Applying Standards and Transient Simulations to Find Root Cause of Fire Incident

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Content Overview

Introduction

- A recent fire incident in oil and gas plant was caused by exploded Nitrogen tank due to overpressure.

- Shrapnel from the tank was released to nearby equipment containing hydrocarbon (some hydrocarbon service was above autoignition temperature)

- Fire caused damage of equipment & piping, consequently some key evidence were destroyed.

Challenges

- Many physical evidence, piping, valves, insulation material were destroyed by fire.

- Damaged Nitrogen Storage tank was owned by third party requiring legal approval which delayed the equipment study.

- Investigation team was unable to visit the site to physically assess the evidence due to current Covid 19 pandemic travel restriction.

Background

- Cryogenic storage tank is used to store Nitrogen
- Nitrogen was only used for catalyst regeneration and blinded from process during normal operation.
- Incident occurred when the Nitrogen storage tank was not in service.

Background: Nitrogen Tank Diagram

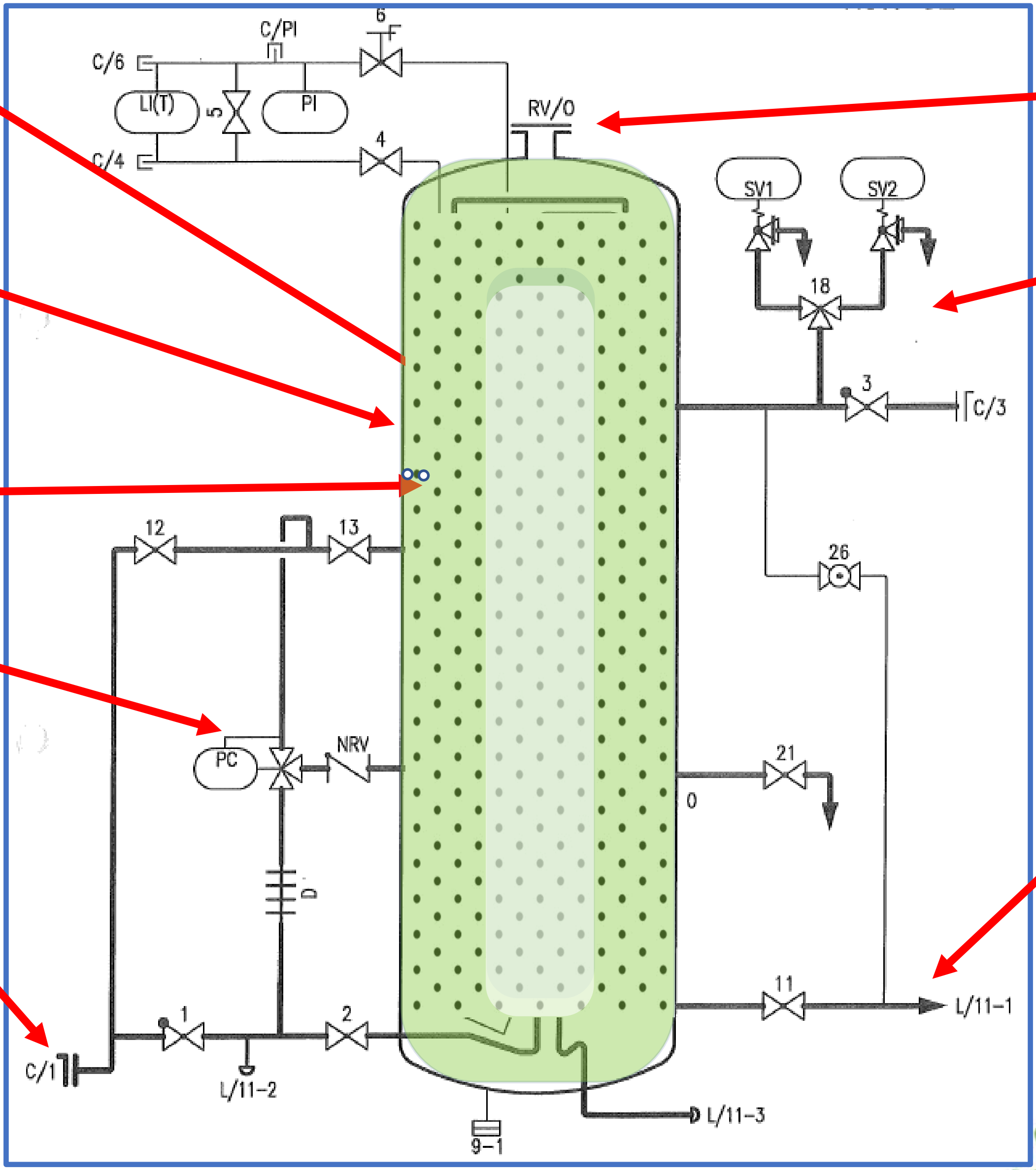
Inner Vessel
- **Stainless Steel, 304**

Outer Vessel
- **Carbon Steel**
- **Operating Pressure – vacuum of < 0.02 mbar**
- **Design Pressure – total vacuum**

Annular Space filled with perlite insulation & under vacuum condition

Pressure Regulator and Vaporizer:
- **To maintain pressure inside Inner Vessel**

Liquid Nitrogen filling line from tanker:
- **Top filling to reduce inner vessel pressure**
- **Bottom filling to increase inner vessel pressure**



