Hazard and Operability (HAZOP) Study
HAZOP Fundamental
A scenario...

- You and your family are on a road trip by using a car in the middle of the night. You were replying a text message while driving at 100 km/h and it was raining heavily. The car hits a deep hole and one of your tire blows. You hit the brake, but due to slippery road and your car tire thread was thin, the car skidded and was thrown off the road.
Points to ponder (Thinkers)

What is the cause of the accident?

What is the consequence of the event?

What can we do to prevent all those things to happen in the first place?

(5 minutes for brainstorming ideas)
What other possible accidents might happen on the road trip?

Can we be prepared before the accident occurs?
Can we make it more systematic?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Guideword</th>
<th>Possible Causes</th>
<th>Consequences</th>
<th>Action</th>
<th>Safeguard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car speed</td>
<td>Too fast</td>
<td>Rushing</td>
<td>Skidded when emergency brake</td>
<td>- Slow down</td>
<td>- ABS brake system</td>
</tr>
<tr>
<td></td>
<td>Too slow</td>
<td></td>
<td></td>
<td>- Speed up</td>
<td>- Safety belt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Air bag</td>
</tr>
<tr>
<td>Tire</td>
<td>No thread</td>
<td>Tire too old, often speeding and emergency break</td>
<td>Car skidded</td>
<td></td>
<td>- Check frequently</td>
</tr>
<tr>
<td></td>
<td>Less thread</td>
<td></td>
<td></td>
<td></td>
<td>- Have spare tire</td>
</tr>
<tr>
<td>Window visibility</td>
<td>Low</td>
<td>Rain</td>
<td>Cannot see the road</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car light</td>
<td>Dim</td>
<td></td>
<td></td>
<td>- Stop car</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No light</td>
<td></td>
<td></td>
<td>- Go to nearest garage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Use emergency signal</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>With holes</td>
<td></td>
<td>Breaks the car tire</td>
<td></td>
<td>- Put a signboard</td>
</tr>
<tr>
<td></td>
<td>Rocky</td>
<td></td>
<td></td>
<td></td>
<td>- Street lights</td>
</tr>
<tr>
<td>Travel time</td>
<td>Night</td>
<td>No street light</td>
<td></td>
<td></td>
<td>- Travel during daylight</td>
</tr>
</tbody>
</table>
What is HAZOP?

- Systematic technique to IDENTIFY potential HAZard and OPERating problems
- A formal systematic rigorous examination to the process and engineering facets of a production facility
- A qualitative technique based on “guide-words” to help provoke thoughts about the way deviations from the intended operating conditions can lead to hazardous situations or operability problems
- HAZOP is basically for safety
  - Hazards are the main concern
  - Operability problems degrade plant performance (product quality, production rate, profit)
- Considerable engineering insight is required - engineers working independently could develop different results
Origin of HAZOP

• Initially prepared by Dr H G Lawley and associates of ICI at Wilton in 1960’s.(UK)
• Subsequently C J Bullock and A J D Jenning from ChE Dept. Teeside Polytechnic under supervision of T.A. Kletz applied the method at higher institution (post-graduate level).
• In 1977, Chemical Industries Association published the edited version.
Later Development - HAZOP

• ICI expanded the procedure called HAZARD STUDY steps 1 to 6.
• The ICI six steps:
  STEP 1: Project exploration / preliminary project assessment
to identify inherent hazards of process chemicals, site
suitability and probable environmental impact.
  SREP 2: Project definition – to identify and reduce significant
hazards associated with items and areas, check
conformity with relevant standards and codes of
practices.
  USE CHECK LISTS
STEP 3: **Design and procurement** – to examine the PID in detail for identification of deviations from design intent capable of causing operability problems or hazards.

STEP 4: **During final stages of construction** – to check that all recommended and accepted actions recorded in steps 1, 2 and 3 implemented.

STEP 5: **During plant commissioning** – to check that all relevant statutory requirements have been acknowledges and all installed safety systems are reliably operable.
STEP 6: During normal operation, some time after start-up – especially if any modification been made. To check if changes in operation has not invalidated the HAZOP report of step 3 by introducing new hazards.

This procedures are adopted fully or partly by many companies around the world.
PRINCIPLE of HAZOP

Concept

• Systems work well when operating under design conditions.
• Problems arise when deviations from design conditions occur.

