IST Concepts and Methodologies for Implementation

Inherently Safer Technology Workshop
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David Moore is the President and CEO of the AcuTech Consulting Group, a process risk management consulting firm based in Alexandria, Virginia. Mr. Moore has over twenty-six years of specialized experience in the field. He is a recognized expert in and frequent speaker on process safety management. He has provided risk consulting services and training to industrial companies worldwide, including at petroleum refineries, chemical plants, gas plants, pipelines, pharmaceuticals, biotech, and manufacturing plants. Mr. Moore has taught process safety and security courses for over 20 years to many of the world’s largest corporations. He has been a consultant to USOSHA, DHS, USCG, AIChE, API, USEPA, and the National Petrochemical and Refiners Association (NPRA), and the American Chemistry Council.

He is a frequent speaker on security, process safety management, human factors, and inherent safety for the petroleum and chemical industry. His firm is actively involved in chemical process security and safety consulting and training. He has provided risk consulting services and training to industrial facilities worldwide, including oil refineries, chemical plants, pipelines, and manufacturing plants. Mr. Moore has taught process safety and security courses for over 15 years to many of the world’s largest corporations. He is an instructor on process safety and security for AIChE, API, OSHA, USEPA, and the NPRA.

Mr. Moore was formerly a Senior Engineer with Mobil Corporation; and a Fire Protection Engineer with the National Fire Protection Association. He has been consulting in the industry since 1987.

Mr. Moore is a Registered Professional Engineer. He serves on the AIChE Center for Chemical Process Safety Technical Steering Committee, the CCPS Plant Security Committee, the Canadian Chemical Producer’s Association PSM Committee, and the Mary Kay O’Connor Process Safety Center at Texas A&M University. He has an MBA, (NYU-1987), and a B.Sc., Fire Protection Engineering (University of Md.-1979).
Inherent Safety Status

- **Industry:**
  - IS is gaining popularity as a process risk management strategy but is not universally practiced or documented

- **Government**
  - Recent proposed safety and security regulations are focusing on IS as a first choice strategy for risk reduction
The term inherently safer implies that the process is safer because of its very nature and not because equipment has been added to make it safer.[1]

“Inherent” Definition

- Existing as a natural or basic part of something (Cambridge Dictionary)
- Existing in something as a permanent and inseparable element, quality, or attribute (American College Dictionary)
- Involved in the constitution or essential character of something: belonging by nature or habit (Merriam Webster)
Not So Inherent Safety

Weekly Invention

Safety Device for Walking on Icy Pavements

When you slip on ice, your foot kicks paddle (A), lowering finger (B), snapping turtle (C) extends neck to bite finger, opening ice tongs (D) and dropping pillow (E), thus allowing you to fall on something soft!

Rube Goldberg (TM) RGI 100
Inherently Safer Design (ISD)

A concept of eliminating or reducing hazards to reduce risk through the application of strategic principles of:

- Minimization
- Substitution
- Moderation
- Simplification
Basic Premise of Inherently Safer Design

- It may not be feasible to completely eliminate hazards, but still can be useful to reduce hazards
- The reduction of hazards should be the first priority
- The concept should be practiced by engineers, operations, maintenance personnel, not only by safety personnel
- ISD opportunities should be analyzed at regular intervals or project milestones, and in daily decisions
- While most potent for new facilities, it is also useful and practical for existing facilities
Process safety professionals have embraced the concepts voluntarily for years; 

It is an established method for addressing process risks; 

In balance with other risk management strategies it has a significant place.
Recognized in 1970’s for chemical industry - T. Kletz, “What You Don’t Have Can’t Leak”


1980-2008 - Practiced by many leading companies

Future - More widely practiced as core business principle
Applications of Inherently Safer Design

- Applications are wide-ranging including use a corporate philosophy for reducing risks associated with:
  - Process safety
  - Environmental releases
  - Security
  - Operational upsets
  - Reliability problems
- Proven to have been feasible in some cases and to reduce potential likelihood and consequences of events
# Iherently Safer Design Strategies

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize</td>
<td>Use smaller quantities; eliminate unnecessary equipment; reduce size of equipment or volumes processed.</td>
</tr>
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<td>Replace material with a less hazardous substance.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Use less hazardous conditions, a less hazardous form of material or facilities which minimize the impact of a release.</td>
</tr>
<tr>
<td>Simplify</td>
<td>Design facilities which eliminate unnecessary complexity and make operating errors less likely.</td>
</tr>
</tbody>
</table>
### Inherent Safety Viewpoints