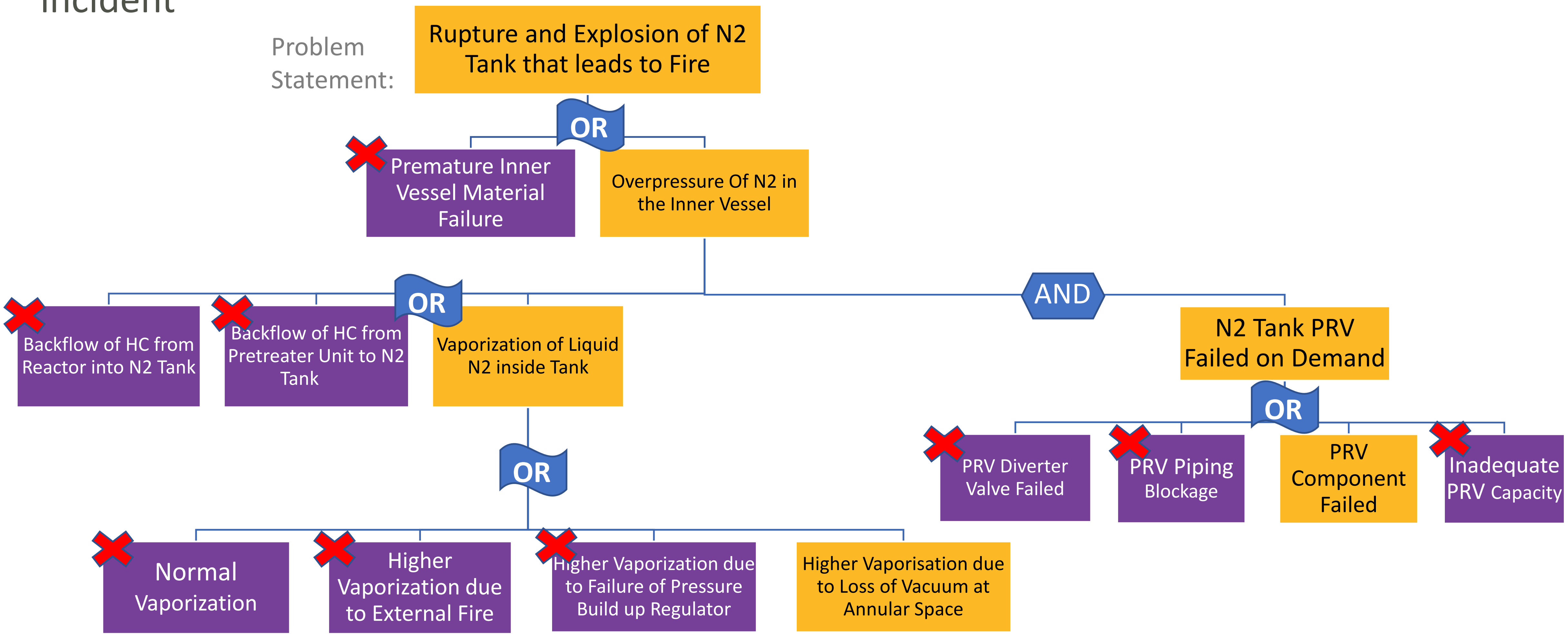
Relief Device at to prevent overpressure in case internal Vessel / Piping leak, as Outer Vessel is not designed as Pressure Equipment

Two Pressure Relief Valves set at design pressure.

Liquid N2 Discharge to Users through Vaporizer

Methodology

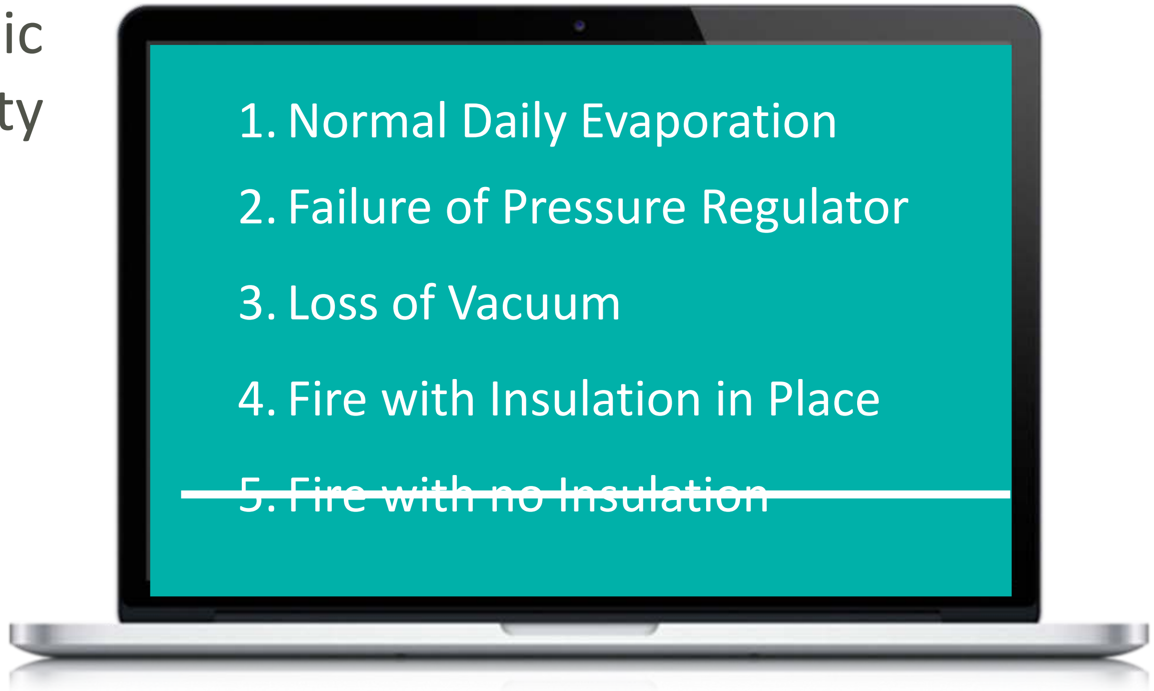
- Fault Tree Analysis (FTA) was the tool used to determine the failure mechanism of the incident



Reference to ISO Standards

- In FTA, team considered possible scenarios of caused of overpressure due to evaporation as highlighted in ISO 21013 - 3 Cryogenic Vessels – Pressure relief accessories for cryogenic service, Part 3: Sizing and capacity determination.