Basis

• a word model, a process flow sheet (PFD) or a piping and instrumentation diagram (P&ID)

Method

• use guide words to question every part of process to discover what deviations from the intention of design can occur and what are their causes and consequences may be.
How and Why HAZOP is Used

<table>
<thead>
<tr>
<th>GUIDE WORDS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>NONE</td>
</tr>
<tr>
<td>MORE OF</td>
</tr>
<tr>
<td>LESS OF</td>
</tr>
<tr>
<td>PART OF</td>
</tr>
<tr>
<td>MORE THAN</td>
</tr>
<tr>
<td>OTHER</td>
</tr>
</tbody>
</table>

CAUSE                       DEVIATION (from standard condition or intention)   CONSEQUENCES (trivial, important, catastrophic)
- hazard
- operating difficulties

*COVERING EVERY PARAMETER RELEVANT TO THE SYSTEM UNDER REVIEW:
i.e. Flow Rate. Flow Quantity, Pressure, Temperature, Viscosity, Components
**STUDY NODES**

The locations (on P&ID or procedures) at which the process parameters are investigated for deviations. These nodes are points where the process parameters (P, T, F etc.) have an identified design intent.

**INTENTION**

The intention defines how the plant is expected to operate in the absence of deviations at the study nodes.

**DEVIATIONS**

These are departures from the intension which can be discovered by systematically applying the guide words.

- Process conditions
- activities
- substances
- time
- place
HAZOP - Hazard and operability

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

\[ 1 + 1 = 3 \]

**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 know a safe “normal” operation.*
HAZOP - Hazard and operability

NODE: Pipe after pump and splitter

PARAMETER*: Flow rate

GUIDE WORD*: Less (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

A group members focus on the same issue simultaneously
Question: How can one be certain to identify all possible deviations?

Answer: No absolute certainty as the study is subjective and 100% achievement in this context can have no significance. Any individual or corporate effort will yield results directly proportional to the appropriate background experience of those taking part.

However, with the appropriate levels of individual project-related expertise, such a procedure is fully capable of identifying at least 80% of potential deviations which could rise during normal operation.
### Features of HAZOP Study

| Subsystems of interest | line and valve, etc  
<table>
<thead>
<tr>
<th></th>
<th>Equipment, Vessels</th>
</tr>
</thead>
</table>
| **Modes of operation** | Normal operation  
|                        | Start-up mode  
|                        | Shutdown mode  
|                        | Maintenance /construction / inspection mode |
| **Trigger events**     | Human failure  
|                        | Equipment /instrument/component failure  
|                        | Supply failure  
|                        | Emergency environment event  
|                        | Other causes of abnormal operation, including instrument disturbance |
# Features of HAZOP Study

<table>
<thead>
<tr>
<th>Effect</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effects within plant</strong></td>
<td>Changes in chemical conditions&lt;br&gt;Changes in inventory&lt;br&gt;Change in chemical physical conditions</td>
</tr>
<tr>
<td><strong>Hazardous conditions</strong></td>
<td>Release of material&lt;br&gt;Changes in material hazard characteristics&lt;br&gt;Operating limit reached&lt;br&gt;Energy source exposed etc.</td>
</tr>
<tr>
<td><strong>Corrective actions</strong></td>
<td>Change of process design&lt;br&gt;Change of operating limits&lt;br&gt;Change of system reliability&lt;br&gt;Improvement of material containment&lt;br&gt;Change control system&lt;br&gt;Add/remove materials</td>
</tr>
</tbody>
</table>
## Features of HAZOP Study

<table>
<thead>
<tr>
<th>How would hazardous conditions detected?</th>
<th>During normal operation</th>
<th>Upon human failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>During normal operation</td>
<td>Upon human failure</td>
</tr>
<tr>
<td></td>
<td>Upon component failure</td>
<td>In other circumstances</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contingency actions</th>
<th>Improve isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Improve protection</td>
</tr>
</tbody>
</table>
Documents Needed for HAZOP Study

- **For Preliminary HAZOP**
  - Process Flow Sheet (PFS or PFD)
  - Description of the Process

- **For Detailed HAZOP**
  - Piping and Instrumentation Diagram (P & ID)
  - Process Calculations
  - Process Data Sheets
  - Instrument Data Sheets
  - Interlock Schedules
  - Layout Requirements
  - Hazardous Area Classification
  - Description of the Process
P&ID and Safety

- P&I Diagram
  - ISA Standard
  - DIN Standard

- Layers of protection
HAZOP Study Procedure

• Procedure in HAZOP study consist of examining the process and instrumentation (P&I) line diagram, process line by process line.

