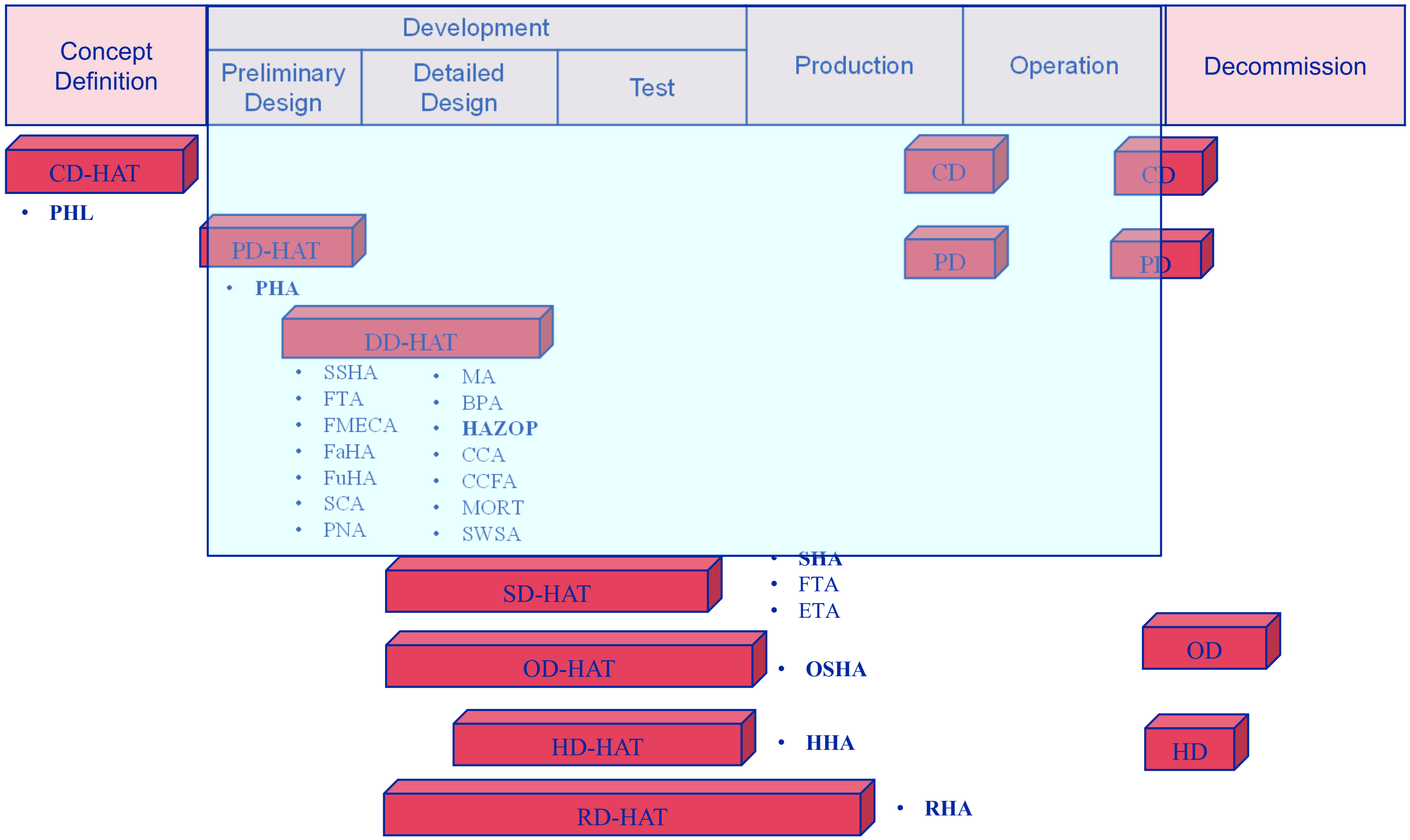
Hazard and Operability Study
HazOp

FPST 4333

Life Cycle Phase



Hazard and Operability (HAZOP)

- systematic team approach

- scenario development
  - Brainstorming what can go wrong
  - determine the consequences
  - deviations from the intended operation.

HAZOP Concept

- Objective: Identify, analyze, and control hazards and operability problems
  - Team Approach:
  - Multi-Disciplinary
- Traces flow of materials through a system operation divided into nodes
- Guide word based