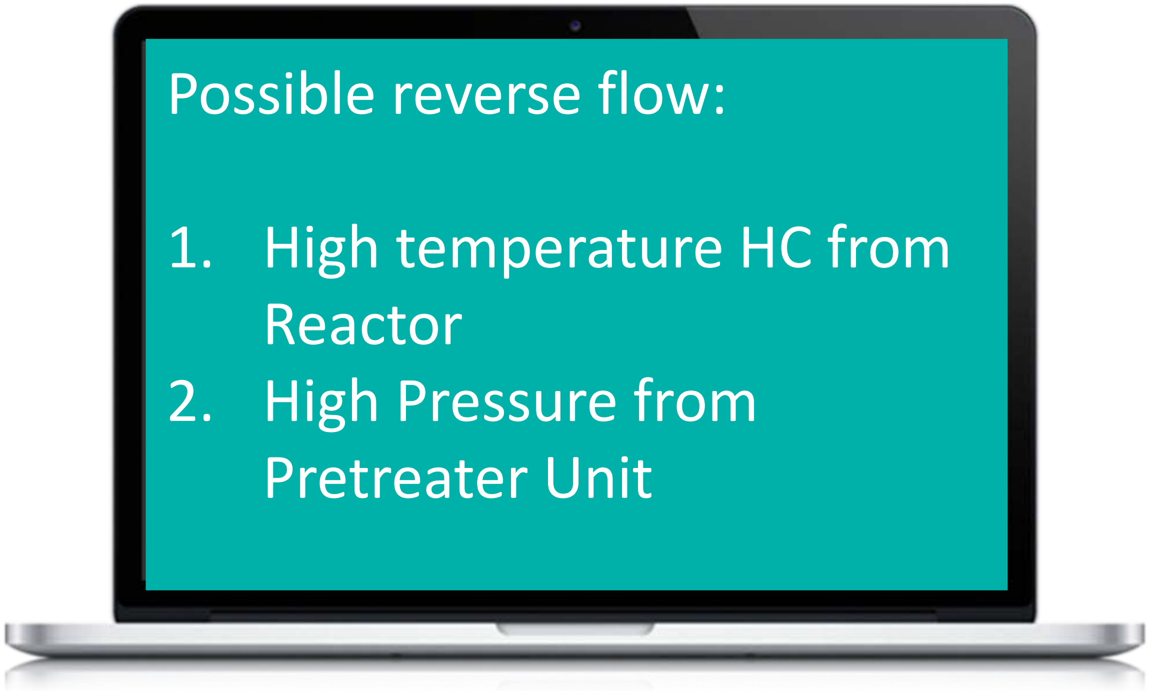
- The PRVs installed were adequately sized for scenarios 1-4. Scenario 5 is not applicable as insulation was in place during Fire.



Reference To API

- Apart from N2 evaporation inside the vessel, as per API Std 521, plausible causes of overpressure is due to failed of Non Return Valve (NRV) on process lines.

- The PRVs installed are not sized for these scenarios.



Shortlisted Possible Causes

NORMAL DAILY BOIL OFF
Level of N2 in tank reduced gradually seen from the Nitrogen tonnage trend.

FAILURE OF PRESSURE REGULATOR
Present of Pressure Regulator within the system

FIRE
Evidenced from the CCTV, fire did not occur before vapor released. Overpressure was not due to fire.

LOSS OF VACUUM/PERLITE
Credible case as defined in Standards

a) **Loss of vacuum due to outer vessel relief device seal leak**

b) **Loss of vacuum due to pinhole**

BACKFLOW FROM REACTOR
The duty from backflow is too high, resulted in much faster evaporation and not aligned with level trending (0.5 tonne/day – through manual calculation)

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BACKFLOW FROM PRE-TREATER
Evidence indicated blind was installed in closed position. Backflow is not possible

