Driving Process Safety Excellence in Ammonia Refrigeration: Real-world Lessons from U.S. Food Industry & Practical Applications for Indian Facilities

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Agenda

After participating in this activity, attendees will be able to…

- Learning Objective #1 – Recognize how small process safety gaps escalate into major ammonia incidents, using real-world U.S. food industry accidents and root cause analysis.
- Learning Objective #2 – Understand and apply a structured Process Safety Management (PSM) framework, including Swiss Cheese model, LOOP-BAR Barrier Assurance concepts for ammonia refrigeration systems.
- Learning Objective #3 – Identify practical, low-cost actions to strengthen ammonia process safety in Indian facilities

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Why Process Safety in Ammonia Matters Today?

- Process Safety in Ammonia matters because of Rapid Cold Chain expansion, Aging ammonia systems, Higher production demands, Increasing regulatory scrutiny
- Ammonia is not the problem – as we know its natural refrigerant with excellent thermodynamic efficiency and environmentally friendly BUT it has ZERO tolerance for weak systems
- Most Major ammonia incidents begin small in the form of minor leaks being ignored, temporary bypasses, informal changes, poor documentation etc

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Root Cause of Major Ammonia Accidents

Millard Refrigerated Services, Theodore, AL – August 23rd, 2010

- Catastrophic release of approx. 32,000lbs of anhydrous ammonia.
- Affected 152 individuals from a nearby site, reporting symptoms of ammonia exposure, with 4 in intensive care

Root cause -

- Caused by hydraulic shock that's caused when there is sudden change in pressure within the refrigeration system
- This shock resulted from a programming error that caused a valve to open unexpectedly, allowing low temp liquid ammonia to mix with hot high-pressure gas. This caused rapid condensation of gas into liquid which led to a significant pressure surge resulting in ammonia release.

Key Lessons learned -

- Avoid grouping multiple, large-capacity evaporators to a single set of control valves.
- Program the defrost control sequence to automatically depressurize or bleed the coil upon restart after an outage or interruption, prior to opening the suction stop valve to set the evaporator into cooling mode.
- Avoid the manual interruption of evaporators while in defrost and equip control systems with password protected controls to ensure only trained and authorized personnel have the authority to manually override system processes.
- For time-initiated hot gas defrost systems, ensure pump-out times are long enough to remove all liquid refrigerant from the evaporator coils prior to introducing hot gas, especially after low-load periods or power outages.
- In the event of an ammonia release, activate the emergency shut-down switch to de-energize pumps, compressors and valves instead of attempting to isolate leaking equipment while the refrigeration system is running.

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Heat Exchanger Failure, Good Year, June 11, 2008

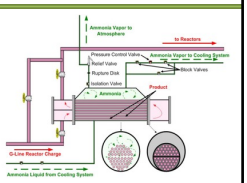
- This incident injured 6 employees
- Hours after plant responders declared the emergency over, the body of an employee was discovered in the debris next to HX

Root Cause –

- Isolating the relief valve protecting the heat exchanger while injecting steam into the equipment in an attempt to clean the product side

Lessons Learnt –

- Emergency Procedures: Onsite emergency response, training, plant alarm systems, accounting for workers in an emergency
- Maintenance work permit: work permit & LOTO, Turnover process improvement
- Pressure vessel over pressure protection



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LOOP-BAR Framework – Layered Operations Overlay of PSM with Barrier Assurance Register

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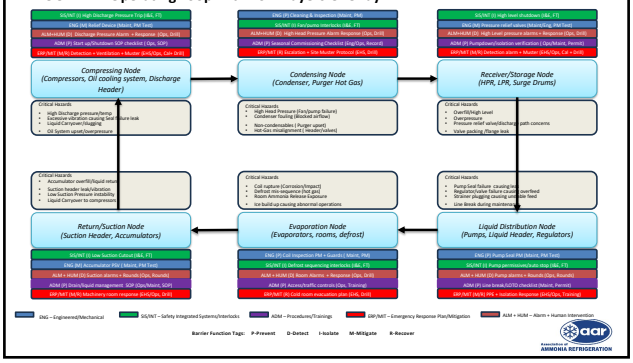
LOOP-BAR Framework

LOOP-BAR Operating Loop with PSM Layers Overlay



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How to Build Your PSM Layers Overlay (Real-World Steps)

Step 1 — Draw the Operating Loop (not a full P&ID)
Create a clean loop map using 6 nodes: Compression, Condensing/High-Side, Receiver/Storage, Liquid Distribution, Evaporation/Load, Return/Suction.