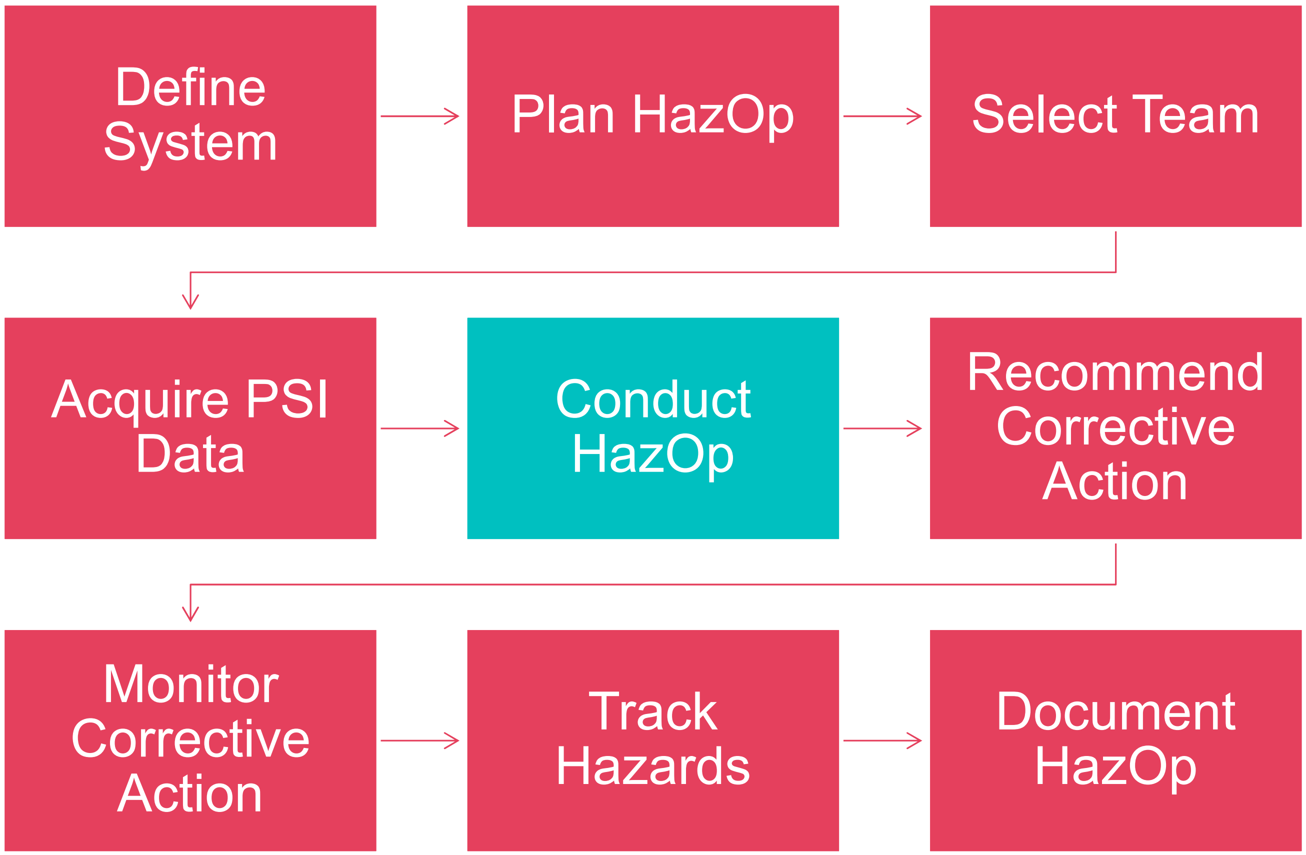
HAZOP Differences

- System safety analysis is done as close to design origins and development as possible with a PHA completed by ~ 35% development.
  - ⇨ HAZOP is performed when system design is mature but not fully settled.
  - ⇨ FMEA concern hardware failures only
- HAZOP includes human factors and operator errors in addition to other failures.

HAZOP Terminology

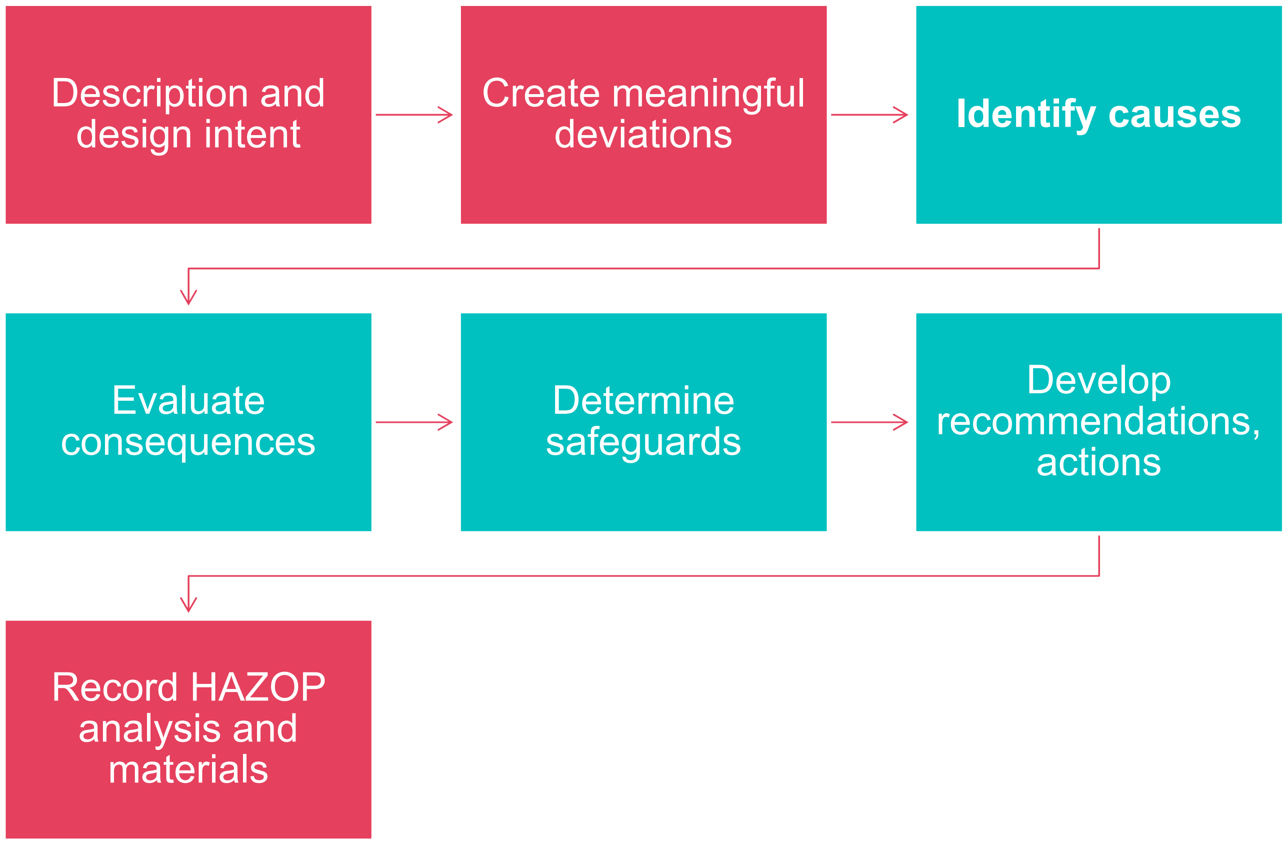
1.	Intentions	How the process is expected to operate or the activity is expected to be performed
2.	Deviations	Departures from the design intentions
3.	Causes	Ways deviations might occur
4.	Consequences	Results of the deviations
5.	Safeguards	Provisions for reducing the frequency or the consequences
6.	Actions	Suggestions for procedural changes, design changes, or further study

The HazOp Process



HazOp
Methodology

HAZOP Method



Guidewords, Parameters

- Guidewords (action words, keywords) help find deviations
  - Select a set of guidewords for the system type
- Select parameters for the system type, process, or operation
  - Parameter: variable, component, or activity in system under analysis

Deviations

- Begin search for deviations from the design intent
- Create a deviation statement
- Select a system parameter and link with a guideword or action phrase
- Check if the combination is meaningful or can be understood on a physical basis.

Combination

Guide Word + Paremeter =

Deviation

HAZOP Guidewords

Guideword		Meaning
No, not, none		None of the design intent is achieved
More, more of, higher		Quantitative increase in a parameter
Less, less of, lower		Quantitative decrease in a 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 intention occurs
Other than, other		Complete substitution – another activity occurs

Additional Guidewords

Guideword		Meaning
Where else		For flows, transfers, sources, destinations
Before, after		Step occurs out of sequence
Early, late		Timing is different than the intention
Faster, slower		Step is/is not with the right timing

Process Parameter Examples

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

Combination Examples

Guideword Combination Ex.	Parameter
None, more of, less of, reverse, elsewhere, as well as	Flow
Higher, lower	Temperature
Higher, lower, reverse	Pressure
Higher, lower, none	Level
More, less, none	Mixing
Higher rate, lower rate, none, reverse, as well as, other than, part of	Reaction

Parameter Guide Word Combinations, Process Lines

Table 10-4 Valid Guide Word and Process Parameter Combinations for Process Lines (x's represent valid combinations)

Process parameters	No, not, none	More, higher, greater	Less, lower	As well as	Part of	Reverse	Other than	Sooner, faster	Later, slower	Where else
Flow	x	x	x	x	x	x	x	x	x	
Temperature		x	x					x	x	
Pressure		x	x	x				x	x	
Concentration	x	x	x	x	x		x	x	x	
pH		x	x					x	x	
Viscosity		x	x					x	x	
State				x				x	x	

