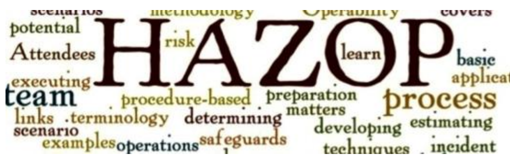

PROCESS SAFETY ENGINEERING (0905477)

15- INTRODUCTION TO HAZARD AND OPERABILITY STUDIES (HAZOP)

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The superior man, when resting in safety, does not forget that danger may come.... When all is orderly, he does not forget that disorder may come. Confucius (551 BC – 479 BC)

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Outline

- Finding Hazards!
- HAZOP
- What can HAZOP be applied to?
- When to Perform a HAZOP?
- History of HAZOP
- Scope of HAZOP
- Hazards
- HAZARD STUDIES 1, 2, 3 (ICI, BP, Courtaulds etc)
- HAZOP Team
- HAZOP Procedure
- HAZOP Implementation
- HAZOP Example

Finding Hazards!

Hazards

- Obvious
  - We know them already
  - We design and train for these
  - Complacency is a trap
- Hidden
  - The one that gets you!
  - This is why we do PHA

What you can't see can hurt you!

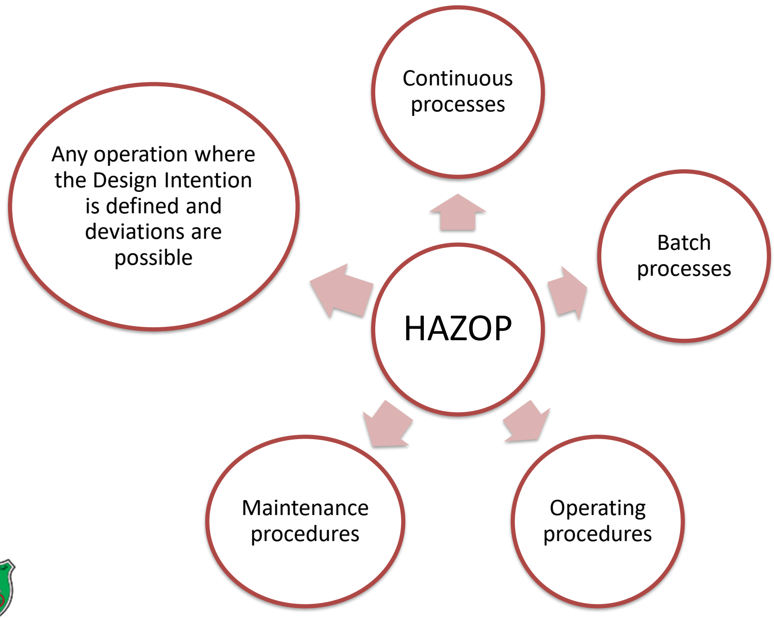
HAZOP

- Acronym for **haz**ard and **op**erability.
- A structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to **personnel or equipment, or prevent efficient operation**.
- Commonly used by designers of plant to identify possible dangers during intended operation.
- Conditions during abnormal operation (start-up and shutdown) or commissioning are different from normal operation, so may not have been included in the study.

PHA: Process Hazard Analysis

HAZAN: Hazard Analysis

What can HAZOP be applied to?



When to Perform a HAZOP?

- The HAZOP study should preferably be carried out as early in the design phase as possible - to have influence on the design.
- When the final P&ID are available.
- During construction and installation to ensure that recommendations are implemented.

History of HAZOP

- Initially developed to analyze chemical process systems, but has later been extended to other types of systems.
- First main textbook: Kletz, T. A.: "HAZOP and HAZAN - Identifying and Assessing Process Industry Hazards", Institution of Chemical Engineers (IChemE).
- The first published paper on HAZOP was by H.G. **Lawley** in 1974. It was presented at the AIChE Loss Prevention Symposium in Philadelphia the previous year.

History of HAZOP

Concept →Bert Lawley at I.C.I. in the late 1960's.

↓

Result of a desire to have structured check on PIDs.

↓

Spread through I.C.I. in early 1970's.

↓

Endorsed by the "Health and Safety Directorate" of the U.K. government

↓

U.K. HSE and the Dutch Arbeidsinspectie began to mandate HAZOP as part of Safety Report for "Seveso Directive".

↓

I.C.I. by this time were doing HAZOP on "everything".