Step 2 — Add a Hazard Box to each node
List 3–5 realistic scenarios per node using your incident history, near-misses, and common failure modes.

Step 3 — Assign Barrier Functions (P/D/I/M/R) to every layer
Tag each barrier by its purpose: Prevent, Detect, Isolate, Mitigate, Recover. This makes safeguards teachable and LOPA-ready.

Step 4 — Overlay the layers with a consistent legend
For each barrier, show: Barrier name + P/D/I/M/R + Owner (Ops/Maint/Eng/EHS/I&E) + Proof hook (CMMS PM, calibration, functional test, drill log).

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Barrier Assurance Register (BAR)

Use the BAR to turn every box on the overlay into a testable, owned barrier with evidence.

- Node + Scenario (Cause, Event, Consequences)
- Barrier Type (ENG/SIS/ALM/ADM/ERP) and Function (P/D/I/M/R)
- Trigger → Action (what makes it activate, what it does)
- Performance Standard (setpoints, response time, acceptance criteria)
- Verification Method + Frequency (PM, calibration, functional test, drill)
- Owner (Responsible/Accountable) + Evidence location (CMMS, logs)
- Impairment management (what to do if the barrier is out of service)

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Ammonia refrigeration & PSM – Roles & Responsibility R2 Matrix Framework

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R² Matrix – Roles and Responsibilities

Ammonia PSM Stakeholder Roles & Responsibilities Matrix (R²M)

PSM Element	Operators	Engineers	Maintenance	Contractors	Plant Manager	Corporate
1. Employee Participation	R	C	I	I	A	C
2. Process Safety Information	I	A	C	I	A	C
3. Process Hazard Analysis	C	A	C	C	A	I
4. Operating Procedures	R	C	C	I	A	I
5. Training	R	A	C	C	A	I
6. Contractors	I	C	C	R	A	I
7. Pre-Startup Safety Review	C	A	R	C	A	I
8. Mechanical Integrity	I	A	R	C	A	I
9. Hot Work Permits	R	C	R	R	A	I
10. Management of Change	I	A	C	C	A	I
11. Incident Investigation	C	A	R	C	A	I
12. Emergency Planning & Response	R	C	C	I	A	I
13. Compliance Audits	I	C	C	I	A	R
14. Trade Secrets	I	C	I	I	A	R

Legend	
R	Responsible
A	Accountable
C	Consulted
I	Informed

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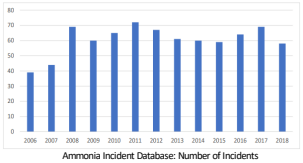
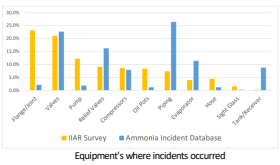
Accidental Chemical Releases Trend



Ammonia Incident Database: Number of Incidents

- Between 2006 and 2018, ammonia incidents per year was relatively constant, averaging 64 reported incidents in US and Canada.

Industry Sector	Number of Incidents
Meat and poultry processing	159
Cold storage	134
Ice rinks	103
Dairy and related facilities	80
Frozen food	75
Beverage	71
Fruit and vegetables	71
Ice plants	48
Seafood processing	30
Bakeries	18
Total in all industry sectors	789



Equipment's where incidents occurred

Causes of Releases

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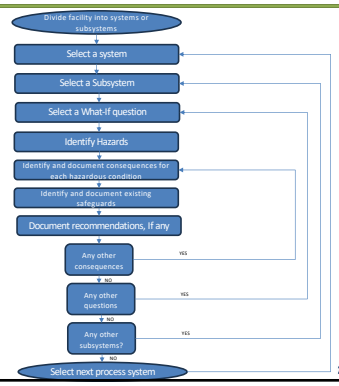
Process Hazard Analysis

PHA Procedure Flow Chart



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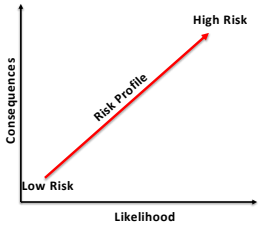
What is a Risk?