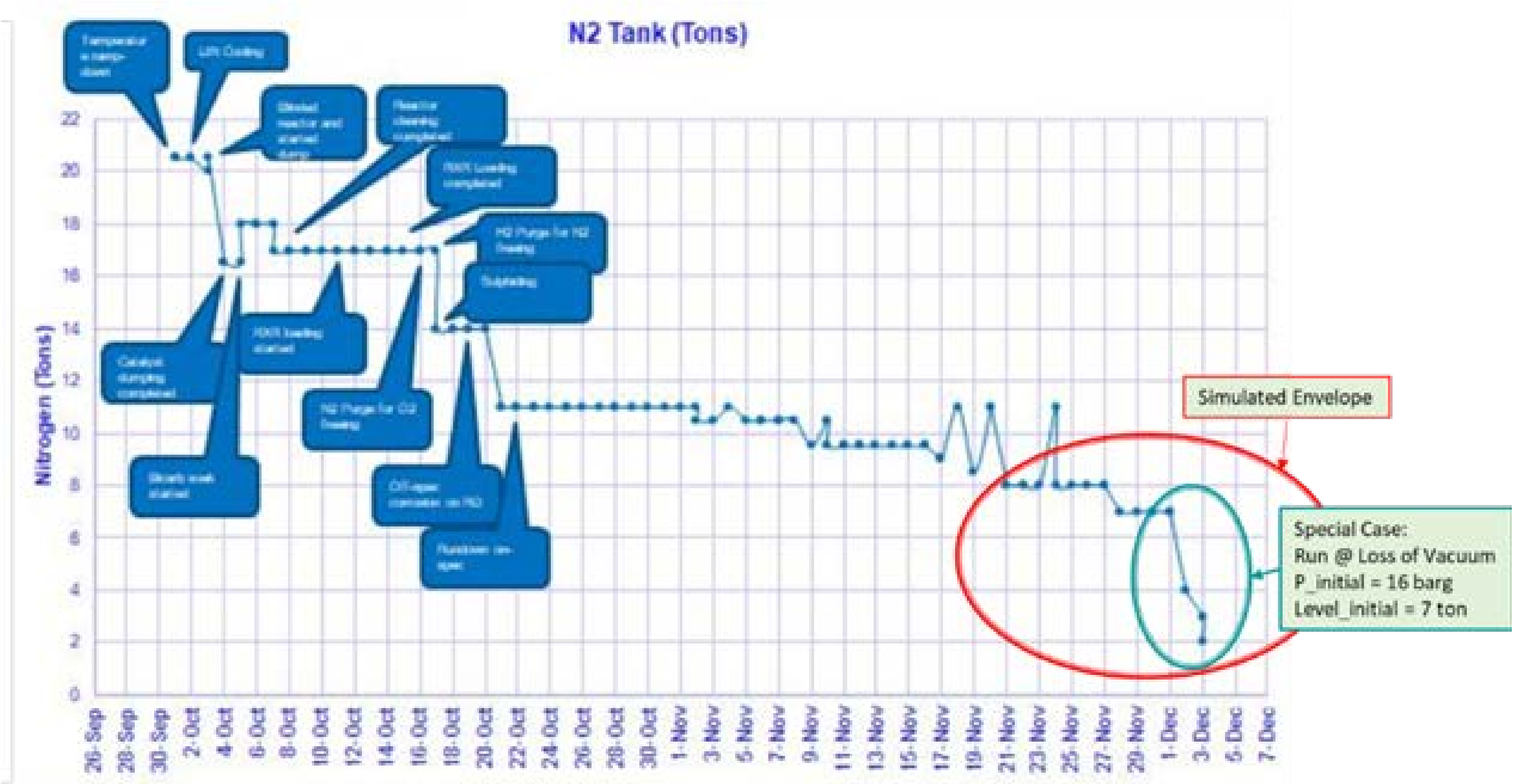
Only 3 cases are credible and can potentially cause the overpressure inside Inner Vessel.

Dynamic Simulation Cases and Basis

- Process Simulator: iCON Symmetry
- Thermodynamics package: APR-LK is utilized - high accuracy estimation on vapor liquid equilibrium and fluid properties of the process mixture
- 3 simulation cases were set up:
  1) Normal Evaporation Rate of 0.3% per day
  2) Pressure Regulator Fails
  3) Loss of Insulation/Vacuum
     a. Outer Vessel Relief Device Seal Leak
     b. Nitrogen Leak-through Pinhole from Inner Vessel to Outer Annulus.