Crowl, D.A. and Louvar, J.F., *Chemical Process Safety*, 2nd ed, Prentice Hall, 2002

Parameter Guide Word Combinations, Vessels

Table 10-5 Valid Guide Word and Process Parameter Combinations for Process Vessels (x's represent valid combinations)

Process Parameters	No, not, none	More, higher, greater	Less, lower	As well as	Part of	Reverse	Other than	Sooner, faster	Later, slower	Where else
Level	x	x	x	x	x		x	x	x	x
Temperature		x	x					x	x	
Pressure		x	x	x				x	x	
Concentration	x	x	x	x	x		x	x	x	
pH		x	x					x	x	
Viscosity		x	x					x	x	
Agitation	x	x	x		x	x		x	x	
Volume	x	x	x	x	x			x	x	x
Reaction	x	x	x				x	x	x	
State				x			x	x	x	
Sample	x			x	x		x	x	x	

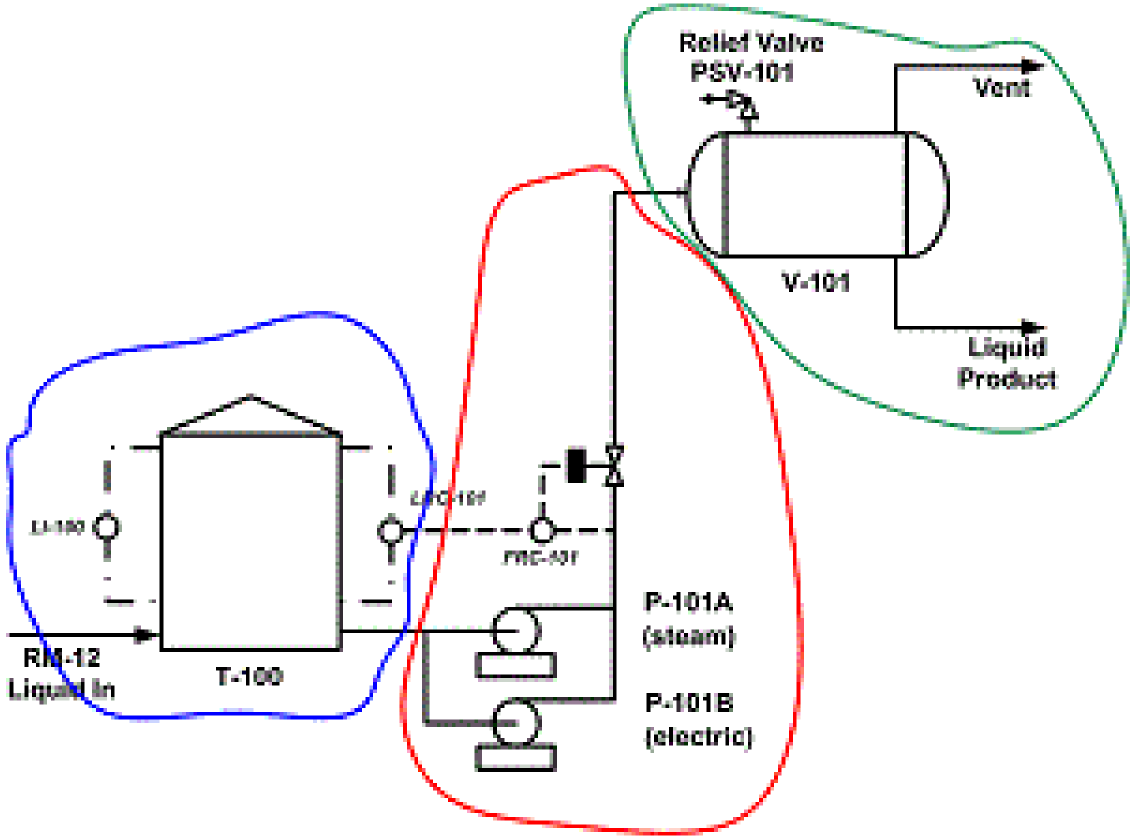
Crowl, D.A. and Louvar, J.F., *Chemical Process Safety*, 2nd ed, Prentice Hall, 2002

What is a Node?

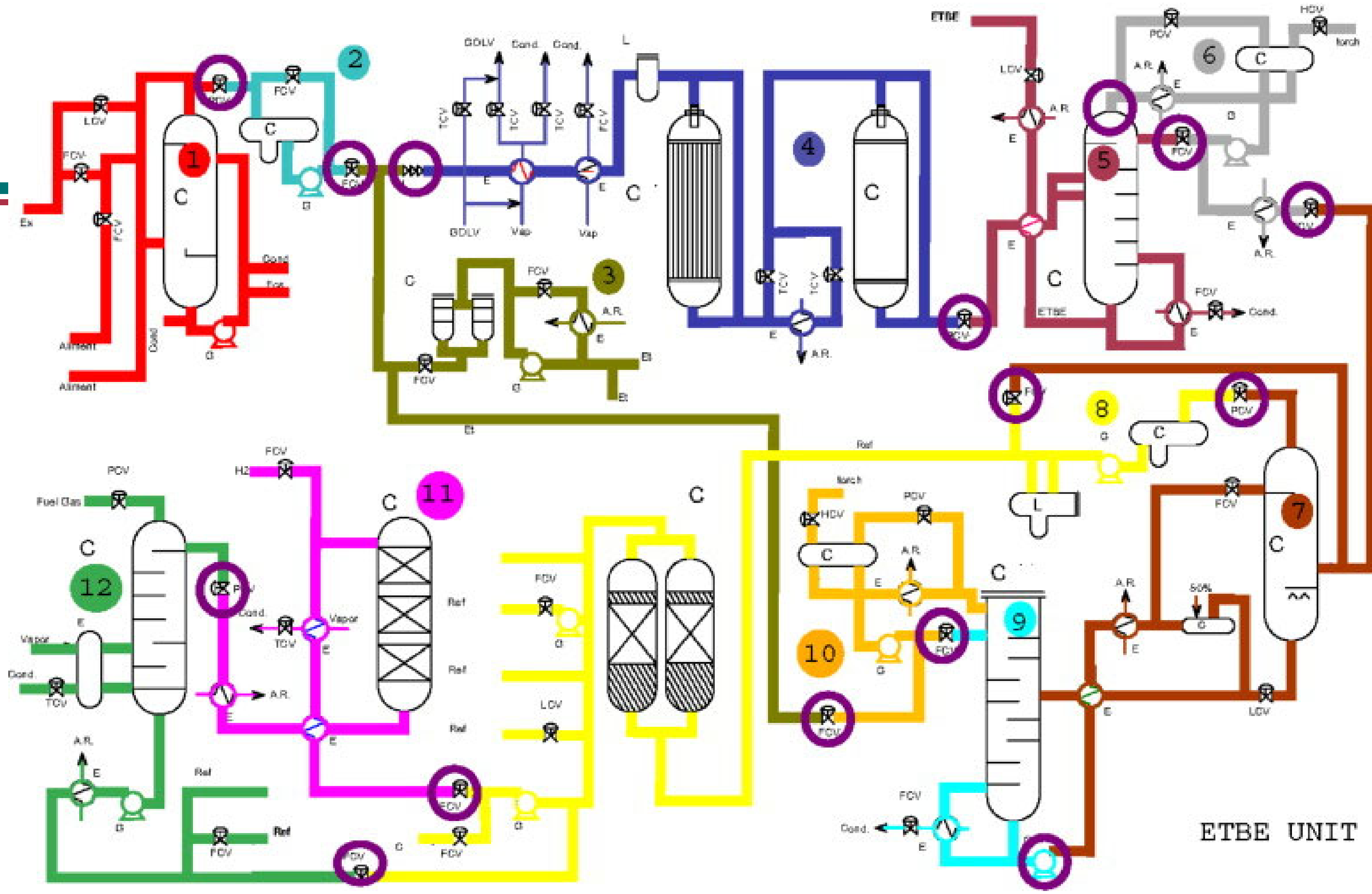
- Nodes are small, manageable and logical portions into which the process is divided.