↓

Dow incorporated in its Risk Management process based on its own criteria (focusing on highest risk).

ICI Contribution to HAZOP

In 1963 the Heavy Organic Chemicals (HOC, later Petrochemicals) Division of ICI was designing a plant for the production of phenol and acetone from cumene. It was a time when the cry was for 'minimum capital cost' (rather than minimum lifetime cost or maximum profit) and the design had been cut back of all but essential features. Some people felt that it had been cut back too far. It was also a time when method study and, in particular, 'critical examination' were in vogue. Critical examination is a formal technique for examining an activity and generating alternatives by asking, 'What is achieved?', 'What else could be achieved?' and so on.

The production manager had recently spent a year in ICI's Central Work Study Department. He decided to see if critical examination could be applied to the design of the phenol plant in order to bring out into the open any deficiencies in design and find the best way of spending any extra money that might be available. A team was set up including the commissioning manager, the plant manager and an expert in method study and critical examination. During 1964 they met for three full days per week for four months, examining the phenol plant line diagrams and covering acres of paper with all the questions and answers. They discovered many potential hazards and operating problems that had not been forseen, modifying the technique as they did so. Mr. H. later wrote, "We concocted an approach for trial.. and to cut a long story short this approach did not work. Not because it did not do the job but because it was too detailed, penetrated into too many corners, all good stuff but life was just too short. After a good many tries we came up with an approach which has much of the principle of critical examination but was somewhat bent in style". The essence of the new approach was that a technique designed to identify alternatives was modified so that it identified deviations. It was recognizably hazop as we know it today though it was further modified during later studies to the form described in this Training Course.

Scope of HAZOP

- Limited to the piping, instrumentation and equipment shown on the PID's (**do not re-design**)
- Limited to deviations from **normal** operations
- Impact of process unit on the utility systems or other process units will be noted as requiring further study
- Primary intent is to identify hazards and define action items for additional safeguards, if appropriate

Hazards

HAZARD STUDIES 1, 2, 3 (ICI, BP etc.)

HAZOP Studies

HS1 - Project Scoping
- initial assessment of hazards and techniques required

HS2 - Draft Flowsheet
- categorizes hazards and precautions

HS3 – HAZOP on PID
- Detailed review of process operation

HAZOP Team

- The HAZOP study is a team activity. This is important because when working as a team, more problems can be identified than when individuals working separately combine results.

HAZOP team leader	HAZOP secretary	HAZOP team members
1.Define the scope for the analysis 2.Select HAZOP team members 3.Plan and prepare the study 4.Chair the HAZOP meetings	1.Prepare HAZOP worksheets 2.Record the discussion in the HAZOP meetings 3.Prepare draft report(s)	The basic team for a process plant might include: Project engineer Commissioning manager Process engineer Instrument/electrical engineer Safety engineer Design engineer Operations supervisor Instrument engineer Chemist Maintenance Engineer R & D representative

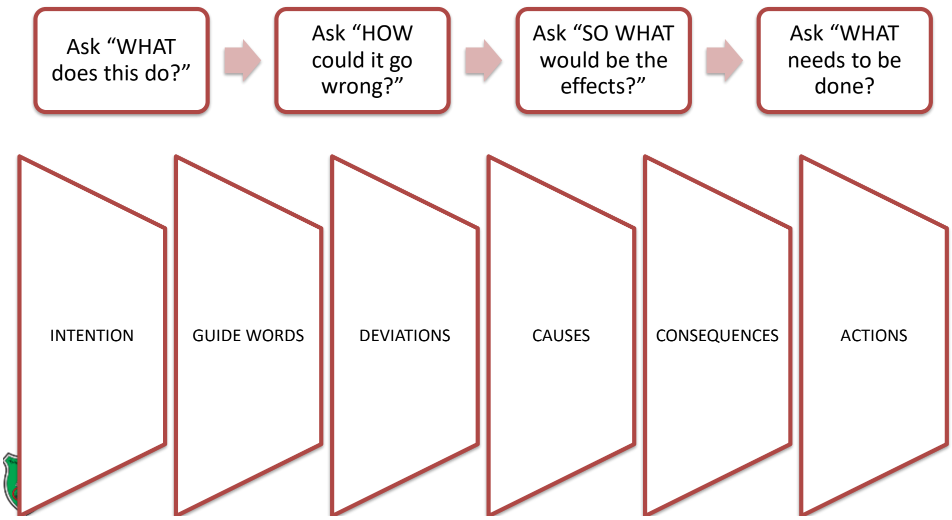
Term used in HAZOP study	Description
Leader/Chairman	The HAZOP member who leads the discussion using parameter-guidewords.
Recorder/Scribe	The HAZOP member who keeps a record of the discussions.
P & ID	Process and Instrumentation Diagram
Design Intent	This defines how the plant is expected to operate in the absence of deviations at the study nodes.
Node	The segment of P & ID at which the process parameters are investigated for deviations.
Guideword	Guide words are simple words which are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations. Some examples of guidewords are: No, Reverse, Less, Also, High, Other than, More, etc.