<table>
<thead>
<tr>
<th>Viewpoint</th>
<th>Examples</th>
</tr>
</thead>
</table>
| **Macro** | • Use alternative technology that has a lower operating pressure  
• Substitute feedstocks with less toxic substance  
• Substitute entire process |
| **Micro** | • Reduce the size of a particular vessel or line in a process  
• Use a catalyst that is less toxic  
• Simplify DCS controls |
Market-Driven Inherent Safety

SafeDeNOx® Reactor System

Overall reaction

\[(NH_2)_2CO + H2O \rightarrow CO_2\uparrow + 2NH_3\uparrow\]

Urea + water vapor  carbon dioxide + ammonia
American Institute of Chemical Engineers
Center for Chemical Process Safety
Concept Book (1996)

‘The Gold Book’
Of CCPS

Inherently Safer Chemical Processes
A Life Cycle Approach

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David G. Clark
Arthur M. Dowell III
Rodger M. Ewbank
Dennis C. Hendershot
William K. Lutz
Steven I. Meszaros
Donald E. Park
Everett D. Wixom

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AcuTech 2008
Inherent Safety Concept Book Update

- 2nd Edition to be published in mid 2008
- Update prompted by:
  - lessons learned and developments since then
  - inherently safer design (ISD) becoming more widely accepted
- Need for more guidance due to
  - new regulations with requirements for ISD
  - lack of clarity on how to practically implement
Objectives & Scope of Update

- Goal of updated book is to illustrate and emphasize merits of integrating process research, development & design into a comprehensive process balancing safety, capital, and environmental concerns throughout life cycle of process;
- Primary objective is to provide useful tool for any company to understand and employ inherent safety concepts;
- Secondary objective to provide tools and guidance on approaches to implement inherent safety.
Achievements of Updated Concept Book

- Clarified concepts with recent research;
- Introduced new concept of 1st and 2nd orders of Inherently Safer Design (ISD);
- Added examples for each ISD strategy and order;
- Included illustrations of applying ISD across entire life cycle of process;
- New and more complete inherently safer checklist;
- Practical methods of applying ISD to a process & analyzing hazards & opportunities for risk reduction (enhanced PHA methods);
- Included homeland security issues and regulatory issues.
What is Inherently Safer Technology (IST?)

“principles or techniques incorporated in a covered process to minimize or eliminate the potential for an extraordinarily hazardous substance (EHS) accident that include, but are not limited to, the following:

1. Reducing the amount of EHS material that potentially may be released
2. Substituting less hazardous materials
3. Using EHSs in the least hazardous process conditions or form
4. Designing equipment and processes to minimize the potential for equipment failure and human error”

Source: NJ Prescriptive Order 11/21/05
Accident Sequence

- Hazard
- Protective 'Barriers'
- Weaknesses Or 'Holes'
- Accident
Risk-Based Approach for Safety Risk Assessment

Step 1: Hazard Identification
Step 2: Consequence and Impact Analysis
Step 3: Likelihood Analysis
Step 4: Risk Assessment
Step 5: Mitigation Analysis
Layers Of Protection

- RESPONSE
- LIMITATION
- BARRIER
- MITIGATIVE
- PREVENTIVE
- SUPERVISORY
- CONTROL
- INHERENTLY SAFER
Process Safety Strategies

- Inherent
  - Eliminate or modify the hazard and/or risk by employing one of four strategies of substitution, minimization, moderation, simplification.

- Passive
  - Minimize the hazard by process and equipment design features which reduce either the frequency or consequences of the hazard without the active functioning of any device.

- Active
  - Using controls, safety interlocks, and emergency shutdown systems to detect and correct process deviations.

- Procedural
  - Using operating procedures, administrative checks, and emergency response to prevent incidents, or to minimize the effect of an incident.