- Consider the following guidelines for the identification/selection of nodes on a P&ID:
  - ⇨ Input streams to the equipment
  - ⇨ Output streams from the equipment
  - ⇨ Utility connections to/from the equipment
  - ⇨ Vent lines, drain lines, overflow lines
  - ⇨ Major Equipment, such as a reactor, tank, heat exchanger, dryer, centrifuge, etc.

Nodes



Relief Valve
PSV-101
Vent
V-101
Liquid
Product
LI-100
LIC-101
FRC-101
P-101A
(steam)
P-101B
(electric)
RM-12
Liquid In
T-100



ETBE UNIT

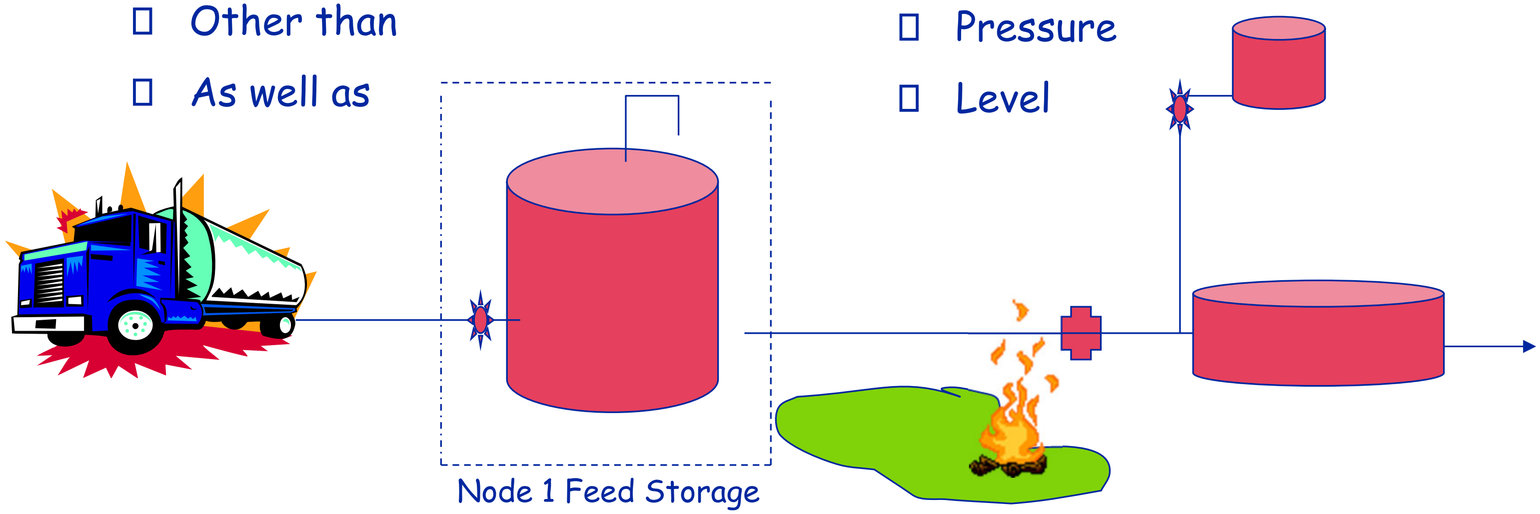
Node 1 intention = store process feed stocks