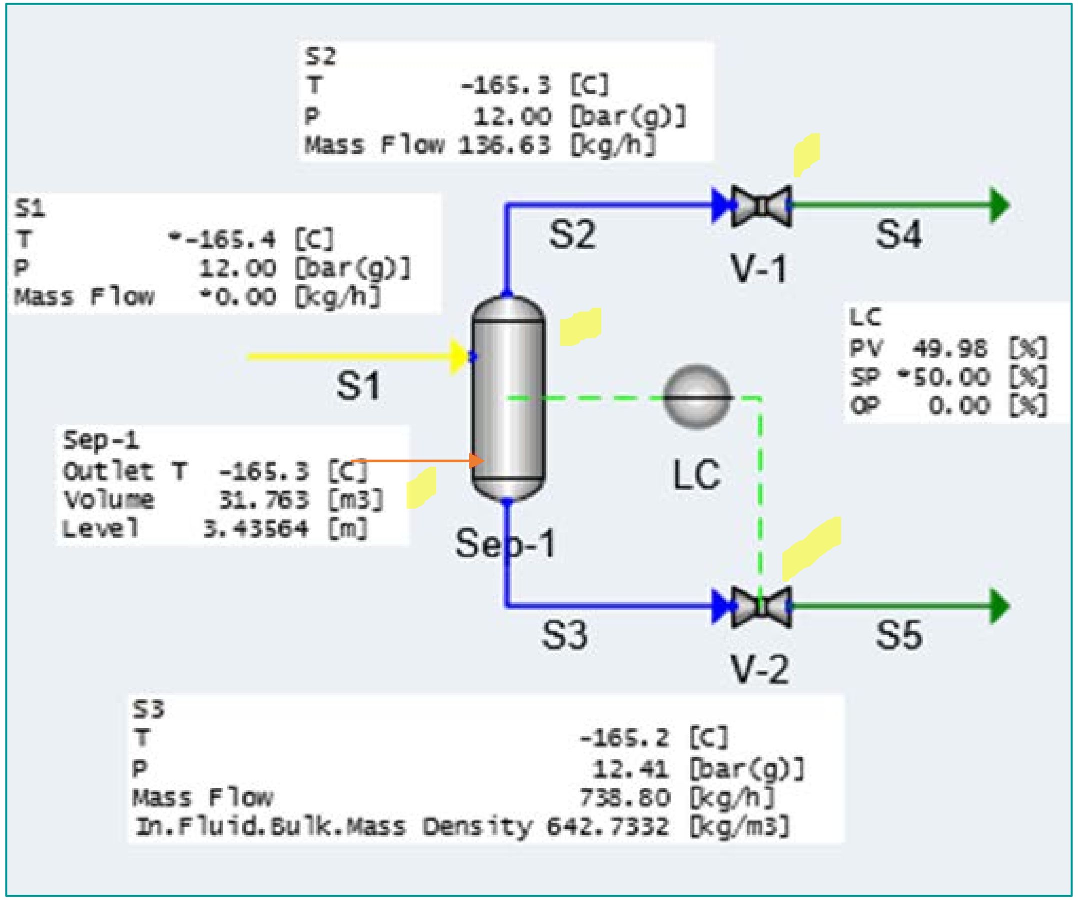
Dynamic Simulation Cases

- N2 Tank Loss (Actual Trending)



