EXPERIENCE WITH CRYOGENICS SAFETY, PROBLEMS AND SOLUTIONS

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Outline

- Introduction
- Cryogenic safety Hazards and Its Causes
- Protection and Prevention Measures
- Personals Protective Equipments
- Cryogenic Safety in IPR
- Practical Problems Experience and Solution
- Cryogenic Safety Guidelines
- Actions at Emergency Conditions
- Summary
- Acknowledgments

Introduction

- The branches of Physics and Engineering that involve the study of very low temperature below 123 K. Low temperature are achieved by the liquefaction of gases.

Some Typical Temperature	Temperature (° C)	Absolute (K)	Liquid to gas Expansion
Tropics	45	318	
Human Body	37	310	
Room Temperature	20	293	
Ice Point	0	273	
Home Refrigerator	-18	255	
Antarctic water	-50	223	
Solid Carbon-dioxide	-78	195	
Liquid Oxygen	-183	90	1 to 860
Liquid Nitrogen	-196	77	1 to 696
Liquid Helium	-269	4	1 to 757
Absolute Zero	-273	0	

Cryogenic Effects on Materials and Accountability in Design

- The mechanical and electrical properties change of many materials very dramatically when cooled to 100 K or lower. (for example plastic, rubber extremely brittle)
- Freezing/Glassing (Liquids, Oil, Greases)
- Condensation/Liquefaction (Gases)
- Stainless steel (304,316), Cu, Al, Ag, and Brass are characterize very good mechanical properties at Cryogenic temperature.
- The thermal contraction typically 3 to 5 mm/m for common structural materials between 300 K and 77 K (little additional change occurs < 77 K)
- Joints and supports must be able to handle induced thermal stresses and transitions between various materials
- An uneven cool down will create large thermal stresses within a vessel

  (Pipeline example: 30 m stainless steel pipeline would contract 8.4 cm on cool down to 77K)

Cryogenics Hazards and Its Causes

[1] Asphyxiation :

A condition of severely deficient supply of oxygen to the body that arises from being unable to breathe normally.

It is due to released cryogens can displace oxygen in a room.

(i) Oxygen deficiency is defined as <19.5% oxygen (OSHA)

(ii) The symptoms of oxygen deficiency are :

19% - 15%	pronounced reduction of reaction / response speed
15% - 12%	deep breaths, fast pulse, co-ordination difficulties
12% - 10%	vertigo, false judgment, lips slightly blue
10% - 8%	nausea, vomiting, unconsciousness
8% - 6% :	death within 8 minutes, 4-8 minutes brain damage
< 4%	coma within 40 seconds, no breathing, death

[2] Cold Contact Burn/Frostbite:

Contact Burns – skin exposure to cold liquid, gas or surface, Similar to heat burns; can cause localized tissue damage can lead to frostbite

Frostbite – freezing of skin or body parts resulting from exposure to low temperature

The causes of cold burns and Frostbite are:

- Cause of frostbite to the hands and body is contact with cold metal surfaces
- Especially when the skin is moist can lead to permanent damage
- Prolonged exposure to cold vapor can damage lungs and eyes
- Handling open cryogen containers, especially when cooling down warm vessels or objects
- De-choking vents/drains of cryogen handling system
- Doing connections/disconnection of piping /hoses.

[3] Over pressurization and physical explosion

- Cryogen liquids do expand by a factor of 500 to 800 when evaporated and warmed up to room temperature.
- Heat input lead to significant pressure build-up to bursting of the cryogen container.

Possible reasons for an elevated heat input are:

1. Fast cool down of components or cryogenic installations

2. Large heat production within the object to be cooled during a quench

3. Loss of the insulation vacuum,

(LHe has very low latent heat of vaporization (1/10th that of LN_2) so it will evaporate rapidly/explosively when heated)

[4] Air Condensation (Fire Hazards)

- Condensation of air/O2 on combustible liquids or materials can create flammable/explosive mixture
- At temperatures < 82 K, metal surfaces will condense oxygen and form enriched air (50% O2 and 50% N2) to drip and pool on surfaces
- Un insulated pipelines provide this surface
- Air boils at 78 K (at 1 atm pressure) in a 6% O2-94% N2 vapor mixture, enriching the O_2 content

[5] ICE PLUGS

- Frozen plugs can form in Dewar plumbing if the cryogenic system is exposed to air

- Moisture in air can also block lines, vent lines path to relief valves from releasing pressure from the Dewars as the cryogen vaporizes
- Over time this will result in a pressure build up that can cause structural failure of the Dewar

[6] ICE BUILD UP:

- Ice build up on uninsulated areas can cause damage to surrounding equipment
- Potentially embrittle sensitive materials
- Ice build up can block relief valves
- Ice build up can freeze O-rings and compromise insulating vacuums