Source: CCPS
## Inherently Safer Technology Strategies

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Inherently Safer Design Strategies

- Minimize
- Substitute
- Moderate
- Simplify

Source: Fig 2.2, CCPS Concept Book
Substitution

- Substitute a less hazardous reaction chemistry
- Replace a hazardous material with a less hazardous alternative
Minimization

- Use small quantities of hazardous substances or energy
  - Storage
  - Intermediate storage
  - Piping
  - Process equipment
Moderation

Reduce temperatures or pressures

- Dilution
- Refrigeration
- Less severe processing conditions
- Physical characteristics
- Containment
  - Better described as “passive” rather than “inherent”
Simplification

- Eliminate unnecessary complexity to reduce risk of human error

**QUESTION ALL COMPLEXITY!**

Is it really necessary?
Which Strategy Should We Use?

- Generally, in order of robustness and reliability:
  - Inherent
  - Passive
  - Active
  - Procedural

- But - there is a place and need for ALL of these strategies in a complete safety program
Figure 1: Inherently Safer Approach to Analyzing & Managing Process Risks

ACTIVITIES

1. Identify hazards and assess risk against risk management objectives. If necessary to further reduce risk, apply Steps 2-4.

2. Apply inherently safer strategies to the hazards and design of the entire plant

3. Apply inherently safer strategies to the design of layers of protection

STEPS

AVOID HAZARDS

REDUCE SEVERITY

REDUCE LIKELIHOOD

APPLY PASSIVE SAFEGUARDS

2. a. Eliminate the hazards altogether

2. b. Reduce the absolute magnitude of severity or impacts of an incident

2. c. Reduce the likelihood of an incident or escalation of an incident

3. a. Use passive safeguards for prevention, protection, and mitigation
Figure 1 - Continued

3. Apply inherently safer strategies to the design of layers of protection
   3. a. Use passive safeguards for prevention, protection, and mitigation
   3. b. Use active safeguards for prevention, protection, and mitigation
   3. c. Use procedures for prevention, protection and mitigation

4. Iterate through inherent safety and layers of protection safeguards until risks are tolerable per objectives in Step 1.

Inherent Safety (IS)  1st order IS  2nd order IS  Layers of Protection

APPLY PASSIVE SAFEGUARDS

APPLY ACTIVE SAFEGUARDS

APPLY PROCEDURAL SAFEGUARDS

CONSIDER HAZARDS & RISKS UNTIL GOALS ARE MET
Inherently Safer Technology (IST)
First v. Second Order

- First order is a change resulting in the highest degree of risk reduction possible by employing the strategy
  - For example, elimination of a material from site with no need for substitution

- Second order is anything less than that and varies in level of risk reduction
  - Substitution of one material for a ‘more inherently safe’ material – still have a consequence, just reduced or different
  - Minimization, but not complete elimination
Example of Minimization

Eliminating 750 tons of liquid Cl2
Figure 1: Original batch reaction system (Carrithers, Dowell and Hendershot)
Figure 2: Modified, Inherently Safer Batch Reactor System

(Carrithers, Dowell and Hendershot)
Inherently Safer Technology (IST) – What It Is and Isn’t

- It is not a ‘Technology’ necessarily
- It could be a reduction in materials onsite using the same technology
- It could be a procedure that is simplified in the broadest definition of IS
- If the technology is to be changed the economics often aren’t favorable for changing existing plants
Chemical Security and Inherent Safety

- New appreciation of intentional acts against hazardous materials
- Public concerns increased
- Cases not previously considered credible are being expected
- Pressure for regulation and action
- Some changes are reasonable and sensible, some are unreasonable
Strategies:
- Consideration or implementation of inherently safer processes to entertain or mandate IST
- Reducing consequences through changing inventories, substitution, or changing production methods and processes
- Avoidance of hazards by rerouting of transported materials (DC Rail)
- Employing inherently safer technologies in the manufacture, transport, and use of chemicals
Proof of Application:
  – Proving most inherently safe ‘system’
  – Proving each hazard is made inherently safe
Public Perception of Inherent Safety

- Often inherent safety is seen as ‘obvious’ and ‘common sense’ when in reality the big picture may not be that simple.

- Risk-risk tradeoffs can have unfortunate results if not properly evaluated.
Inherently Safer Technology (IST) and Security – What It Is and Isn’t

- IST may be useful for reducing consequences of an intentional act but:
  - It may not address the reduction of vulnerability – consequence reduction only
  - It may be less secure – transportation
  - Other security methods may be more cost effective – and lower vulnerabilities more effectively
Priorities to inherent safety may mean compromises elsewhere.