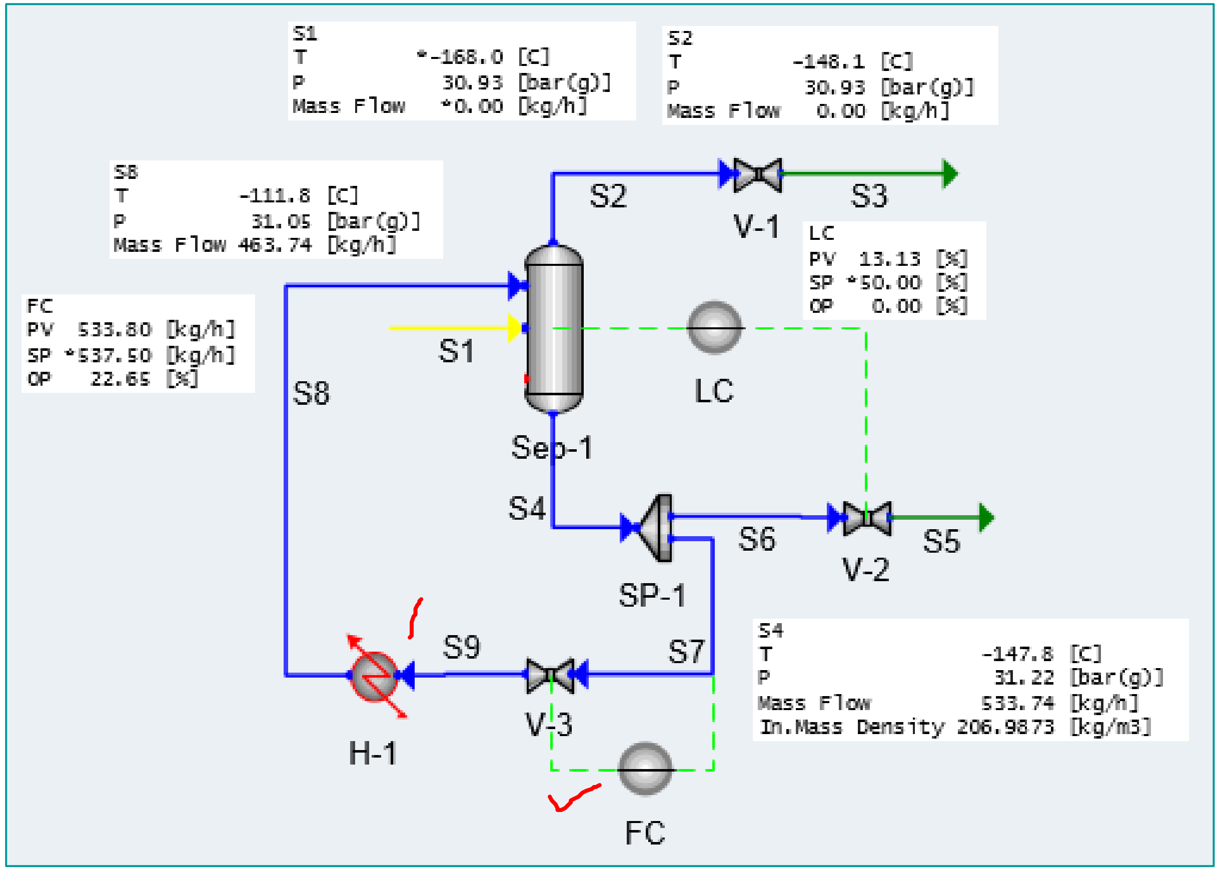
Dynamic Simulation Cases Set-Up

1. Normal Evaporation Rate of 0.3% per day



Dynamic Simulation Cases Set-Up

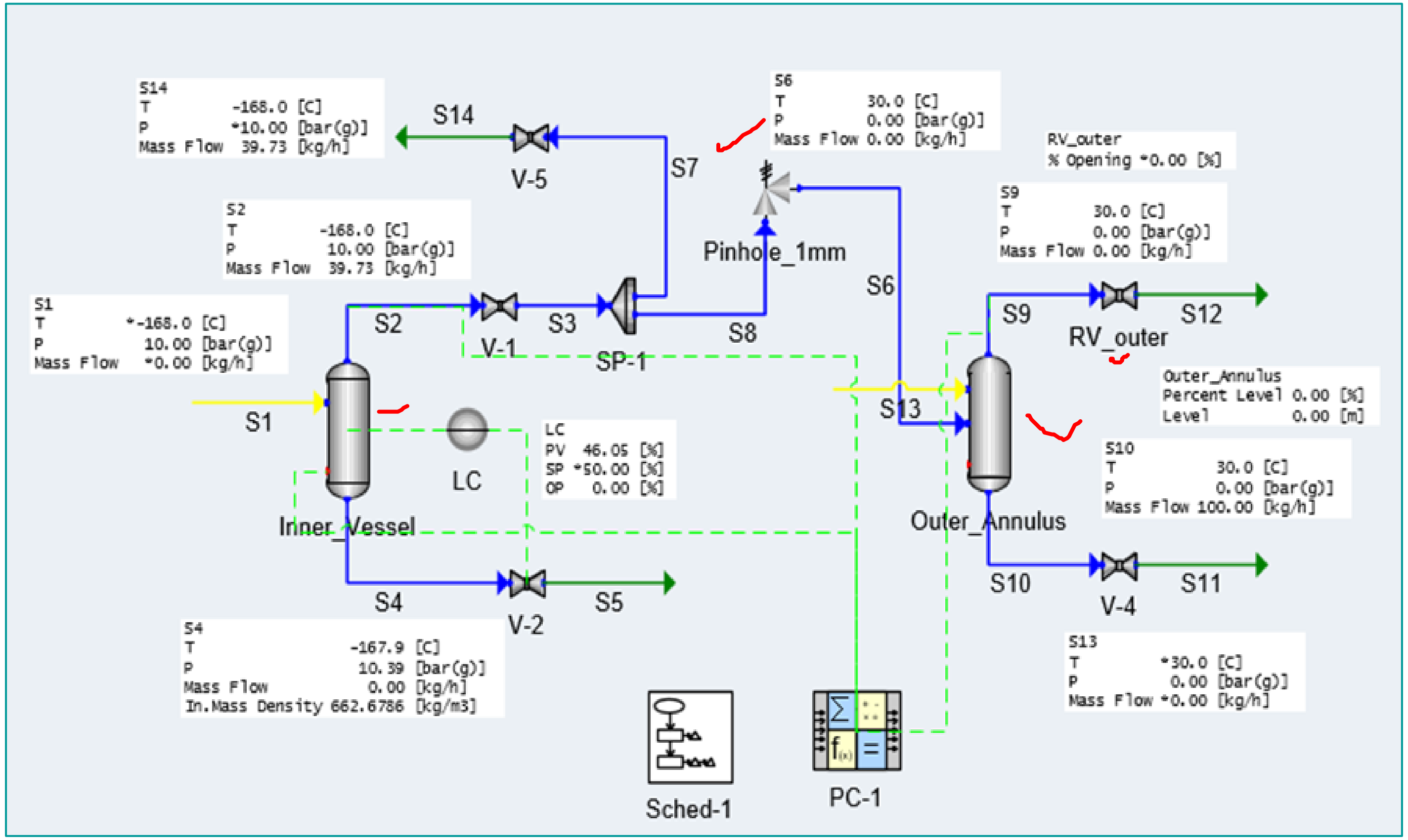
2. Pressure Regulator Fails Case Study



Dynamic Simulation Cases Set-Up

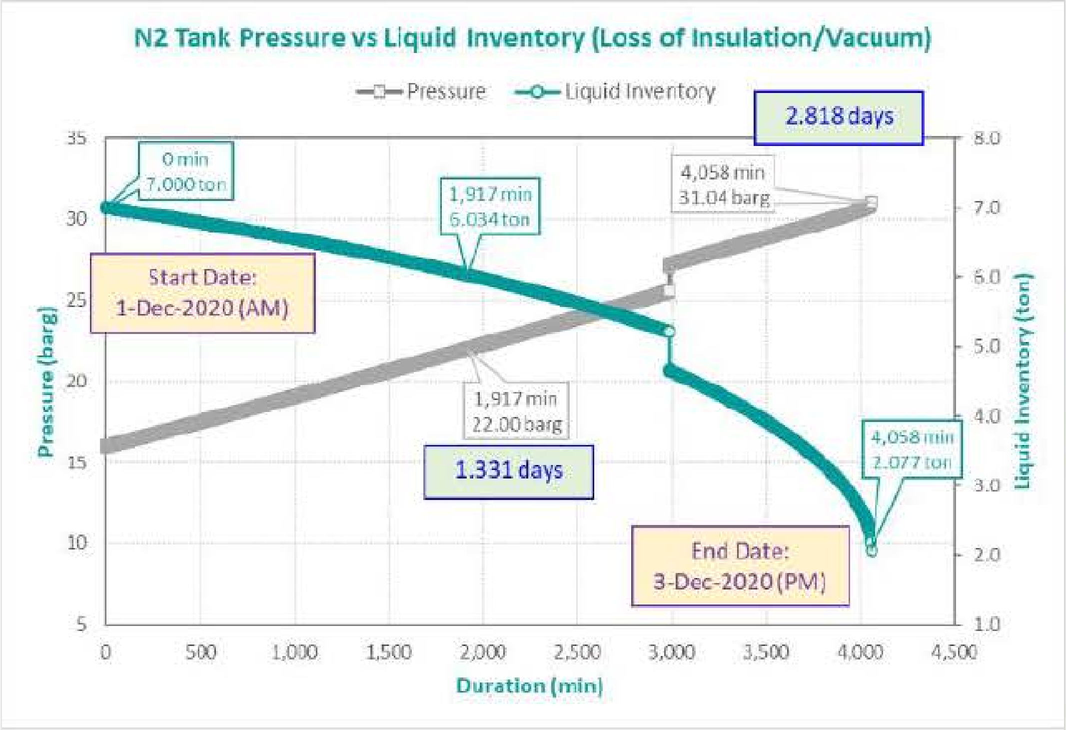
3. a. Loss of Insulation/Vacuum due to RV/0 Seal Leak