Guide Word

- No
- More
- Other than
- As well as

Parameter

- Composition
- Flow
- Pressure
- Level



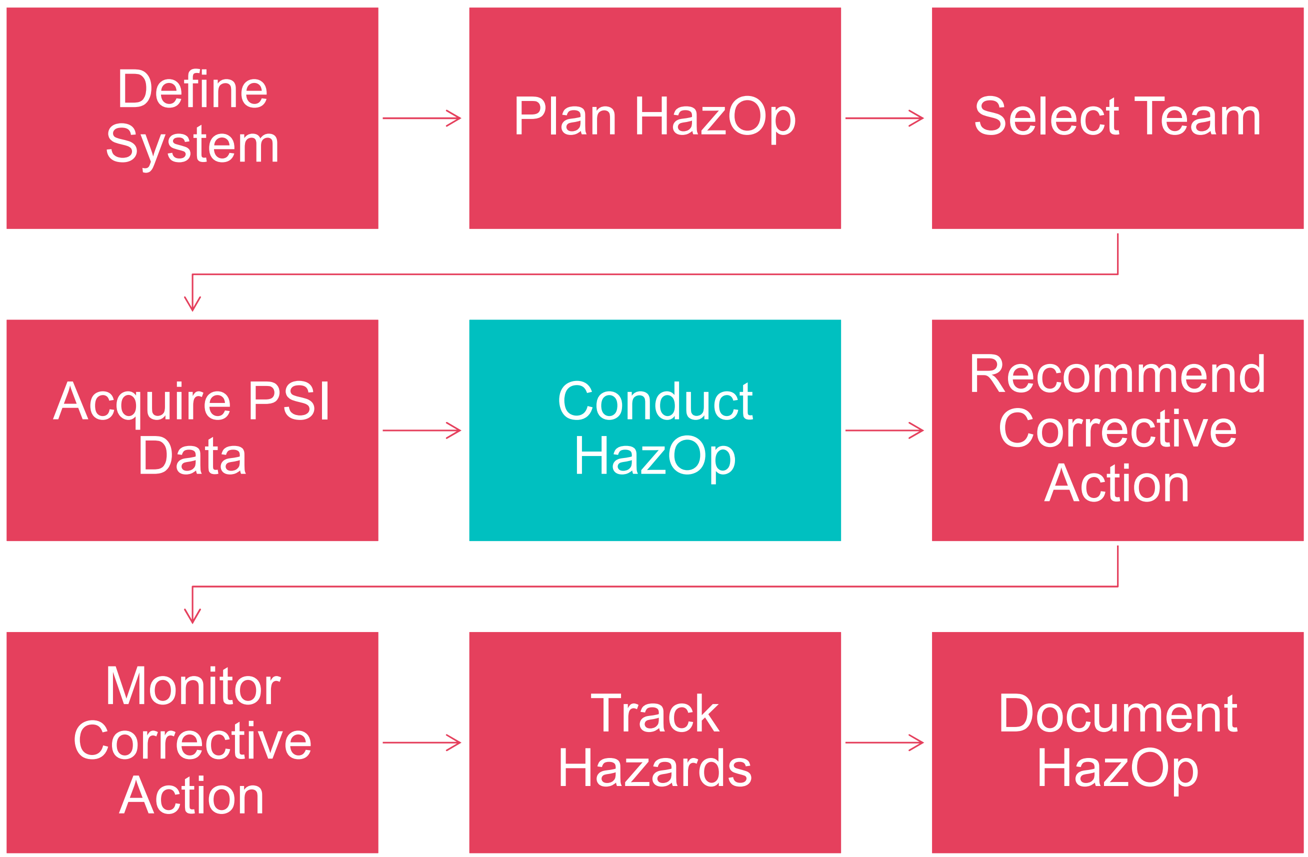
MORE + LEVEL = OVERFLOW

HAZOP Worksheet

HAZOP ANALYSIS											
Node	Item	Function/Purpose	Parameter	Guide Word /Deviation	Consequences	Causes	Hazard	Risk	Recommendations	Comments	Status

HAZOP Process

The HazOp Process



HAZOP Process

Preparation

- Process safety and system information
- Team selection
- HAZOP schedule
- Pre-HAZOP facilitator (leader) and scribe preparation
- Pre-HAZOP team walk-through

HAZOP Process

- **Select study nodes, examples**
  - Major vessels
  - Major lines connected to process or storage vessels
  - Pumps and compressors
  - Heat exchangers
  - Major support systems
- **Apply guide words to study nodes**
  - Determine deviation from design
  - Determine consequences of deviations
  - Evaluate consequences

HAZOP Process

- **Typical causes of deviations**
  - Hardware failures
  - Human error
  - Outside forces
  - Unanticipated process state
- **Suggested actions**
  - Change in design
  - Change in equipment
  - Alter operating procedures
  - Improve maintenance
  - Investigate further

HAZOP Process

- **HAZOP Follow-up**
  - ⇨Assign responsibility for carrying out recommendations
  - ⇨Refer recommendations to appropriate managers
  - ⇨Evaluate and review
- **Hazard containment actions**
  - ⇨Change the process
  - ⇨Change process conditions
  - ⇨Alter the physical design
  - ⇨Change operating procedures
- **Record keeping**
  - ⇨Copy of all data used
  - ⇨Copy of all working papers
  - ⇨HAZOP worksheets

HAZOP Team Composition

- 5-7 team members optimum, All members should contribute
- Team leader - HAZOP expertise
- Technical Members: design expertise, operating and maintenance experience, instruments, electrical, medical, explosion hazards expertise, etc.
  - New Design
    - Design Engineer
    - Process Engineer
    - Commissioning Manager
    - Instrument Design Engineer
    - Chemist
  - Existing Plant
    - Plant Superintendent
    - Process Supervisor
    - Maintenance Engineer
    - Instrument Engineer
    - Technical Engineer
- Scribe
- Consultants

Team Leader Attributes

- Patience
- Stamina
- Organized
- Quick thinking
- Friendly and cooperative
- Able to focus on multiple items
- Able to read people
- Gentle authority
- Imaginative
- Seeks consensus
- Respected by team
- Diplomatic

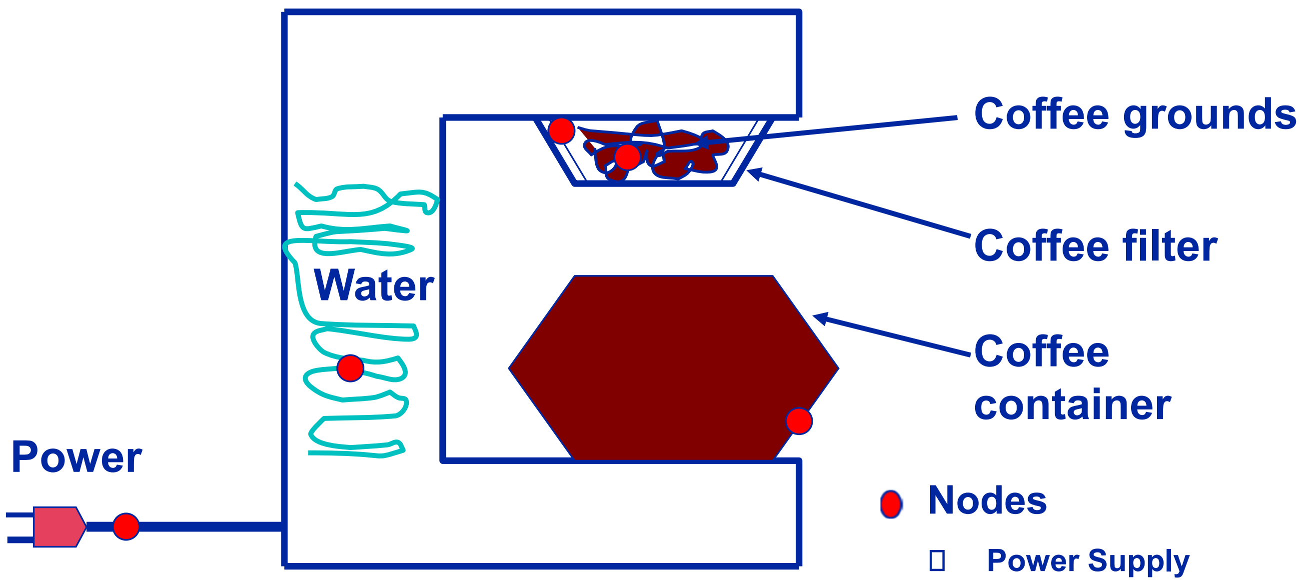
Scribe Attributes

- Attention to detail
- Responsive
- Good listener
- Good computer entry skills
- Good spelling/grammar skills
- Process/technical knowledge

HAZOP Example

Coffee Maker

Coffee Maker



- Nodes
  - Power Supply
  - Water Supply/Heat Exchanger
  - Immersion/Extraction Process
  - Final Product Storage

Select water as a study node.

Apply process parameter of flow.