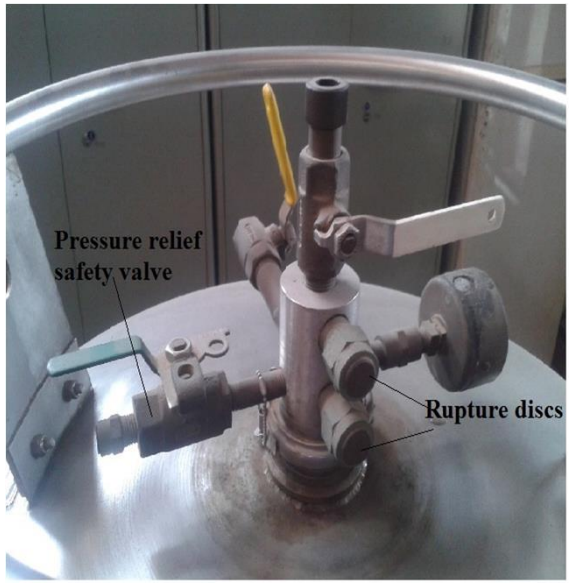
Protection and Prevention Measures

- Cryogenic liquids must be handled in well ventilated areas to prevent excessive concentrations of gas in enclosed spaces.
- Oxygen level detectors to be installed in enclosed spaces
- In case of splash in the eyes flush continuously for at least 15 minutes.
- Any unprotected part of the body must never be allowed to touch uninsulated pipes or vessels containing liquefied gases.
- When pouring liquefied gases from one container to another, the receiving container must be cooled gradually to prevent thermal shock.
- To reduce air condensation is by applying an insulating material on system components.
- To eliminate high-pressure releases of cryogenic vapors, containment systems with special pressure- relief devices and rupture "Burst Disks" to allow over pressures to release safely
- **(LHe Dewar: 2 relief valve (0.5 psi and 10 psi) and 2 no. rupture disc set at 35 psi, LN_2 Dewar: 1 relief valve 22 psi and rupture disc 180 psi)**

Protection and Prevention Measures

- Portable trolleys must be used for moving large containers of cryogens.
- Frost spots may appear in case of loss of insulating vacuum. A vessel in this condition must be removed from service
- Safety glasses and face shield should be used for eye and face protection.
- Cryo hand gloves, Apron must be worn when handling cryogenic liquids.
- Dewars must be kept covered with a loose fitting cap to prevent air or moisture from entering the container, and to allow build up pressure to escape.
- Make sure that no ice accumulates in the neck or on the cover and causes a blockage and subsequent pressure build up.
- Always store and handle liquid helium under positive pressure or in closed systems to prevent the infiltration and solidification of air or other gases.