• A list of guide words is used to generate deviations from normal operation corresponding to all conceivable possibilities.

• Guide words covering every parameter relevant to the system under review: i.e. flow rate and quality, pressure, temperature, viscosity, components etc.

• Flowchart for application of HAZOP is shown in figure.
HAZOP Study Flow Chart

1. Select Line
2. Select deviation e.g. more flow
3. Is more flow possible
   - Is it hazardous or does it prevent efficient operation?
   - Will the operator know that there is more flow?
      - What changes in plant or method will prevent the deviation or make it less likely or protect against the consequences?
      - What change in plant will tell him?
      - Consider other causes of more flow
4. Consider other change(s) or agreed to accept hazard
5. Is the cost of the change justified?
6. Agree change(s) Agree who is responsible for action
7. Follow up to see action has been taken
8. Move on to next deviation

HAZOP Study Procedure

GUIDE WORDS *

POSSIBLE CAUSES

DEVIATION (FROM DESIGN AND/OR OPERATING INTENT)

CONSEQUENCES

ACTION(S) REQUIRED OR RECOMMENDED
# Guide Words

<table>
<thead>
<tr>
<th><strong>NONE</strong></th>
<th>No forward flow when there should be</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MORE</strong></td>
<td>More of any parameter than there should be, e.g. more flow, more pressure, more temperature, etc.</td>
</tr>
<tr>
<td><strong>LESS</strong></td>
<td>As above, but &quot;less of&quot; in each instance</td>
</tr>
<tr>
<td><strong>PART</strong></td>
<td>System composition difference from what it should be</td>
</tr>
<tr>
<td><strong>MORE THAN</strong></td>
<td>More &quot;components&quot; present than there should be for example, extra phase, impurities</td>
</tr>
<tr>
<td><strong>OTHER</strong></td>
<td>What needs to happen other than normal operation, e.g. start up, shutdown, maintenance</td>
</tr>
</tbody>
</table>
NONE

E.g., NO FLOW caused by blockage; pump failure; valve closed or jammed; leak; valve open; suction vessel empty; delivery side over-pressurized; vapor lock; control failure

REVERSE

E.g., REVERSE FLOW caused by pump failure; NRV failure or wrongly inserted; wrong routing; delivery over pressurized; back-siphoning; pump reversed

MORE OF

E.g., MORE FLOW caused by reduced delivery head; surging; suction pressurised; controller failure; valve stuck open; leak; incorrect instrument reading.
Guide Words

MORE OF MORE TEMPERATURE, pressure caused by external fires; blockage; shot spots; loss of control; foaming; gas release; reaction; explosion; valve closed; loss of level in heater; sun.

LESS OF e.g., LESS FLOW caused by pump failure; leak; scale in delivery; partial blockage; sediments; poor suction head; process turndown.

LESS e.g., low temperature, pressure caused by Heat loss; vaporisation; ambient conditions; rain; imbalance of input and output; sealing; blocked vent.

PART OF Change in composition high or low concentration of mixture; additional reactions in reactor or other location; feed change.
MORE THAN

Impurities or extra phase Ingress of contaminants such as air, water, lube oils; corrosion products; presence of other process materials due to internal leakage; failure of isolation; start-up features.

OTHER

Activities other than normal operation start-up and shutdown of plant; testing and inspection; sampling; maintenance; activating catalyst; removing blockage or scale; corrosion; process emergency; safety procedures activated; failure of power, fuel, steam, air, water or inert gas; emissions and lack of compatibility with other emission and effluents.
<table>
<thead>
<tr>
<th>DEVIATION</th>
<th>CAUSES</th>
<th>CONSEQUENCES</th>
<th>EXISTING PROVISIONS</th>
<th>ACTIONS, QUESTIONS OR RECOMMENDATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HAZOP study are applied during:

- Normal operation
- Foreseeable changes in operation, e.g. upgrading, reduced output, plant start-up and shut-down
- Suitability of plant materials, equipment and instrumentation
- Provision for failure of plant services, e.g. steam, electricity, cooling water
- Provision for maintenance.
Strength of HAZOP

- HAZOP is a systematic, reasonably comprehensive and flexible.
- It is suitable mainly for team use whereby it is possible to incorporate the general experience available.
- It gives good identification of cause and excellent identification of critical deviations.
- The use of keywords is effective and the whole group is able to participate.
- HAZOP is an excellent well-proven method for studying large plant in a specific manner.
- HAZOP identifies virtually all significant deviations on the plant, all major accidents should be identified but not necessarily their causes.
Weakness of HAZOP

• HAZOP is very time consuming and can be laborious with a tendency for boredom for analysts.