Parameter	A physical property of a component of the process. For Ex. Temperature, Pressure, flow, level, concentration.
Deviation	The word or phrase expressing a deviation of a parameter from design intent. It is a combination of guideword and parameter. For example, High Temp., Low Pressure, Reverse Flow.
Causes	These are the reasons why deviations might occur. These causes can be hardware failures, human errors, an unanticipated process state (e.g., change of composition), external disruptions (e.g., loss of power), etc.
Consequence	Unwanted process conditions OR events of damage to persons, property or environment.
Safeguards	Existing controls and means of risk reduction.
Recommendations	A mitigation measure the HAZOP team agrees to suggest an improvement aimed at improving safety or plant performance

One Process Unit = "Node"

- There is no "right" way to define nodes
- Usually start with a small node
- As experience builds, move to a larger node
- Follow the leader's intuition
- If the team gets bored, the node is probably too small
- If the team gets confused, the node is probably too big
- Takes 2 hours for an experienced team.
    - Allow more for abnormal operation and commissioning.
    - Less if the item has been studied previously and the notes are available.

HAZOP Procedure



HAZOP Procedure

- **INTENTION**
- **GUIDE WORDS**
- **DEVIATIONS**
- **CAUSES**
- **CONSEQUENCES**
- **ACTIONS**

- What it does
- More, less etc
- How it can go wrong
- Why it can go wrong
- What will happen
- So what should we do about it?

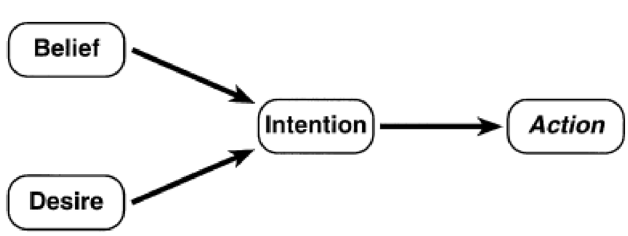
APPENDIX II
HAZOP WORKSHEETS

HAZOP WORKSHEET	
PROJECT: **Kazakhstan - China Pipeline Project** Atasu - Alashankou Crude Oil Pipeline	**Date:** **21/12/12**
Pipeline section: **Node 1a - Station 11 - Pig Receiver Suction to Pig Launcher** Discharge Design intent: To bypass pig traps at Station 11, normal operating route.	**P&iD number: No. 11 Pig Trap Station KCPB01-E-PR-DW-0002-01-1 Rev 1 08/06/05**

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
No Flow	Shut Valve Blockage of line Pig stuck in line	Loss of production	None	1. Operating procedures to be written for Station 11.
More Flow	See Node 6a "More Flow"			
Less Flow	Outage of intermediate pump station Partial blockage	Loss of production	None	2. Operating procedures to include outage of intermediate pump at Pump Stations.
Reverse Flow	Upstream pipeline rupture depending on topology See Node 6a "More Flow"	Loss of production	None	3. Line walk and air inspection to be formalized for the whole pipeline.
Misdirected Flow	Open bypass	NAH		

HAZOP: Intention

- State clearly the **INTENTION** of a piece of process EQUIPMENT or STREAM, trying to use a simple **PROPERTY**.
  - **FLOW** of 18 kg/s of 98% H_2SO_4 from tank T3 to heat exchanger HX17.
  - **HEAT** stream of H_2SO_4 to 80 ^oC.

