1: PT-1 will detect drop in pressure and PC-1 will change the settings of the motor SG3: Low pressure alarm PAL1

Work as a group !

EPFL

6. Implement the alarm system

Marie JONES



- Regular alarms → make a noise → connected to sensors from control loops
- Executive alarms → automatically takes actions to bring process into fail-safe state → independent sensor
- High and low alarms

Questions?