Efforts to reduce risks often neglect the possibility that measures to reduce the “target risk” may introduce or enhance “countervailing risks.”
Holistic Approach

- We need to consider risk management interventions, not a single risk reduction strategy alone.
IST Timing and Costs

- IST best implemented at research/design stages - lower costs may be possible
- IST reviews normally incorporated into PHA for existing facilities
- Costs of implementing changes vary widely with the issue and possible solutions identified
I inherently safer is in the context of one or more of the multiple hazards
- There may be conflicts
- Example - CFC refrigerants
  - low acute toxicity, not flammable
  - potential for environmental damage, long term health impacts
Are they inherently safer than alternatives such as propane (flammable) or ammonia (flammable and toxic)
Multiple Impacts

Different populations may perceive the inherent safety of different technology options differently

- Example - chlorine handling - 1 ton cylinders vs. a 90 ton rail car
- What if you are a neighbor two miles away?
  - Most likely would consider the ton cylinder inherently safer
- What if you are an operator who has to connect and disconnect cylinders 90 times instead of a rail car once?
  - Most likely would consider the rail car inherently safer
Inherent Safety Challenges

Focus on IS as a ‘panacea’ is not effective and regulating it is problematic:
- IS may conflict with other goals – even safety
- Risk: Risk tradeoffs may be worse
- Inherent Safety is not always an objective decision
- Neither industry nor government are clear on how to regulate it fairly and adequately
- Regulation may limit application of IS
  - need to study every suggestion and documentation
  - snapshot studies vs. ‘way of doing business’
Limitations of Inherently Safer Systems

- For example, changing to a “just-in-time” inventory system could increase shipments to a facility, thereby increasing the risk associated with transportation.

- In certain cases, it may not be feasible to create an inherently safer system especially at a macro level.
Broad vs Narrow Definition of Inherent Safety

- Inherent Safety can apply at different levels:
- Macro viewpoint –
  - A more strategic viewpoint for community
  - Consideration of overall societal risk
  - What is the best option for the community/society/nation?
Broad vs Narrow Definition of Inherent Safety

- Micro viewpoint –
  - A more tactical, company or site viewpoint
  - Inherent safety decisions focused on reducing risks to a particular site
  - Not necessarily consistent or beneficial to society as a whole.
Means to Institutionalize IS

- Policy and procedure
  - Management commitment, accountability
  - Policy, procedures encouraging IS
  - Principles, goals and incentives
  - Auditing protocols

- Practical tools to facilitate IS
  - Checklists
  - Analytical methods
    - Independent/dedicated
    - Integrated during routine activities
  - Indices
Possible IST Review Team Members

- Facilitator/Scribe
- Process Engineering or Technologist
- Design Engineering
- Operations
- Maintenance
- EHS
- Security
IST Review Methodology

For each covered process:
- Identify IST improvements already made
- Review existing PHA recommendations for IST opportunities
- For each IST checklist item, identify:
  - Current status (including N/A, IST implemented, or existing PHA recommendation)
  - Any recommendations/followup
  - Responsible person for followup
  - Resolution including completion or rationale for rejection
## Life Cycle Timing for IS Analysis for New Processes

<table>
<thead>
<tr>
<th>Project Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Chemistry forming (synthesis) phase</td>
</tr>
<tr>
<td>- Facilities design scoping and development</td>
</tr>
<tr>
<td>- Basic design phase</td>
</tr>
</tbody>
</table>
## Life Cycle Timing for IS Analysis for Existing Processes

<table>
<thead>
<tr>
<th>Project Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modification</td>
</tr>
<tr>
<td>Operating</td>
</tr>
<tr>
<td>Decommissioning</td>
</tr>
</tbody>
</table>
Recommendations

- IS should be promoted as a way of doing business
- Develop methods to measure various inherent safety options – risk matrix
- Develop guidance on how to conduct an IS review internally
- If conducting an IS study for regulatory purposes be prepared to explain:
  - basis of your decisions on ‘how safe is safe enough’
  - technical basis of IS method used
Inherently Safer Design Analysis Approaches

- Multiple ways inherent safety can be analyzed
- Intent is to formalize consideration of inherent safety rather than to include it by circumstance
- Including inherent safety in either a direct or indirect way, potential benefits are fully realized and considerations are documented