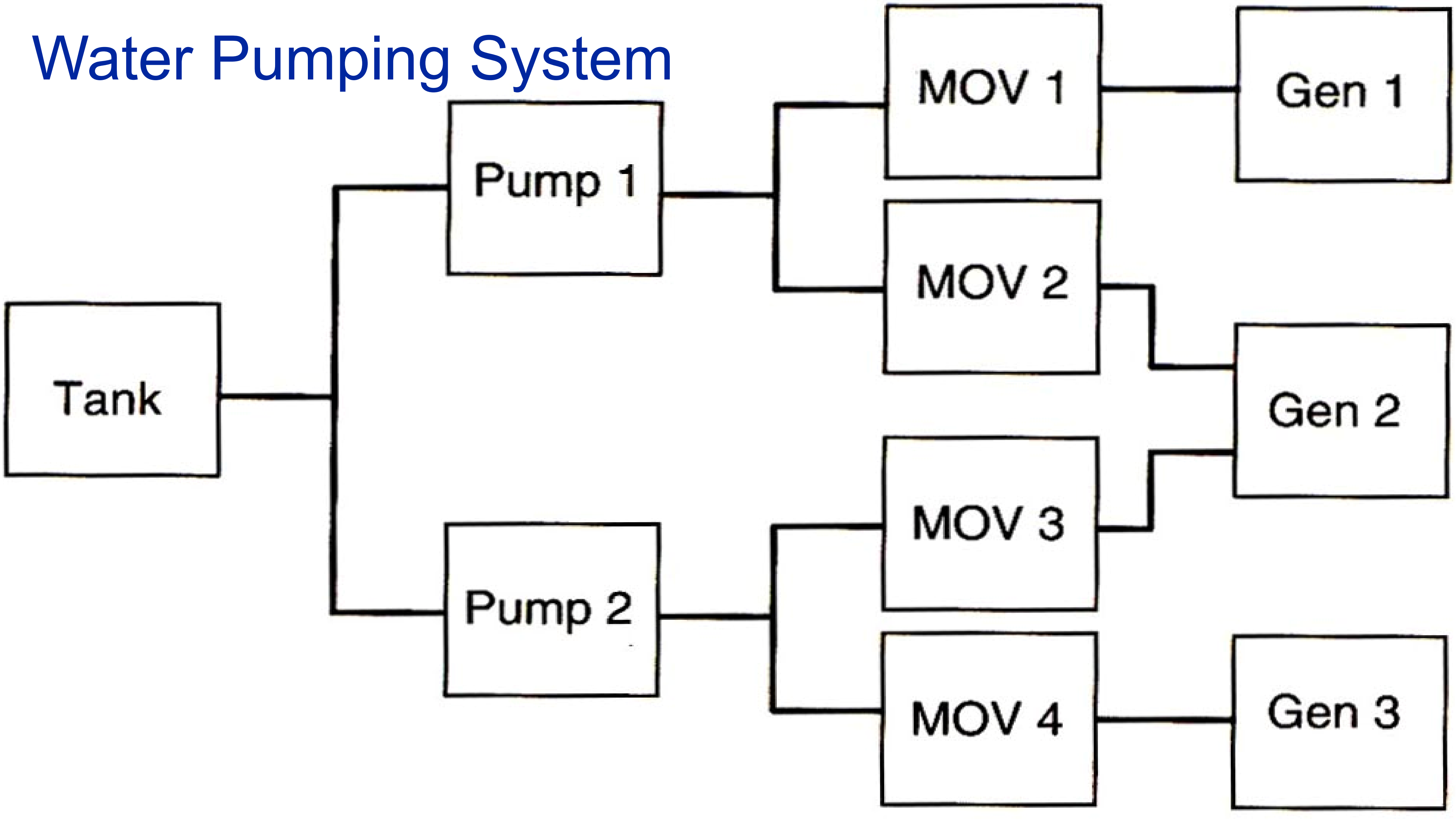
HAZOP Worksheet

HAZOP ANALYSIS											
Node	Item	Function/Purpose	Parameter	Guide Word /Deviation	Consequences	Causes	Hazard	Risk	Recommendations	Comments	Status
Water	1	To supply water to brewer system	Level	Less (8 oz) More no	No product Burned out pump Burned out pot						
	2		temp	high low							
	3		quality	poor							
			flow	high Low No reverse							

HAZOP Example

Water Pumping System

Water Pumping System



Water Pumping System

- Water is supplied to 3 steam generators, 2 of which are always needed.
- Electric drive pumps transfer the water from the tank to the motor operated valves (MOVs).
- The pumps, MOVs, and generators are monitored and controlled by a computer and powered from a common source.
- Parameters for HAZOP analysis: fluid, pressure, temperature, electricity, and steam.

HAZOP Analysis

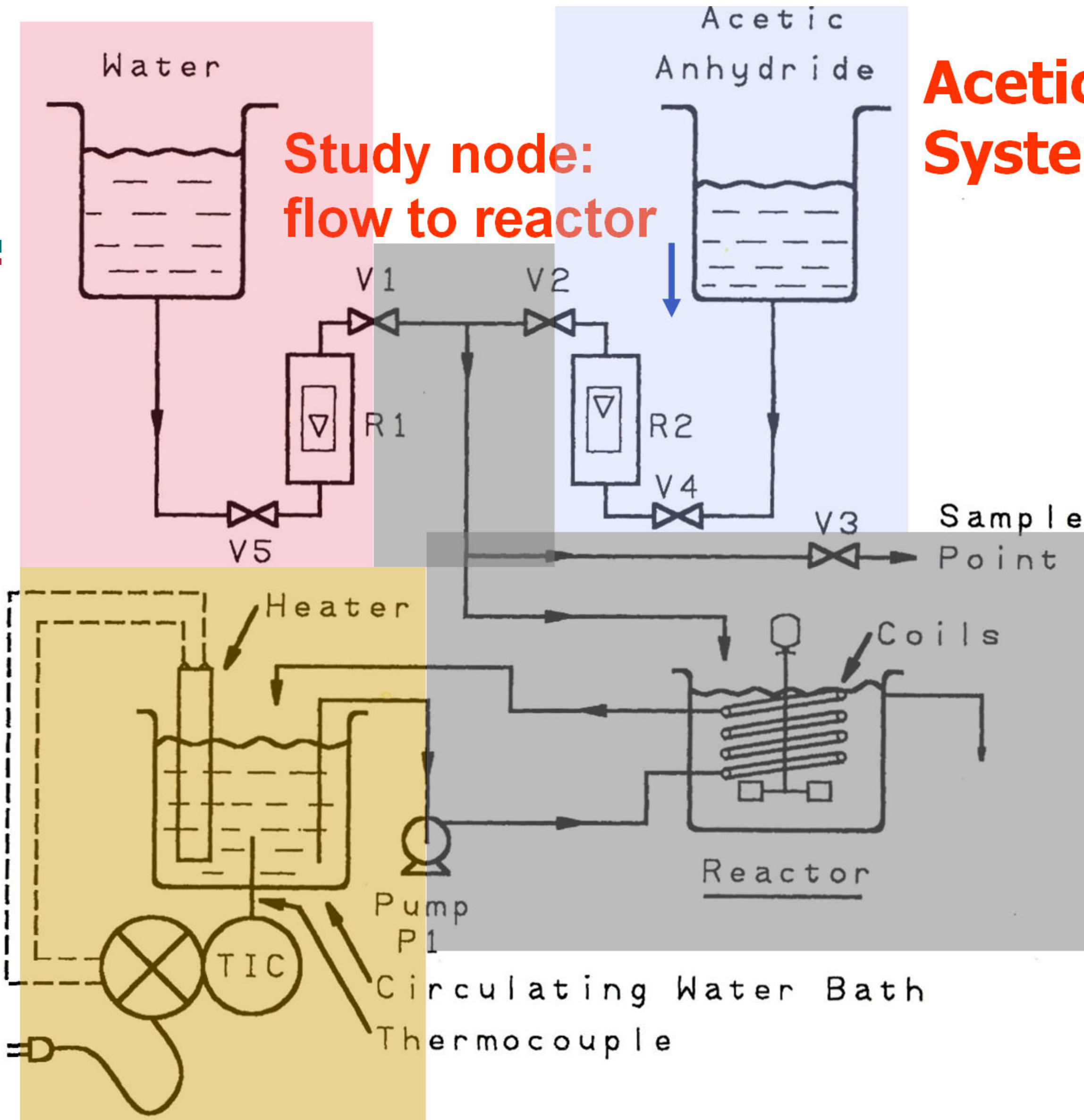
No.	Node Item	Function/ Purpose	Parameter	Guide Word	Consequence	Cause	Hazard	Risk	Recommendation	Comments
1	Pipes	To carry water through system	Fluid	No	Loss of fluid, system failure; equipment damage	Pipe leak; pipe rupture	Equipment damage	2D		
2				More	Pressure becomes too high, resulting in pipe rupture	No pressure relief valves in system	Equipment damage	2C	Add pressure relief valves to system	
3				Less	Insufficient water for operation of generators	Pipe leak; pipe rupture	Equipment damage	2D		
4				Reverse	Not applicable			—		
5	Electric power	To provide electricity to operate pumps, MOVs, and generators	Electricity	No	Loss of power to operate system components	Power grid loss; circuit breakers trip	Loss of system operation	2D	Provide source of emergency backup power	