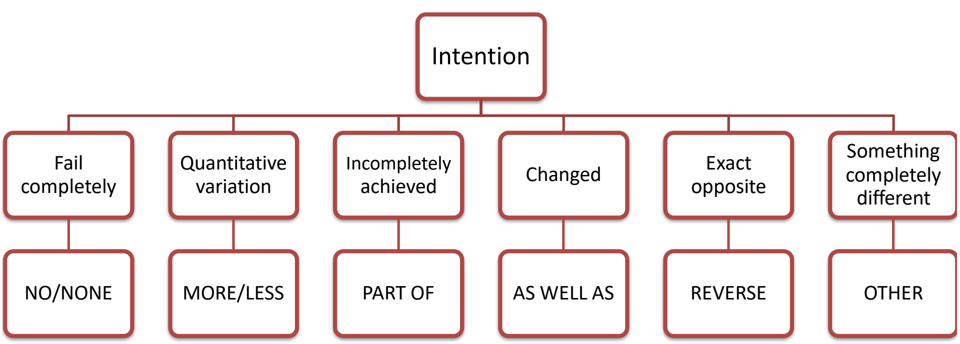


HAZOP Guide Words

- Apply **GUIDE WORDS** to the **PROPERTY** intention.
- See if a meaningful deviation occurs.
- Note that some deviations are much more likely during start-up/shut down/commissioning.

HAZOP Guide Words

- Words used as keys to suggest the various ways in which deviations from an intention can occur



Examples

- Intention can fail completely and nothing at all happens.
  - "NO flow" situation can exist if a pump fails to start.
- Quantitative variation refers to quantities, physical properties and activities.
  - MORE of a charge of reactant, a high mole ratio in a reactor, LESS reaction.
- Intention is changed, a qualitative deviation results.
  - An additional activity may occur AS WELL AS the original intention.
  - If a motor starts-up on auto start, a drop in the power supply may upset other equipment.
- Intention may be incompletely achieved,
  - PART OF: A diesel fire-pump may start-up, but fail to reach full speed.
- Exact opposite of what was intended
  - REVERSE flow is a common occurrence, very often in spite of the use of check valves.
  - In a reaction kinetics situation, the REVERSE reaction may occur.
- OTHER is a guide word used as a final catch all.
  - It is used to identify something completely different.
  - Following the reaction kinetics thought, a different reaction mechanism may be more important under certain conditions.
  - OTHER is also used to call up requirements for maintenance, start-up, shut-down, catalyst change, etc.

Meaningful Deviations

- **NO FLOW** of H_2SO_4 to heat exchanger.
- **LESS FLOW** than intended.
- **MORE FLOW** than intended.
- **OTHER FLOW**: water instead of H_2SO_4.
- **REVERSE FLOW** to tank T3.
- **ALSO FLOW**: oil as well as H_2SO_4.
- **EARLY, LATE FLOW.**

Hazards are caused by DEVIATIONS from the DESIGN INTENTION
HAZOP is a method for generating these "DEVIATIONS" using "GUIDE WORDS"

Process PARAMETERS

Flow	**Time**	**Frequency**	**Mixing**
Pressure	**Composition**	**Viscosity**	**Addition**
Temperature	**pH**	**Voltage**	**Separation**
Level	**Speed**	**Information**	**Reaction**

Guide Words		**Parameter**		**Deviation**
NO	+	FLOW	=	NO FLOW
MORE	+	PRESSURE	=	HIGH PRESSURE
AS WELL AS	+	ONE PHASE	=	TWO PHASE

CAUSES

- The reason(s) why the deviation could occur. Several causes may be identified for one deviation. It is often recommended to start with the causes that may result in the worst possible consequence.
- Consider only the causes that **originate within the node (consequences may be outside of the node)**
- Deviations could be caused by:
  - Equipment or process control failure
  - Human error
  - Loss of utilities
  - External events such as fire
  - Long term processes, e.g. erosion, corrosion, coking
- If process instrumentation crosses a node boundary, control malfunction is considered a cause in both nodes.
- Deviations that require the simultaneous occurrence of two or more unrelated causes are not considered.

CAUSES OF ACCIDENTS

1. I DIDN'T THINK
2. I DIDN'T SEE
3. I DIDN'T KNOW

CONSEQUENCES

- The results of the deviation, in case it occurs.
- List all POSSIBLE consequences, even those that propagate outside the node. Consequences may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product.
- Several consequences may follow from one cause and, in turn, one consequence can have several causes.
- Consequences are described assuming there are no safeguards.
- Describe consequences as a **chronological** sequence of events.