- Risk = Consequences x Likelihood



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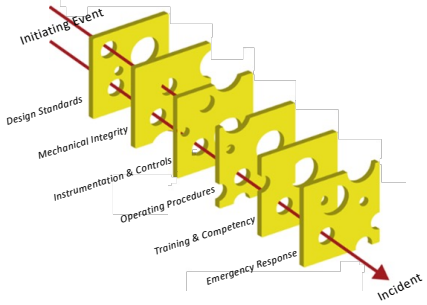
Ammonia Swiss Cheese Incident Framework



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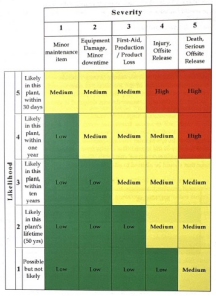
Risk Matrix



Risk Ranking Chart

S/L Rating	Time Alloted
Low	Up to 1 Year
Medium	180 Days or Less
High	30 Days or Less

- Based on the S/L rating, we determine a safe response time to mitigate the hazard.

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Mechanical Integrity (Keep it in the pipes)

- Under MI, we need to ensure we identify all safety critical equipment's
- All identified critical equipment's, need to have an inspection protocol and frequency
- Ensure to have a CMMS to help manage assets
- Focus on PM completions and follow ups- Overdue PMs

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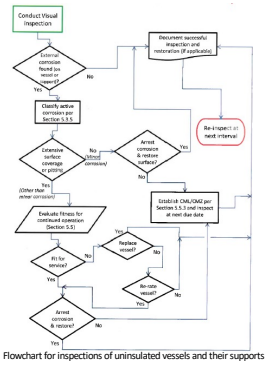
Mechanical Integrity Guidelines for uninsulated vessels



Flowchart for inspections of uninsulated vessels and their supports

5.3.5 Corrosion Classification

- Classified as no active corrosion, minor corrosion and other than minor corrosion
- No active corrosion is defined as free from any active visible oxidation
- Minor corrosion is defined as surface oxidation that does not cover the circumference & no localized pitting corrosion
- Other than minor corrosion is defined as the active external oxidation covering entire circumference

5.5.3 Conditioning Monitoring locations and Conditioning monitoring zones

- The establishments of CML/CMZ is not required if prompt action is taken to arrest the active corrosion areas.
- It's required when it's decided to allow known areas of active corrosion areas to persist , CML/CMZs should be established

5.5 Determining Fitness for Continued Operation

- When corrosion is discovered, NDE technology is required to determine vessel wall thickness as a necessary step to determine or not the vessel is for for continued safe operations
- We need to know the Actual vessel wall thickness at the location where MI is most degraded, so it can be compared to design minimum allowable wall thickness tmin
- If Actual wall thickness < tmin, then replace unless it could be re-rated
- If Actual wall thickness > tmin, then fit to use

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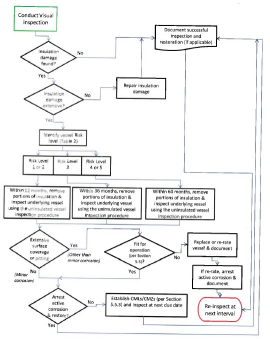
Mechanical Integrity Guidelines for Insulated Vessel



Vessel Type	Paint/Coating	Operating Temperature	Risk
Transfer vessels and controlled pressure receivers	Unpainted/uncoated	Normally operating at a temperature below the ambient dew point but above 10°F (-12°C) and frequently cycling to higher pressures/temperatures	1
Vessels (e.g. surge drum, suction accumulator, recirculator)	Unpainted/uncoated	Normally operating at temperatures below the ambient dew point but above 10°F (-12°C)	2
Transfer vessels and controlled pressure receivers	Painted/coated	Normally operating at temperatures below the ambient dew point but above 10°F (-12°C) and less frequently cycling to higher temperatures	3
Vessels (e.g. surge drum, suction accumulator, recirculator)	Unpainted/uncoated	Consistently operating colder than 10°F (-12°C)	4
Vessels (e.g. surge drum, suction accumulator, recirculator)	Painted/coated	Consistently operating colder than 10°F (-12°C)	5