HAZOP Analysis									
No.	Item	Function/ Purpose	Parameter	Guide Word	Consequence	Cause	Hazard	Risk	Recommendation
6				More	Trips circuit breakers	Power surge	Loss of system operation	2C	Provide for fault detection and isolation
7				Less	Insufficient power to adequately operate system components	Power grid fault	Equipment damage	2D	Provide source of emergency backup power
8				Reverse	Not applicable			—	
Analyst:				Date:					Page: 1 of 1

HAZOP Example

Acetic Anhydride System

Acetic Anhydride System



Acetic Anhydride System

- Hydrolysis of acetic anhydride (AA) system in a continuously stirred tank reactor (CSTR).
- Water and AA are gravity fed from reservoirs and through rotameters to measure flow rate.
- Water is mixed with AA just prior to entering the reactor.
- Reactor temperature is maintained by water circulated by a pump through coils in the reactor from a temperature bath with controller.
- Samples are taken from the "Sample Point" to measure the AA concentration.

Project Name: Problem 10-2 | Date: February 19, 2002 | Page 1 of 2 | Completed:

Process: Acetic Anyhydride Reactor System | No Action:

Section: Reactor | Reference Drawing: Figure 10-14 | Reply Date:

Item	Study Node	Process Parameters	Deviations (Guide Words)	Possible Causes	Possible Consequences	Action Required	Assigned To: ↓	↓	↓	↓
1A	Reactor Feed	Flow	No	1. No stock in stock tanks	1 No feed and therefore no reaction	1. Operator must check prior to start-up to insure proper feed quantities - check pre-start-up checklist. Operator must check reactant levels during operation of unit.	DAC	6/02		
				2. Feed line is plugged.	2. No feed and therefore no reaction	2. Update maintenance procedures.	JFL	5/02		
				3. Feed line is cut.	3. No feed and therefore no reaction. Possible spill of feed materials.	3. Update maintenance procedures. Insure that spill containment, spill kits, and proper clean-up PPE is available.	JFL	5/02		
				4. All feed valves are closed.	4. No feed and therefore no reaction.	4. Update start-up procedure so that valves are closed prior to start-up.	DAC	7/02		
1B			More	1. Rotameters are miscalibrated leading to higher flows than expected.	1. High reactant feed. High reaction rate. High temperature in reactor. Improper conversion to product.	1. Update calibration procedure. Add item to pre-startup check list to check for recent calibration.	DAC	5/02		
				2. Throttling valves V1 - V5 cannot be shut or throttled, leading to higher flow.	2. Same as 1.	2. Valves must be of the correct type, materials of construction and properly maintained. Check type, construction and maintenance.	JFL	4/02		
				3. Addition of fresh stock to feed tanks resulting in higher level and higher gravity flow.	3. Same as 1.	3. Update procedure and train operator and feed stock charging procedure.	DAC	4/02		
1C			Less	1. Partially plugged feed line.	1. Less feed and less reaction. Improper product conversion.	1. Check and update maintenance.	DAC	4/02		

Project Name: Problem 10-2 (continued) | Date: | Page 2 of 2 | Completed:

Process: | No Action:

Section: | Reference Drawing: | Reply Date:

Item	Study Node	Process Parameters	Deviations (Guide Words)	Possible Causes	Possible Consequences	Action Required	Assigned To: ↓	↓	↓	↓
				2. Leaking feed lines.	2. Spill of reactants. Less feed to reactor, improper reactor conversion.	2. Update maintenance procedures. Insure that spill containment, spill kits, and proper clean-up PPE is available.	DAC	7/02		
				3. Valve V-3 opened, leading to leakage of reactants.	3. Possible spill of reactants from sample line. Less feed to reactor, improper reactor conversion.	3. Check pre-start-up checklist to insure that this valve is closed. Insure that spill containment, spill kits, and proper clean-up PPE is available.	DAC	6/02		
1D			As well as	1. Contamination of feed stock reactants.	1. Possible side reactions, unknown chemical exposures, contamination of product.	1. Stock feed materials must be checked prior to usage.	JFL	5/02		
1E			Reverse	1. Not possible - gravity feed system.	1. No consequence.	1. No action.			X	
1F			Other than	1. Wrong material place in feed tank.	1. Unknown and potentially severe consequence. Possible toxic contamination, runaway reaction, etc.	1. Feed materials must be carefully checked prior to operation to insure they are the proper materials. Check pre-start-up checklist.	JFL	6/02		