- Three methods can be employed:
  - Checklist Process Hazard Analysis (PHA)
  - Independent Process Hazard Analysis (PHA)
  - Integral to Process Hazard Analysis (PHA)
Risk Ranking Scheme

- In all cases it is recommended to use a risk ranking scheme which defines likelihood and consequences.
- Inherent safety should be considered in light of risks as with other risk management strategies.
- A basis for decisions is needed.
# Risk Ranking Scheme

## Table 1: Risk Matrix (R)

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Very High (4)</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (3)</td>
<td></td>
<td>Low 2</td>
<td>Medium 3</td>
<td>High 4</td>
<td>Very High 4</td>
</tr>
<tr>
<td>Medium (2)</td>
<td></td>
<td>Low 2</td>
<td>Medium 3</td>
<td>Medium 3</td>
<td>High 4</td>
</tr>
<tr>
<td>Low (1)</td>
<td></td>
<td>Low 1</td>
<td>Low 2</td>
<td>Low 3</td>
<td>Medium 3</td>
</tr>
<tr>
<td></td>
<td>Low (1)</td>
<td>Medium (2)</td>
<td>High (3)</td>
<td>Very High (4)</td>
<td></td>
</tr>
</tbody>
</table>

**Severity**
### Risk Ranking Scheme (continued)

#### Table 2: Severity (S)

<table>
<thead>
<tr>
<th>Category</th>
<th>Low (1)</th>
<th>Medium (2)</th>
<th>Moderate (3)</th>
<th>High (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health &amp; safety impacts</td>
<td>Minor injury or health effect</td>
<td>Moderate injury or health effect</td>
<td>Major injury or health effect; offsite public impacts</td>
<td>Fatality offsite, multiple onsite injuries or fatalities,</td>
</tr>
<tr>
<td>Asset damage (replacement cost)</td>
<td>$</td>
<td>$</td>
<td>$$$</td>
<td>$$$$$</td>
</tr>
<tr>
<td>Business interruption (days unavailable or $)</td>
<td>$</td>
<td>$</td>
<td>$$$</td>
<td>$$$$$</td>
</tr>
<tr>
<td>Environmental impact (remediation damages)</td>
<td>$</td>
<td>$</td>
<td>$$$</td>
<td>$$$$$</td>
</tr>
</tbody>
</table>
### Risk Ranking Scheme (continued)

#### Table 3: Likelihood (L)

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Short descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>Not expected to occur in life of facility</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>Possible to occur in life of facility</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>Possible to occur in range of 1 year to 10 years</td>
</tr>
<tr>
<td>4</td>
<td>Very High</td>
<td>Possible to occur at least once a year</td>
</tr>
</tbody>
</table>
Inherent Safety Analysis Method Synopsis

- Method 1 – a checklist is used that contains a number of practical inherent safety considerations organized around the four strategies of minimization, substitution, moderation, and simplification
  - Direct & asks pointed questions that have proven to be valuable in reducing hazards at past locations
  - May be limiting; other ideas may surface if the team was asked to more creatively determine applications for the inherent safety strategies given a safety objective
Method 2 – team is asked to avoid a particular hazard at a part of the process

- Team reviews a problem and determines which of the inherently safer strategies may apply and brainstorms possible ways the hazard can be reduced or eliminated.
Inherent Safety Analysis
Method Synopsis

- Method 3 – integrate ISD into every PHA study (What if?, HAZOP, FMEA or other similar methodology)
  - The concept is both to include questions (for What if?) or guidewords (for HAZOP) to introduce ISD to the discussion, and then to use the four strategies (minimization, substitution, moderation, and simplification) as possible means to mitigate each hazard identified in addition to the other layers of protection strategies that may be used
## Checklist Process Hazard Analysis (PHA)