Flowchart for inspections of insulated vessels and their supports

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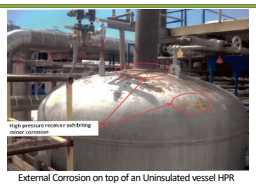
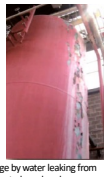
Mechanical Integrity audits - insulated vessel and non insulated vessel flowchart analysis


External Corrosion on an Uninsulated vessel



External Corrosion on top of an Uninsulated vessel HPR



HPR with surface coating damage by water leaking from evaporative condenser sump located overhead



Uninsulated vessel with degraded surface coating due to temp cycling allowing external corrosion

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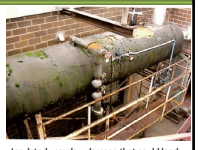
Mechanical Integrity DON'TS


HPR with corrosion at the base support due to moisture exposure


LPR being supported by laminated sandwiched plywood


Insulated vessels – damage that could lead to CUI due to failed insulation system


HPR with supports not anchored


External corrosion – other than minor corrosion

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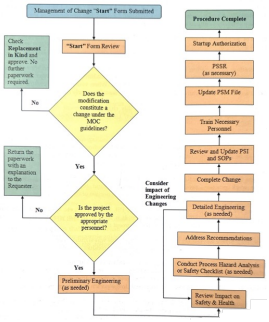
Management of Change



Management of Change Procedure Flow Chart

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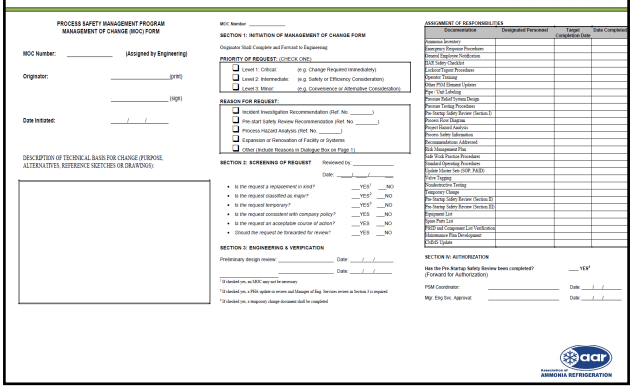
Management of Change



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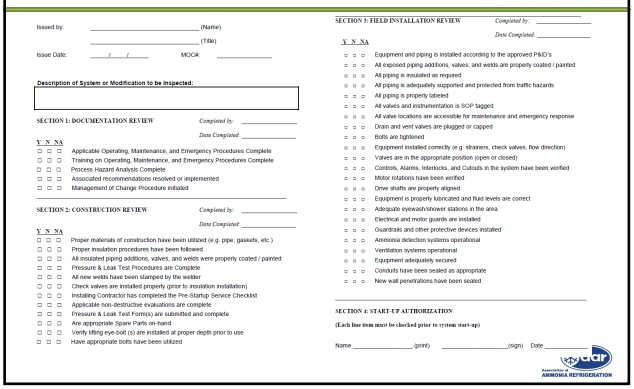
Pre-Start up Safety Review



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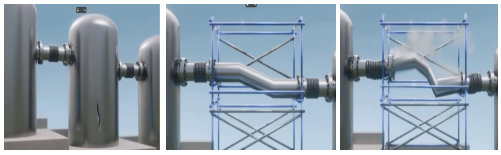
Case Studies

The Piper Alpha Oil Rig

- 1988, Piper Alpha Disaster – killed 167 men working on the petroleum platform
- A pump had failed causing the operators to switch to a back up pump
- Unknown to the operators who were making the switch, a relief valve had been taken out of service by maintenance crew and replaced with a temporary blank.
- Neither the person switching the pump nor the maintenance tech replacing the relief were aware of the other persons work.
- When back up pump started, vapor leaked from the blank and started a fire.