Leak of flammable gas
Fire
Damage to adjacent units

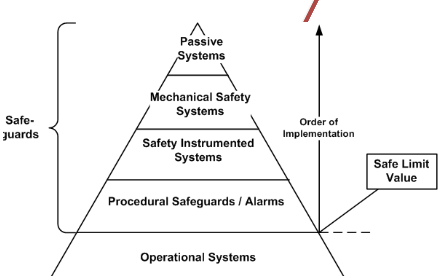
Consequences

- Personnel injury.
- Environmental damage.
- Equipment damage.
- Property loss.
- Extended downtime.
- Operability/Quality problems.

Safeguards

- Facilities that help to reduce the occurrence frequency of the deviation or to mitigate its consequences. There are five types of safeguards that:
- Safeguards may include:
  - Equipment design.
  - Instrumentation (control, alarm and shutdown).
  - Pressure relief devices.
  - Administrative procedures.
- Only list those instrument systems that have at least an alarm as a safeguard.
- Control instrumentation must automatically correct or mitigate a process deviation.
- Operator training and administrative procedures should be listed provided they are part of Operational Data Management System (ODMS).

Types of Safeguards



- Identify the deviation:
- Compensate for the deviation:
- Prevent the deviation from occurring:
- Prevent further escalation of the deviation:
- Relieve the process from the hazardous deviation.

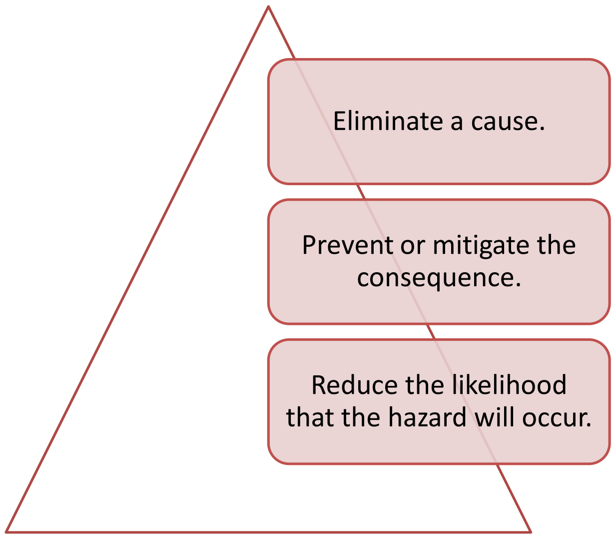
ACTIONS

- POSSIBLE but PRACTICAL things that could be done to PREVENT the problem or REDUCE its effects.
- Team may decide if any new action is needed.
- Can record any protective devices or alarms which become active e.g. PSV's.
- Can refer decision outside the team.
- Can refer serious consequences for "consequence analysis".
- MUST NOT REDESIGN THE PLANT in the Hazop study session!!
  - Fit an instrument to detect deviation
  - Clear the area of sources of ignition
  - Have emergency equipment ready

Decisions

- Following a HAZOP, decisions must be taken, perhaps:
  - Not to do it that way at all.
  - Modify the equipment.
  - Modify the procedure.
  - Go ahead – it seems OK.
  - Further serious consideration (money?)

Recommendations



Recommendations Examples

Equipment/instrumentation changes/additions (retrofitting or revamping).	Further study needed.	Inspection and maintenance.
Training.	Administrative systems to manage hazards.	Verification of design assumptions.

Implementation of Recommendations

- The following guidelines are suggested for the :
  - High priority action items should be resolved within 4 months.
  - Medium priority action items should be resolved within 4-6 months.
  - Lower priority action items should be resolved following medium priority items.
- Recommendations include **design**, **operating** or **maintenance** changes that reduce or eliminate Deviations, Causes and/or Consequences.

PROBABILITY					
A Very Likely	HIGH	HIGH	HIGH	Medium	Low
B Likely	HIGH	HIGH	Medium	Medium	Low
C Possible	HIGH	Medium	Medium	Medium	Low
D Unlikely	Medium	Medium	Medium	Low	Low
E Very Unlikely	Low	Low	Low	Low	Low
CONSEQUENCE	1	2	3	4	5
Human	Death or Multiple Major Injuries	Multiple Serious Injuries	Single Serious Casualty	Minor Injuries	No Injury Likely
Production	3 day or more shutdown	1 to 3 days shutdown	Reduced capacity	Short interruption	Minor disturbance
Reputation	Major Loss	Some Loss			