• It tends to be hardware-oriented and process-oriented, although the technique should be amenable to human error application.

• Difficulty in identifying important deviations and consideration of multiple, compound and repeated deviations.

• Limitations of guide words

• HAZOP does not identify all causes of deviations and therefore omits many scenarios.
Weakness of HAZOP

• It has difficulties in focusing on specific HAZARD types.
• It tends to assume defects or deterioration of materials of construction will not arise.
• Challenges in addressing chemical reactivity hazards and process changes. It tends to ignore the contribution which can be made by operator interventions.
HAZOP - Hazard and Operability

ATTITUDE CHECK

All of these terms! This stupid table! I hate HAZOPS. Why don’t we just learn the engineering?
I suppose that I should have done that HAZOP Study!
HAZOP - Hazard and Operability

You are responsible for the safety team.

Without HAZOP

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

What is required?

• Define objectives and scope - define scope of work.
  • To new design - applied to a detailed design.
  • To existing design - identify hazards not previously identified probably because not being HAZOPED.
  • To plant modification

• Select team members. Two types of person needed:
  • Detailed technical knowledge of the process.
  • Those with knowledge and experience of applying highly structured, systematic HAZOP approach.
Planning for HAZOP

- Prepare for the study. Need sufficient information:
  - Process Flow Sheet (PFS or PFD)
  - Piping and Instrumentation Diagram (P & ID)
  - Process Calculations
  - Process Data Sheets
  - Instrument Data Sheets
  - Interlock Schedules
  - Layout Requirements
  - Hazardous Area Classification
  - Operating instructions
Planning for HAZOP

• Prepare for the study. Need sufficient information:
  • Safety procedures documents
  • Relief/venting philosophy
  • Chemical involved
  • Piping specifications
  • Previous HAZOP report
Planning for HAZOP

• Carry out the study
• Record the results (may need a secretary)
• Follow-up of actions noted
  – final report contain resolution of all recommended actions
  – must appoint someone as leader to check progress of action
  – team may meet again if answers to questions do not simply lead to an action
  – team may meet again if significant design changes in interim report
- Members share common objectives.
- Everybody contributes and knows his/her roles, not leader dependent too much.
- Each members values and respects contribution of others.
- Members learn while they work.
- Over a period of time, individual contribution level are more or less equal.
- Disagreement are worked through by discussion.
- The use of voting procedures is sparing and normally only last resort if highly necessary.
- Members enjoy team meetings.
Questioning Techniques

• Open questions
  – Help person being asked to think – use words how, what and why.

• Closed questions
  – To focus on an issue or problem. Start with words who, when, where.
  – Required answer yes or no only.

• Question mix
  – Mix between open and closed questions.
Questioning Techniques

- Things to avoid
  - Ambiguous or vague questions.
  - Double barrelled/multiple questions.
  - Long complicated questions.
  - Interrogation type of questions.
  - A loaded questions – implied judgement.
Responsibility of HAZOP Team Members

HAZOP leader

- Plan sessions and timetable
- Control discussion
- Limit discussion
- Encourage team to draw conclusion
- Ensure secretary has time for taking note
- Keep team in focus
- Encourage imagination of team members
- Motivate members
- Discourage recriminations
- Judge importance issues
Checklist for HAZOP Leader

- Always prepare study program in advance.
- Agree on the format or form to be used.
- Prepare follow up procedures.
- Brief members about HAZOP during first meeting.
- Stop the team trying to redesign the process.
- HAZOP is a team exercise. Do not let anybody (including the leader himself) to dominate.
Checklist for HAZOP Leader

- If conflict arises, handle with care.
- Avoid long discussions by recording areas which need to be resolved outside meeting.
- Leader must be strong, yet diplomatic.
- Speak clearly. Make you point.
- Better have experience working as team member previously.
- Do not skip anything….some time small things may cause big accident.
HAZOP STUDY - TEAM COMPOSITION

- A Team Leader, an expert in the HAZOP Technique
- Technical Members, for example

**New Design**
- Design or Project Engineer
- Process Engineer
- Commissioning Manager
- Instrument Design Engineer
- Chemist

**Existing Plant**
- Plant Superintendent
- Process Supervisor (Foreman)
- Maintenance Engineer
- Instrument Engineer
- Technical Engineer
THANKS FOR LISTENING