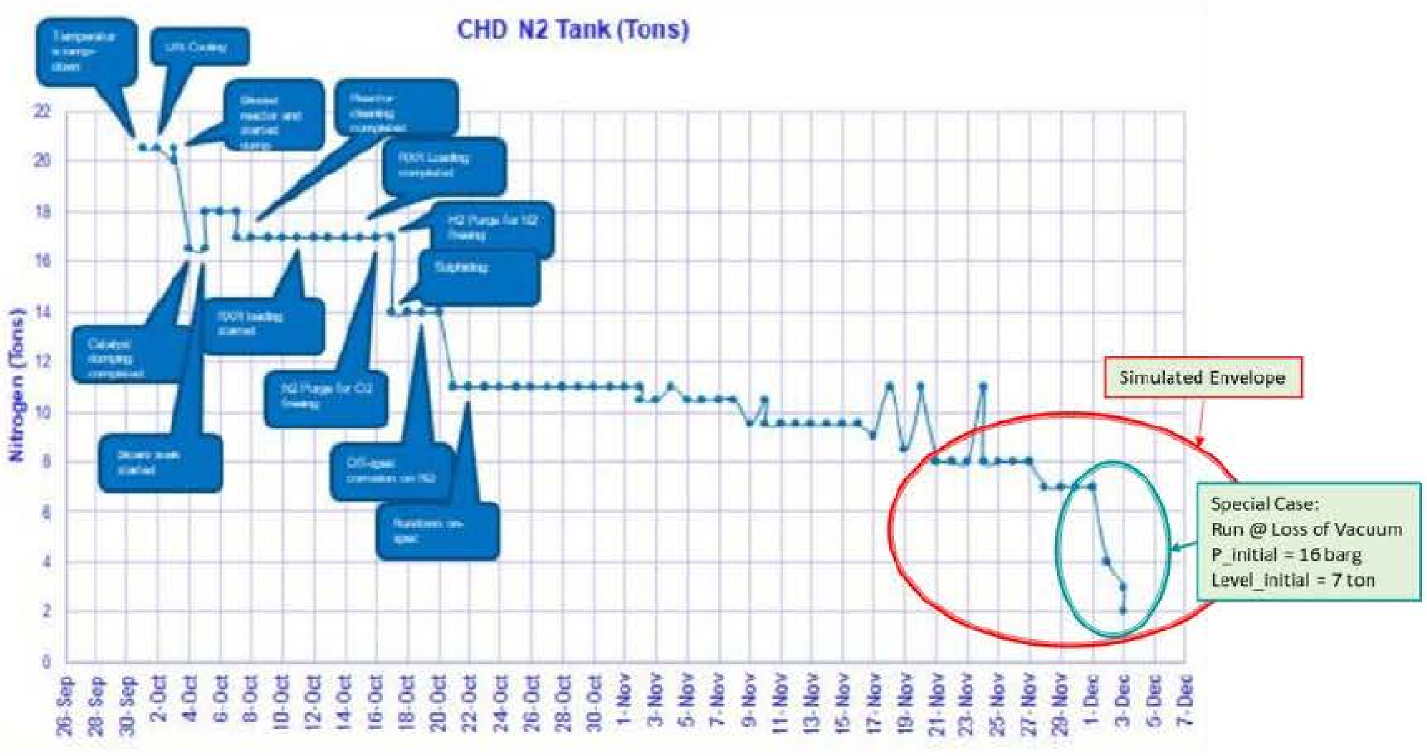
   b. Loss of Insulation/Vacuum due to N2 Leak through Inner Vessel to Outer Annulus



Dynamics Results

Simulation revolves around trying to estimate the duration it takes to lose liquid nitrogen level and compare it with actual tonnage trend from the plant. This is repeated for all cases, with different heat input.





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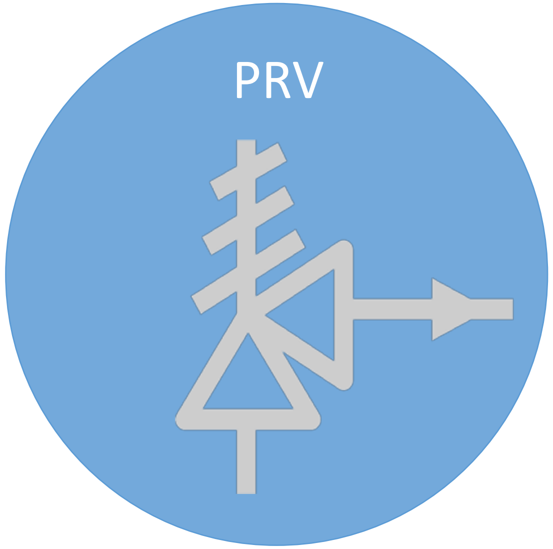
Dynamics Results to support Hypothesis Basis

No	Case	Heat Input (W)	Start pressure (barg)	End Pressure (barg)	Drop of level (tonne)	Duration (days)	Credible
Base	N2 tank tonnage trending	Unknown	Between 10 – 16	Unknown	From: (i) 8 to 7 (ii) 7 to 2	(i) 1 (ii) 3	
1	Simulation – Normal Boil Off	83	16	19.3	From 8 to 5.2	48	✗
2	Simulation – Pressure Regulator Fail	21,080	16	30.97	From 8 to 4	0.2	✗
3a	Simulation – Loss of Vacuum due to Pinhole Leak	92 – 1,403	16	8	From 8 to 7	5.8	✗
3b	Simulation – Loss of Vacuum due to Seal leak	1,427	16	31.04	From 7 to 2	2.8	✓