Flixborough Explosion

- 1974, Flixborough Explosion – killed 18 people and injured several
- A temporary bypass pipe was installed to avoid a faulty vessel that had developed cracks.
- The Bypass was designed by engineer's w/o experience in high pressure pipework – no calcs or formal plans, was not pressure tested, supported by temporary poles that allowed the pipe to mode while in operation leading to the piping failure releasing 40 Tons of flammable has resulting in an explosion

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Process Safety Information

- PSI is what your employees need to know about the chemical, the process and the equipment in the process to operate the process safely, reliably and efficiently.
- PHA, developing trainings, Operating Procedures, PSSRs, Emergency planning and response etc
- Information pertaining to chemical – chemical properties corrosivity data, reactivity data, hazardous effects of inadvertently mixing different chemicals
- Information pertaining to technology of the process – block flow diagram, process chemistry, Max intended inventory, Safe upper and lower limits as temps, pressures, flows
- Information pertaining to equipment – materials of construction, P&IDs, electrical one line diagrams, PRV piping and design, ventilation system design, mass and energy balance calcs, safety systems

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Emergency Response

- Emergency response & Planning is about preparing for a release before it happens so that you can react in a timely manner to minimize the impact of the release on your employees, facility and the community
- Should include –
  - Real life scenario Drills,
  - Ensure that we have right and ready to go equipment onsite,
  - Trained Hazmat personnel to be able to respond to the leaks,
  - Incident command trained,
  - Plant evacuation routes,
  - LEPC,
  - Plant emergency shutdown procedures,
  - King valves (emergency shutdown valves to mitigate the leak)

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Incident Investigations

Why should I investigate all the near misses and process upsets?

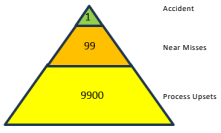
- Every incident indicates an opportunity to improve the process, procedures, PSM systems that controls it
- Every process upset has a potential to escalate to a near miss

What is Incident Investigation?

- Il is a chance to learn from an incident so that we can prevent incidents like it in the future

What must an investigation include?

- Initiated prompt within 48 hours
- Must include at least one person involved in the accident, contractor if involved
- Detailed report – Date, Time of the incident, Description, Facts, Recommendations, Follow up dates



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SOP, Training, Contractors AND Hot Work Elements

Operating procedures

- Detailed written procedures and practices for the safe operation of refrigeration system during:
- Startup, shutdown, emergency conditions, and temporary operation includes operating limits, consequences of deviation, and steps required to correct deviations

Training

- Employees and contractors that operate the ammonia system require training
- Process hazards, operating procedures (normal & emergency), specific tasks, safe practices
- Training is required before operating a covered process

Contractors

- Employers evaluate contractors' capabilities and safety
- Contractors require training on the covered process

Hot work

- A formal program to prevent fire and explosions from occurring while conducting hot work (welding, cutting, brazing, grinding, etc.)

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Employee Participation, Auditing, Trade Secrets

Employee Participation

- Is how we ensure that PSM is not merely a top-down program. Employee participation from bottom-up enhances employee buy-in of the program and improves implementation of all the facets of the program.
- New equipment design, upkeep of the system and implementation of PSM program

Auditing

- Is one of the best tools to gauge the effectiveness of PSM program
- Good industry practice to have an external audit as it more effective at finding areas of improvements

Trade Secrets

- Is there to ensure that all the information is readily available to all the employees operating and analyzing a PSM covered process
- Generally, ammonia refrigeration systems do not have information that would be considered Trade Secrets.