Cryogenic Personnel Protective Equipments in IPR



Pressure safety device in LHe Dewar

Trolley for LN_2 Dewar movement

Face shield

Cryo hand gloves

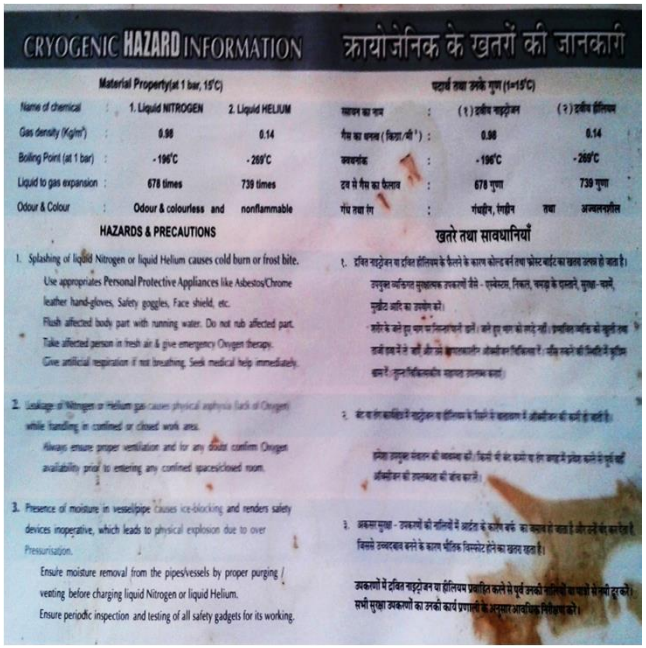
Safety goggle

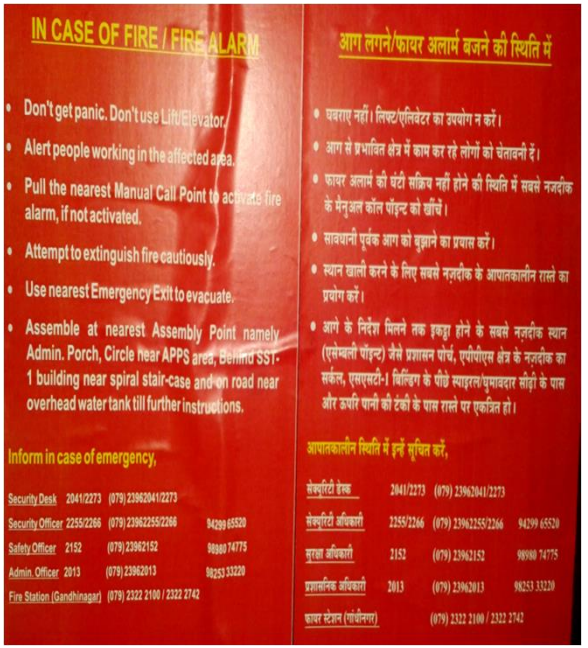
Cryo Apron

Fire Alarm System

O_2 Sensor and Monitor

Emergency Shower & Breathing Set





Display Information about System, Cryogenic Hazards and Fire Alarm System in IPR

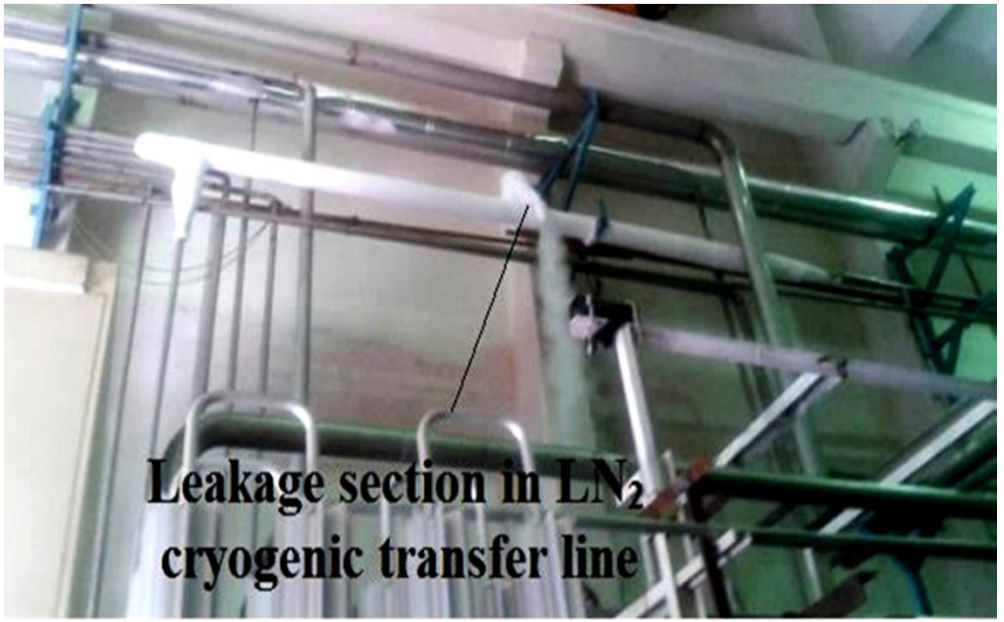
Cryogenics Safety at IPR

- LHe and LN_2 cryogens are used for the cooling of superconductive magnets, 80K thermal shields of vacuum vessel, cryostats, Purifier of SST-1 machine and experimental test facilities.
- LHe produce in Helium Refrigerator and Liquefier Plant in IPR
- 2200 l/hr of LN_2 consumption, transfer from 105 kL cryogenic LN_2 tanks through ~ 270 meter long vacuum jacketed cryogenic transfer lines.
- Spring loaded safety valves in 2 stages, pressure relief valves, rupture disc, cryogenic bellows to take care of high pressure, thermal contraction and induced thermal stresses in the system.
- Cryogenic experimental Dewars of 50, 100, 150, 250 L capacities in Labs.
- Transfer siphon for liquid helium transfer, LN_2 withdrawal pressure device
- Follows the Cryogenic safety protocols and procedures, permit to work systems, equipped with cryogenic personal protective equipments, First aid treatment kit, information about the systems, emergency procedure and important contacts details have displayed on wall at the required locations in case of an emergency/accident.

Practical Problems Experience and Its Solution

[1] Repairing of Main LN2 Cryogenic Transfer line of LN2 Distribution of SST-1

- Huge frosting and condensation observed on a long section of transfer line
- Loss of cryogens and risk of cryogens falling down on personals working
- Damage to the equipments due to LN_2 dripping on
- In-house repaired and carried out the performance test at operating conditions of LN_2 transfer line
- Vacuum, multilayer insulation wrapping, welding, helium leak test and assembly in congested space and safety aspect at 12 meter height.