Merits and Demerits of HAZOP

Merits	De-merits
1. Helpful when confronting hazards that are difficult to quantify a) Hazards rooted in human performance and behaviours. b) Hazards that are difficult to detect, analyse, isolate, count, predict, etc. c) Methodology doesn't force you to explicitly rate or measure deviation probability of occurrence, severity of impact, or ability to detect. 2. Built-in brainstorming methodology. 3. Systematic & comprehensive methodology. 4. More simple and intuitive than other commonly used risk management tools.	1. No means to assess hazards involving interactions between different parts of a system or process. 2. No risk ranking or prioritization capability.. ❑ Teams may optionally build-in such capability as required 3. No means to assess effectiveness of existing or proposed controls (safeguards). ❑ May need to interface HAZOP with other risk management tools for this purpose

EXAMPLE

A5.1 BACKGROUND

This example is based upon the HAZOP study of a planned modification of an existing process operation (Figure A5.1).

An intermediate storage tank (IST) receives a C_6 hydrocarbon stream (averaging 25 m^3/hour) from the reflux drum of an atmospheric pressure distillation column, run down on exit level control via the reflux pumps into the 250 m^3, nitrogen-blanketed tank. This conical-roofed tank serves as a buffer and temporary storage for the material before the C_6 material is pumped by the J1 centrifugal pump, on level control, to the plant petrol blending unit. The IST operates at ambient temperature and at 500 Pa on split range pressure control and is inerted by nitrogen from the 1.3 bar site nitrogen supply. The tank is protected by a pressure (vacuum) valve (PV) set at −250/ + 750 Pa. It is in a bunded enclosure with an overflow, sealed with glycol, which empties into the bund. There is adequate instrumentation, including level indication with high- and low-level alarms and high-level trip plus temperature and pressure indication, all to the site control room.

Crawley and Tyler , HAZOP: Guide to Best Practice, 3rd Edition, 2015, Elsevier.

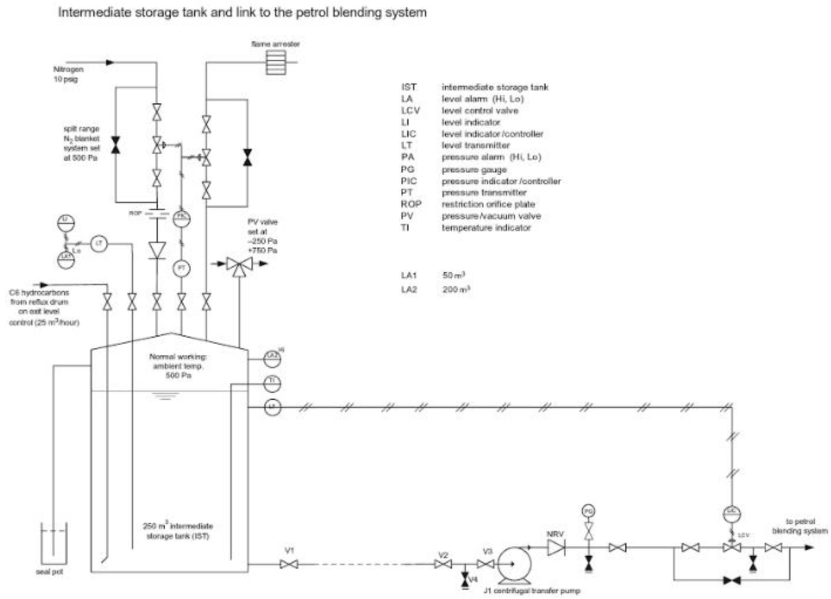


Figure A5.1 P&ID for the existing process.

A5.2 DETAILED PROPOSED SEQUENCE

The operation will be carried out by an operator stationed near J1 who will be the lead operator and a second operator, in radio communication, at the tank to operate valve V1. The lead operator will control the procedure.

The initial set-up is for all valves V1–V6 closed and with the line between V1 and V2 containing C_6 liquid.

1. Open V6 then open V5 to prove line clear of debris and to displace any air in the hose.
2. Close V6 then open V4.
3. The operator at the J1 pump should open V2 slowly until fully open.
4. The operator at the tank is then instructed to open V1 slowly by one or two turns.
5. The operator at V1 should wait until nitrogen is heard passing through the valve into the IST then the tank operator will close V1.
6. The tank operator should then cautiously reopen V1 by one or two turns to ensure as much liquid as possible has been blown back to the IST.
7. Close V4.
8. Close V1 after allowing any residual N_2 in the line to depressure into IST.
9. Pump-based operator to close V2.
10. Close V5.
11. Verify V2, V4, and V5 are all closed.
12. Open V6 to depressurize the line.
13. Disconnect the hose at V4.