HAZOP Example

Olefin Dimerization Plant

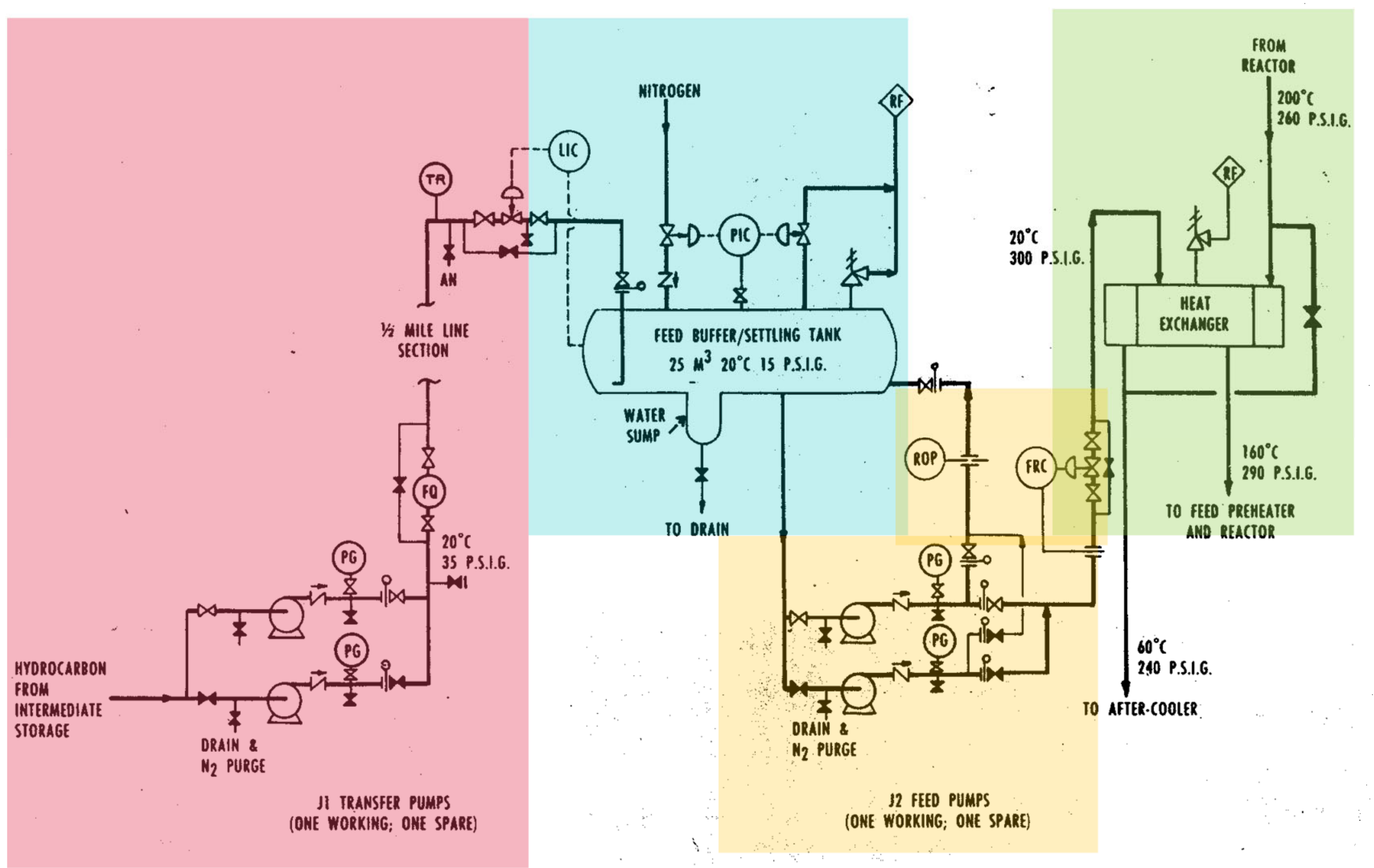


Figure 1. Feed section of proposed olefin dimerization plant.

Olefin Dimerization Feed Section

- An alkene/alkane fraction is pumped from storage by pipeline into a buffer/settling tank, where residual water is settled out and drained.
- The fraction is then passed through a feed/product heat exchanger and preheater to the reactor section.
- Residence time in the reactor is held closely for adequate conversion of the alkene and to avoid excessive polymer formation.
- The following is a HAZOP Analysis of the first line section from storage to the buffer/settling tank.

Node 1: Line Section from Intermediate Storage to Buffer Settling Tank
Design Intent: Flow hydrocarbon to the buffer settling tank at 20^{o}C and 35 psig

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations
Flow	No	No flow	(1) No hydrocarbon available at intermediate storage	Loss of feed to reaction section and reduced output. Polymer formed in heat exchanger under no flow conditions.	(a) Ensure good communications with intermediate storage operator (b) Install low level alarm on settling tank LIC
			(2) J1 pump fails (motor fault, loss of drive, impeller, corrosion, etc)	Same as for (1) above	Covered by (b) above
			(3) Line blockage, isolation valve closed in error	Same as for (1) above and also J1 pump overheats	(c) Install kickback on J1 pumps (d) Check design of J1 pump strainers
			(4) Line fracture	Same as for (1) above and also HC discharged into public highway	(e) Institute regular patrolling and inspection of transfer line

Node 1: Line Section from Intermediate Storage to Buffer Settling Tank
Design Intent: Flow hydrocarbon to the buffer settling tank at 20ºC and 35 psig

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations
Flow	More	More flow	LCV fails open.	Settling tank overfills Incomplete separation of water phase in tank, leading to problems on reaction section.	(f) Install high level alarm on LIC and check relief sizing. (g) Install J2 pump suction line to 12” above tank base
Flow	Less	Less flow	Leaking flange. Note: All other causes considered in No flow	Material loss adjacent to public highway.	Covered by (e)

Node 1: Line Section from Intermediate Storage to Buffer Settling Tank
Design Intent: Flow hydrocarbon to the buffer settling tank at 20°C and 35 psig

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations
Flow	Part of	Higher water concentration Higher concentration of lower alkanes	High water level in intermediate storage tank Disturbance on distillation columns upstream of intermediate storage	Water sump fills up more quickly and increased chance of water passing to reaction section Higher system pressure	(i) Arrange for frequent draining off of water from intermediate storage tank. Install high interface level alarm on sump. (j) Check that design of settling tank and associated pipework, including relief sizing will cope with sudden ingress of more volatile HCs
Flow	More than	Organic acids present	Disturbance on distillation columns upstream of intermediate storage	Increased rate of corrosion of tank base, sump and drain line	(k) Check suitability of materials of construction (l) Conduct sample analysis at appropriate frequency

Node 1: Line Section from Intermediate Storage to Buffer Settling Tank
Design Intent: Flow hydrocarbon to the buffer settling tank at 20^{o}C and 35 psig

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations
Pressure	More	More pressure	Isolation valve closed in error or LCV closes, with J1 pump running Thermal expansion in an isolated valved section due to fire or strong sunlight	Transfer line subjected to full pump delivery or surge pressure Line fracture or flange leak	(m) Covered by (c) except when kickback blocked or isolated. Check line and flange ratings. Install a PG upstream of LCV and an independent PG on settling tank (n) Install thermal expansion relief on valved section
Pressure	Less	Less pressure	Covered by less flow analysis.		

Node 1: Line Section from Intermediate Storage to Buffer Settling Tank
Design Intent: Flow hydrocarbon to the buffer settling tank at 20^{o}C and 35 psig

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations
Temperature	More	More temperature	High intermediate storage temperature	Higher pressure in transfer line and settling tank.	(o) Install high temperature indicator at intermediate storage
Temperature	Less	Less temperature	Winter freeze	Water sump and drain line freeze up	(p) Steam trace drain valve and drain line downstream

HAZOP Advantages/Disadvantages

- Guide word tools help to identify hazards.
- Provides analysis of how hazards can develop from operating procedures and operational upsets.
- In practice: less down time, enhanced product quality, less waste, employees are more confident in safety of the system or process.
- Requires significant resources and time.