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Practical improvements for Indian Facilities

Low Cost, High Impact Actions

- ✓ Daily Operators Walkdown
  - ➢ Smell, sound, vibration
  - ➢ Logbook discipline
  - ➢ Daily shift huddle meetings – effective communications between shifts
- ✓ Simple Alarm Management
  - ➢ Test Detectors monthly
  - ➢ Audible alarms, outside engine rooms
  - ➢ Critical safeties check on compressors, vessels annually
- ✓ Mechanical Integrity Focus
  - ➢ Valve Packing leaks
  - ➢ CUI
  - ➢ Relief valve change-out program
- ✓ Contractor Control
  - ➢ Permit to work
  - ➢ Escort rule in engine rooms
- ✓ Emergency readiness
  - ➢ Scenario based drill annually
  - ➢ Local fire dpt collaboration

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Cooler Optimization Experiment – Cargill Inc

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Cooler optimization experiment Analysis

Effect of airflow diffusers on meat log chilling

Objective & experimental setup

- Goal: compare cooling performance with vs. without diffusers (target core temperature 4°C).
- Cooler: 3.66 m × 6.096 m; ammonia refrigeration coil.
- Air movement: five 30 cm fans; five diffusers installed for the "with diffusers" trial.
- Product storage: two rows, twelve racks; core temperatures monitored (upper & lower racks).
- Measured: airflow patterns, cooling rates, and overall heat transfer efficiency.

Test configuration

Racks loaded in cooler (diffusers installed)

Source: Impact of Louvers Vs without louvers on Meat logs

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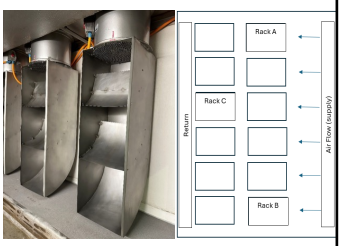
Airflow distribution & temperature uniformity

Key observations from core temperature profiles

- Both trials start comparable: core temperatures ~68–72°C.
- Without diffusers: cooling is slower with a clear spread between racks; upper cores remain ~2–4°C warmer than lower cores (poorer vertical uniformity).
- With diffusers: cooling curves are steeper; cores are typically within ~1–2°C of each other (better rack-to-rack and vertical uniformity).
- Air temperatures are lower and more stable with diffusers, sustaining a larger air–product ΔT (higher effective heat transfer rate).

Diffuser hardware & cooler layout



Source: Impact of Louvers Vs without louvers on Meat logs

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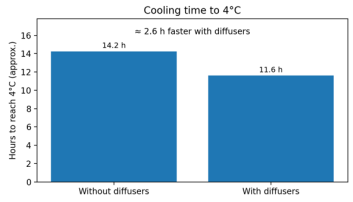
Cooling time to 4°C and overall impact

Quantified effect (approx. from plotted points)



- Without diffusers: coldest cores ~810–840 min; warmest ~840–900 min; all cores ~13.5–15 h to reach 4°C.
- With diffusers: coldest core ~660–690 min; all cores ~705–735 min; all cores ~11–12.25 h to reach 4°C.
- Uniformity improves late-cycle: hot–cold spread reduces from ~3–4°C to ~1–2°C.
- Air temperatures remain lower & more stable with diffusers, supporting sustained cooling.

With diffusers

Source: Impact of Louvers Vs without louvers on Meat logs

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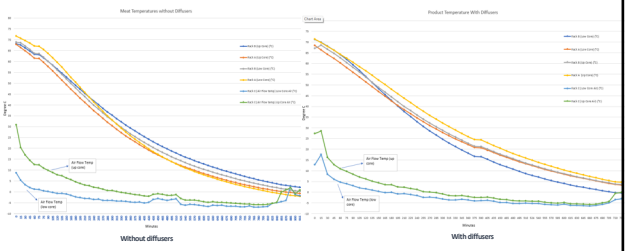
Cooling curves (core + air temperatures)



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Conclusion

- Ammonia is not the problem - weak systems are.
  Most catastrophic releases originate from small, manageable failures that were tolerated or overlooked.
- Major ammonia accidents are rarely single-point failures.
  They occur when multiple barriers - design, mechanical integrity, controls, procedures, training, and emergency response fail together.
- Process Safety must be managed as a system, not as isolated elements.
  Tools like Swiss Cheese, LOOP-BAR help make safeguards visible, testable and owned.
- Mechanical Integrity, MOC, and Operating Discipline are non-negotiable.
  If ammonia is kept inside the pipes, it does not become a hazard outside the system.
- Indian facilities can achieve world-class ammonia safety today.
  Many improvements require discipline, leadership ownership, and consistency - not large capital investment.

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- Q&A

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