HAZOP study team

- Mike Manchester (MM) Facilitator and Scribe
- Brenda Bolton (BB) Production Manager
- Sandy Southport (SS) Senior Operator
- Wally Wigan (WW) Safety Officer

Division into nodes

Node 1

- Steps 1–2: Connect and prove the nitrogen supply. V5–V6.
- Design intention: To prove that the N_2 supply is fitted and to displace any air in the hose.

Node 2

- Steps 3–9: Clear the line by blowback to IST. V5–V1.
- Design intention: To completely clear petroleum feedstock from the 100 m line between the J1 pump and the IST by blowback to the IST using N_2 from the 1.3 barg nitrogen ring main via a temporary connection fitted to an existing drain by the J1 pump. Manual control by operators positioned at each end of the line. After the main clearance, a brief second flush will be applied.

Node 3

- Steps 10–13: Depressurize and disconnect. V1–V6.
- Design intention: Line previously containing C_6 but now containing N_2 to be depressured.

Node 4

- V3-J1-LCV: Line to petrol blending (not completed).

Guide words:

- Out of Sequence—too early, too late
- Rate—too fast, too slow
- Magnitude—more, less
- Pressure—more
- Communication
- Reverse
- Incomplete
- Other

Table A5.2 HAZOP study report for node 2 (to be read in conjunction with figures A5.1 and A5.2)

Steps 3–9: Clear the line by blowback to IST. V5–V1.
Design intention: To completely clear petroleum feedstock from the 100 m line between the J1 pump and the IST by blowback to the IST using N_2 from the 1.3 barg nitrogen ring main via a temporary connection fitted to an existing drain by the J1 pump. Manual control by operators positioned at each end of the line. After the main clearance a brief second flush will be applied.
Status: As at end of Node 1.
Attendees: MM, BB, SS, and WW.

Date 2/1/15.

Ref. No.	Guideword	Effect	Cause	Consequence	Safeguards	Actions	On
2.1	Out of sequence Too early (valve operation)	N_2 flow out of V6	V6 left open	N_2 losses	Valve labeling and practice	2.1.1. Obvious, take corrective action on V6	BB*
		Possible release of C_6 at V6	Human factors. V6 opened and V1 and V2 opened for displacement. V5 not yet opened	Environmental impact and possible fire	Valve labeling and practice	2.1.2. See 1.5.1 and 15.2	BB
2.2	Too late (valve operation)	N_2 in next (downstream) operation	V2 not open, V3 left open	None		2.2 Action to be corrected	BB
						See 1.3	
2.3	Out of sequence	C_6 released from V6	V1 and V2 open, V6 left open, and V5 closed	Environmental impact and possible fire	Valve labeling and practice	2.3.1 Consider the need for an NRV at the N_2 side of V4	BB
						2.3.2 Review how this operation should be supervised. This part of the procedure should have "one on one" supervision. See 1.5.2	WW
2.4	Too fast (valve opening)	V5 too far open	Human factors	Possible overpressure of IST due to high N_2 flow	PRV on IST	2.4.1 Assess the capacity of IST PRV against blow by	BB*
	More flow pressure—more in IST		Poor understanding of operation	As above		2.4.2 Consider the need for a flow restrictor in N_2 supply	BB*
	Magnitude (more than two turns on V1)	More N_2 flow into IST	Poor understanding of operation	As Above		2.4.3 If a flow restrictor is inserted how will it be controlled as it is now a "Safety Critical Item"?	BB*

(*Continued*)

Table A5.2 (Continued)