Leaked Line section

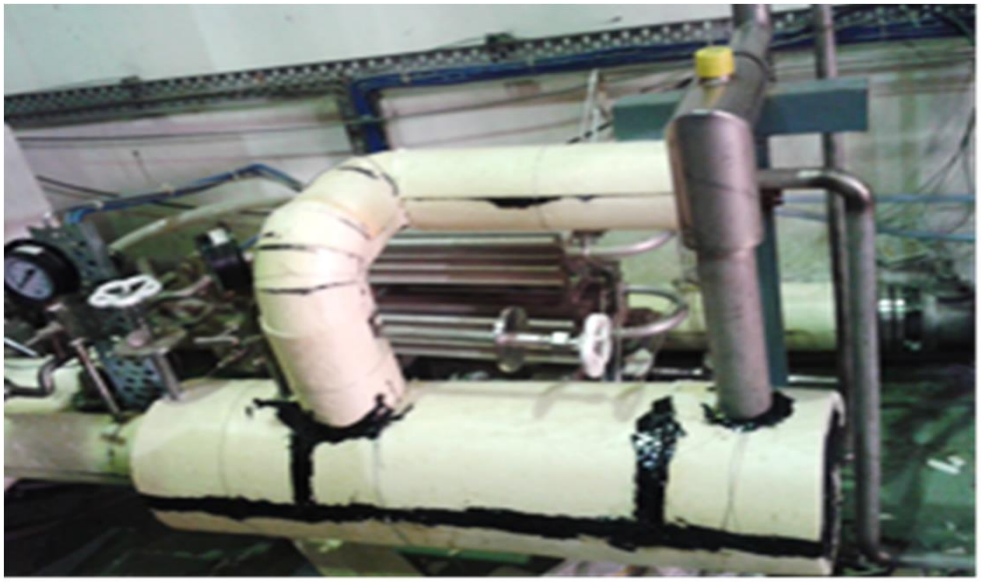
After repairing Transfer Line at 80 K

[2]Replacement of Old Insulation and Vacuum of Cryogenic Transfer Lines of 80 K Distribution System

- The ice blocks and water drops were falling down in the working area which was not safe for the system and personals
- Replaced old mineral glass wool insulation to Polyurethane insulation (PUF) of Cryo grade class P
- Vacuum in cryogenic transfer lines degraded to > 500 mbar
- Evacuation of transfer lines level up to 10^{-3} mbar
- Thermal performance of the LN_2 systems enhanced up to 80-90%.

Glass wool insulation

Frosting on vent line



PUF insulation

[3] Rectification and Mitigation of Helium leaks in Cryogenic Systems

- Leaks localized, mitigated and repaired in cryogenic systems at high pressure 14 bar pressure in safety valves, rupture discs, hand valves of high pressure helium gas storage vessels .
- Replaced developed mixed metal (AL+PTFE) seals, elliptical type O ring and PTFE gasket as per standard B16 .
- Helium gas losses were reduced significantly and prevented the risk of high pressure gas bursting at any leaked location.
- Helium leak hunting and repairing at 12 meter height @ 100 bar, Helium leak rate achieved $<10^{-6}$ mbar l/s

Rupture disc on high pressure helium gas vessels

Cryogenic Safety Guidelines

The general cryogenic safety checks must be followed by the personals working and responsibility to ensure by the management and safety In-charge.

- Safety extraction equipment is available and ready to use
- Personnel are trained and certified for cryogenic tasks
- Have a checklist and use it for any task
- Ensure adequate warning signs are posted
- Complete a JSA and review with team operations and procedures prior to doing job
- Always work as a team of two or more
- Developing a written policy to show commitment and assign responsibility at every level
- Identifying and evaluating all hazardous substances in the workplace date MSDS for them
- Implementing safe work procedures and appropriate administrative and engineering controls, educating workers about labels, MSDS, safe handling, storage, disposal and emergency response
- Identifying required personal protective equipment and educating workers in its care and use

Actions at Emergency Conditions

- The personnels who are working in cryogenic plant must be aware of system information, cryogens information , PPEs, condition and type of cryogenic hazards or danger signs and what procedure should be followed in case of an accident or emergency conditions.

- Inform control room, identified personnel regarding emergency, safety In-charge for any accident, activation of emergency services like rescue, transportation of victims and calling fire brigade if necessary as a part of disaster management.

Summary

- The employer should show commitment towards safety and health practice and give full priority to promote and enforce the safety culture and health rules in workplace.
- At IPR, we are adopting and following the cryogenic guidelines and established procedures.
- By applying this practice results the safe long working in cryogenic environment without meeting any emergency condition.

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Thanks to All