**Location:**

**PFD No.:** 1234-5678

**Node:** Isobutane Storage

**Design Conditions/Parameters:** Storage of isobutene in five bullets and two process vessels near the unit

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>POTENTIAL OPPORTUNITIES</th>
<th>FEASIBILITY</th>
<th>CONSEQUENCES</th>
<th>EXISTING SAFEGUARDS</th>
<th>S</th>
<th>L</th>
<th>R</th>
<th>RECOMMENDATIONS</th>
<th>COMMENTS/STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reduce hazardous raw materials inventory</td>
<td>Lower storage tank volume or eliminate some storage if possible.</td>
<td>Lowering tank volumes is already done. There may be one tank that could be eliminated.</td>
<td>Potential release from storage and exposure to south plant from unconfined vapor cloud explosion.</td>
<td>1. Administrative controls limit fill level of the five tanks.</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1. Eliminate one of five flammable storage bullets to reduce potential releases from storage.</td>
<td>In review.</td>
</tr>
<tr>
<td>2 Reducing in-process storage and inventory</td>
<td>Interim storage adds to inventory and could be eliminated.</td>
<td>Will require engineering analysis to evaluate.</td>
<td>Potential leak, fire and explosion.</td>
<td>1. High level alarms 2. Flammable gas detectors</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>2. Consider eliminating interim storage and providing a continuous flow operation</td>
<td>In review.</td>
</tr>
<tr>
<td>3 Reducing finished product inventory</td>
<td>Not applicable (NA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Reduce hazardous material by using alternate equipment</td>
<td>No alternatives available or feasible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Independent Process Hazard Analysis (PHA)

### Figure 2

Inherent Safety Analysis - Independent Process Hazard Analysis (PHA)

### Node: 1. Feed system to reactor

#### Objective: 1. Minimize potential for runaway reaction in the feed to the reactor

<table>
<thead>
<tr>
<th>CAUSES</th>
<th>CONSEQUENCES</th>
<th>EXISTING SAFEGUARDS</th>
<th>S</th>
<th>L</th>
<th>R</th>
<th>OPPORTUNITIES</th>
<th>FEASIBILITY</th>
<th>RECOMMENDATIONS</th>
<th>COMMENT/STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High water content in feed tank due to settlement or water carryover from upstream process</td>
<td>1. Excess water in the reactor may cause shorter run life due to catalyst fouling; this has a possible safety hazard in more startups and shutdowns over the life of the process. Worst credible case excessive water may cause a runaway reaction.</td>
<td>1. Control of unit operation to meet feed and operator monitoring of process conditions.</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Evaluate way to positively eliminate water from entering the reactor rather than controls.</td>
<td>It may be feasible to switch to a ‘clean’ tank without the potential for water with minor piping changes.</td>
<td>1. Change from feeding from Tank 1 to only Tank 3 since Tank 1 has high water settlement potential. Tank 1 has water in upstream units that cannot be completely avoided whereas Tank 3 is clean feedstock.</td>
<td></td>
</tr>
<tr>
<td>2. Water into the feed from wrong valve opened in one of the water wash cross connections</td>
<td>1. Potential for operator error to leave water online or valve not fully closed, or failure of the valve allowing leak of water into the feed line.</td>
<td>1. Proper procedures for water washing</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>Evaluate ways to eliminate water contamination risk from human error</td>
<td>Operating procedures can be improved.</td>
<td>2. Improve operating procedures for water washing to ensure operators check the valve closure and water flow following a water wash.</td>
<td></td>
</tr>
</tbody>
</table>

2. Operator training
3. Temperature

There is an excess number of cross connections so

3. Reduce the number of water cross connections.
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<tr>
<td>1. Settlement or water carryover from upstream process</td>
<td>1. Excess water in the feed and then reactor which may cause shorter run life due to catalyst fouling; this has a possible safety hazard in more startups and shutdowns over the life of the process. Worst credible case excessive water may cause a runaway reaction.</td>
<td>1. Control of unit operation to meet feed and operator monitoring of process conditions.</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Evaluate way to positively eliminate water from entering the reactor rather than controls</td>
<td>It may be feasible to switch to a ‘clean’ tank without the potential for water with minor piping changes.</td>
<td>1. Change from feeding from Tank 1 to only Tank 3 since Tank 1 has high water settlement potential. Tank 1 has water in upstream units that cannot be completely avoided whereas Tank 3 is clean feedstock.</td>
<td></td>
</tr>
<tr>
<td>2. Potential for operator error to leave water online or valve not fully closed, or failure of</td>
<td>1. Excess water in the reactor may cause shorter run life due to catalyst fouling; this has a possible</td>
<td>1. Proper procedures for water washing</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>Evaluate ways to eliminate water contamination risk from human error</td>
<td>Operating procedures can be improved.</td>
<td>2. Improve operating procedures for water washing to ensure operators check the valve closure and water flow following a water wash.</td>
<td></td>
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