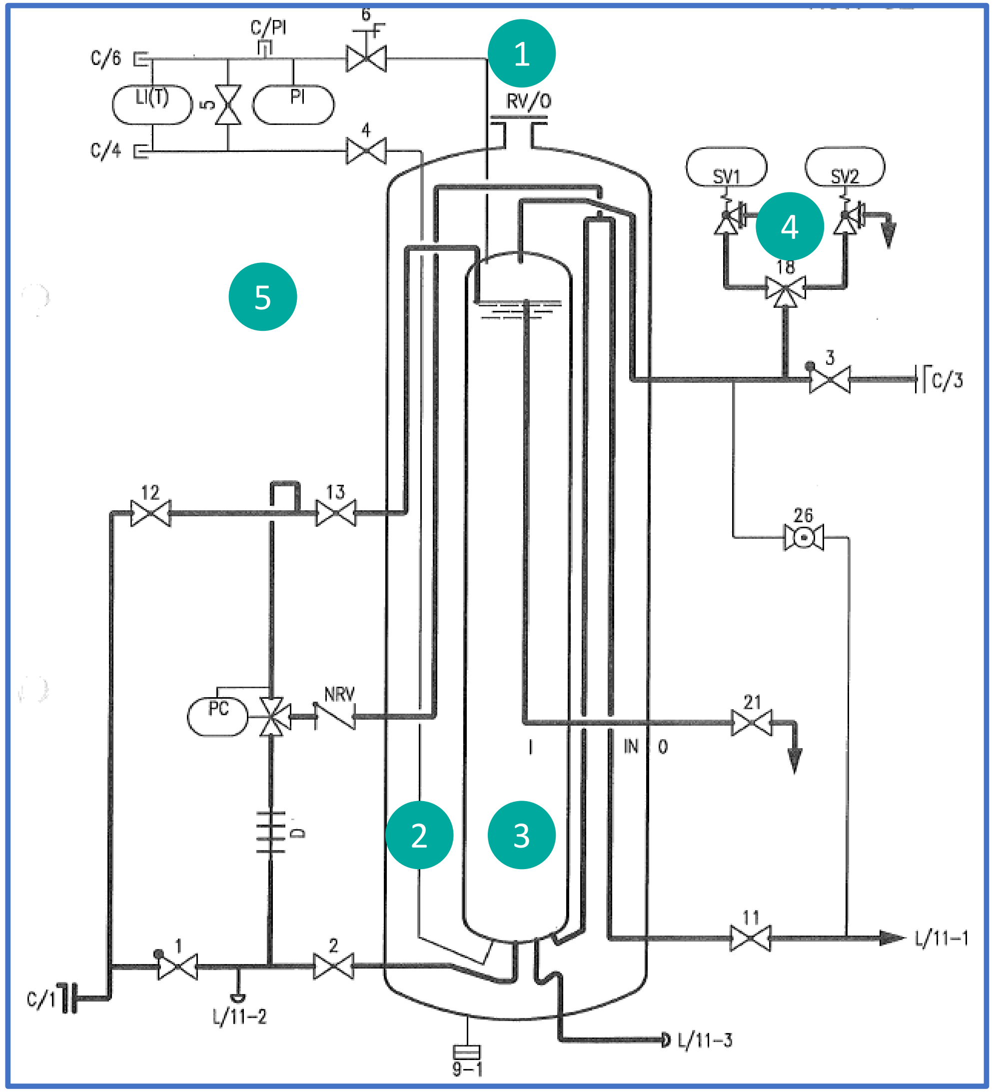
EVIDENCE OF PRV FAILURE



PRV POP TEST

- PRV body was found intact
- Based on Lab Analysis, the PRV in operation failed to 'pop' at set pressure.
- The reason of the failure could not be determined.

Hypothesis of Failure Mechanism



1 Seal leak / Loss of vacuum in the annular space.

2 The annular space experience ambient condition which warms up the N_2 in the inner vessel.

3 N_2 in the inner vessel expands and pressure increases until its vessel mechanical limit.

4 Safety valve, SV 1 or SV 2 (whichever operating) has failed on demand and resulting Nitrogen overpressure, thus vessel rupture.

5 Projectiles from the ruptured tanks hit nearby equipment and piping containing hydrocarbon (operating at 320 C) above its auto-ignition temperature (at about 210 C), resulting in secondary explosion and major fire.

Lesson Learnt

- The hazards is not fully understood especially by oil and gas users, thus Nitrogen has always been taken for granted as inert/non-flammable gas.

- To ensure HAZOP and LOPA covers third party equipment to ensure adequacy of independent protection layer (IPL).

Recommendations

- Finite element analysis can be done on the vessel debris to estimate the pressure at which the vessel ruptured.

- Training on hazards of Nitrogen storage and operations to be done to the operation personnel (user).

- Safe Nitrogen operation system and maintenance need to be improved with agreement and commitment from the third party storage tank owner and user.

Conclusion

- Design Standards can be used to guide on possible root cause for N2 tank failure.

- Dynamic Simulation can be used as a tool support hypothesis with regards to finding duration of overpressure in a storage tank.

- Loss of vacuum and PSV fails upon demand causing overpressure was concluded as the root cause for this Nitrogen tank failure

Thank You