Ref. No.	Guideword	Effect	Cause	Consequence	Safeguards	Actions	On
2.5	Too slow (valve V5 opening) Low flow N_2 and C_6	C_6 not displaced	No true indication of N_2 flow rate	Slower displacement of C_6 due to N2 "slippage"—wavy flow may result in limited C_6 removal	None	2.5.1 The flow of C_6 will not necessarily be plug flow. In what two-phase flow regime is the displacement expected to operate?	BB*
						2.5.2 How can the regime be controlled?	BB*
2.6	More flow N_2 High flow	See 2.4 and 2.5	See 2.4	See 2.4	See 2.4	2.6.1 See 2.5.1 2.6.2 See 2.5.2 2.6.3 See 2.4.2/2.4.3	BB* BB* BB*
2.7	Incomplete	C_6 left in line	Line not true, hogs and hollows plus elevation changes	Some C_6 trapped in the line at the end of the final blow through. Environmental impact and possible fire	None obvious	2.7.1 Check the line slope and sags 2.7.2 Is there too much line distortion to make the blow out viable? A site visual check should be carried out	BB BB
2.8	Reverse flow of C_6	C_6 released from V6	V6 left open and V5 closed at the end of cycle. Some C_6 still in the line	Environmental impact and possible fire	Valve labeling and practice	As 2.3.1	BB
2.9	Communication	As above	As above	As above	Valve labeling and practice	2.9.1 Review how this operation should be supervised How long might it take?	BB*
		Misinterpretation	Human factors What is the significance of a change in the noise? What will it sound like?	Wavy flow may produce a sound like gas passing into the IST.		2.9.2 Ensure the operators are trained in the use of radios	BB*
						2.9.3 Review this parameter. Is it really safe for operation and a credible control parameter?	BB*

(*Continued*)

Table A5.2 (Continued)

Ref. No.	Guideword	Effect	Cause	Consequence	Safeguards	Actions	On
2.10	Communication	As above Possible source of ignition	Misunderstanding of the point in the sequence without a clear lead operator Misunderstanding of the point in the operation due to poor radio protocol Radios not compatible with Hazardous Area Classification	Possible upset not easy to define As above Possible fire (remote possibility)	Lead operator is specified in the procedure	2.10.1 Ensure that one operator is clearly the lead operator controlling the actions and the other takes instructions from the leader 2.10.2 Ensure that the operators are competent in the use of radios and language protocol 2.10.3 Verify that the radios are compatible with the area classification	BB WW WW
2.11	Incomplete	Possible reverse flow from IST during the step 8 depressuring cycle	Hydrostatic head in IST	Live V1−V2 is recontaminated with C_6 Possible environmental impact and fire during final blow down through V6	None	2.11.1 Consider closing V1 IMMEDIATELY the gas flow is detected and then depressure via V6 2.11.2 Review the operation step 8 in the procedure. Is it viable?	BB BB
	Other guidewords	No effects identified					

Table A5.3 HAZOP study report for node 2, final blow through, steps 6−9 (to be read in conjunction with figures A5.1 and A5.2)

(Immediate continuation of node 2 after first nitrogen flush of the line, i.e., completion of step 5.)
Status: As at the end of main blow through. V1, V3, and V6 closed; V2, V4, and V5 open.
Team/date as Table A5.2.

Ref. No.	Guideword	Effect	Cause	Consequence	Safeguards	Actions	On
2.12	Less flow Incomplete	Line V1−V2 incompletely cleared. C_6 still in line	Flow regime uncertain and line slopes uncertain	Significant final C_6 left in line which has to be drained. Environmental impact and risk of fire	None	2.7 (see 2.5.1 and 2.5.2; 2.6.1 and 2.6.2)	BB
2.13	More flow (N_2) (V5 too far open) (See 2.3)	V5 too far open	Human factors Poor understanding of operation	Possible overpressure of IST	PRV on IST	2.12.1 Assess the capacity of IST PRV against blow-by. See 2.4.1 2.12.2 Consider the need for a flow restrictor in N_2 line. See 2.4.2 2.12.3 If a flow restrictor is inserted how will it be controlled as it is now a "Safety Critical Item"? See 2.4.3	BB* BB* BB*
2.14	Communication	C_6 still in line. Could result in a major spill later in the process	"Sound" is the only variable. What will it "sound like"?	Environmental impact and possible fire if incompletely drained	None	See 2.5 and 2.9.3 Review this parameter. Is it really safe for operation?	BB
	No other differences between first and final clearing						

at the bottom of the line, and this will not necessarily be the low point—there could be "hogs and hollows" in the line especially if it slopes to the pump J1. A foam pig would pass the fully open gate valve V2 and be stopped by the partially open gate valve V1 (open one or two turns). This method would give a more complete line clearance and so a pig run may be preferable.

The objective of this exercise was to demonstrate the use of HAZOP in a procedure, but it has produced more issues than expected! This shows the strength of HAZOP.

شكرا لحسن ألاستماع

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