HAZARD AND OPERABILITY ANALYSIS (HAZOP)

HAZOP

1. Hazard and Operability (HAZOP) analysis is a systematic and structured analysis of an operation/ equipment functioning to identify and evaluate problems/ defects/ events or Hazards, that may create risk to personnels or equipment or environment. This study is particularly carried out in process plants to identify potential hazards to the functioning of the plant/ equipment.

2. **HAZOP Analysis Procedure**. The procedures/ step caried out during the analysis are as follows: -

(a) **Plan and prepare**. To get the proper risk analysis there must be a proper plan to analyse the problem statement, hence there must be a good understanding of the problem.

(i) **Constitute HAZOP Team**. It is a panel of experts typically five to eight persons who possess extensive knowledge about the design, operation, and maintenance of the plant, and thus should be able to evaluate all the likely effects of deviations/ hazards from the design intent.

(ii) **Prepare Relevant Information**. This may include process flowsheets, piping and instrumentation diagrams (P&IDs), equipment details, piping and instrumentation specifications, control system logic diagrams, layout drawings, operation and intervention procedures, emergency procedures, codes of practice, etc.

(iii) **Divide the System into Nodes**. The system or equipment must be divided into *NODES,* which are subsets/ broken down version of main system. The analysis of these nodes with processes (operating parameter viz a viz flow, pressure, level, temperature etc) will overall constitute the study for the main system. These nodes can be subsystem/ auxiliaries likes pumps, piping, pressure tanks, control instrumentations etc.

(b) **Identify possible deviations/ Hazards**. This step identifies the defects/ hazards/ events that might arise due to improper functioning of the node.

(i) These includes any parameters that may go out of normal working range and thus are deviation from the correct functioning. E.g. High Flow rate, High Temperature, Low level etc.

(ii) The aim of this step is to identify '*What possibly can go wrong?*' i.e. Source of possible harm, accident or conditions that trigger accidents. E.g. Explosion, gas leak, flooding etc.

(c) **Determine causes of deviations/Hazards**. One of the most important aspects of HAZOP is getting to the cause of the hazard. This also includes the Human, Technical and Organisation causes that are affecting Equipment, People and Environment. These include factor that led to an accident/ hazard.

(d) **Determine consequences of deviations**. Based on the accident/ hazard, the consequence or effect on the machinery, people and environment is listed qualitatively.

(e) **Identify existing barriers/safeguards**. These are the components, devices, control instrumentation that prevent or minimise the consequences of the potential hazard/ accident. The HAZOP team considers whether the existing safeguards are sufficient or there is any need for incorporation of further barriers/ safeguards. Examples are Alarms, Trips, Interlocks, RFID tags etc.

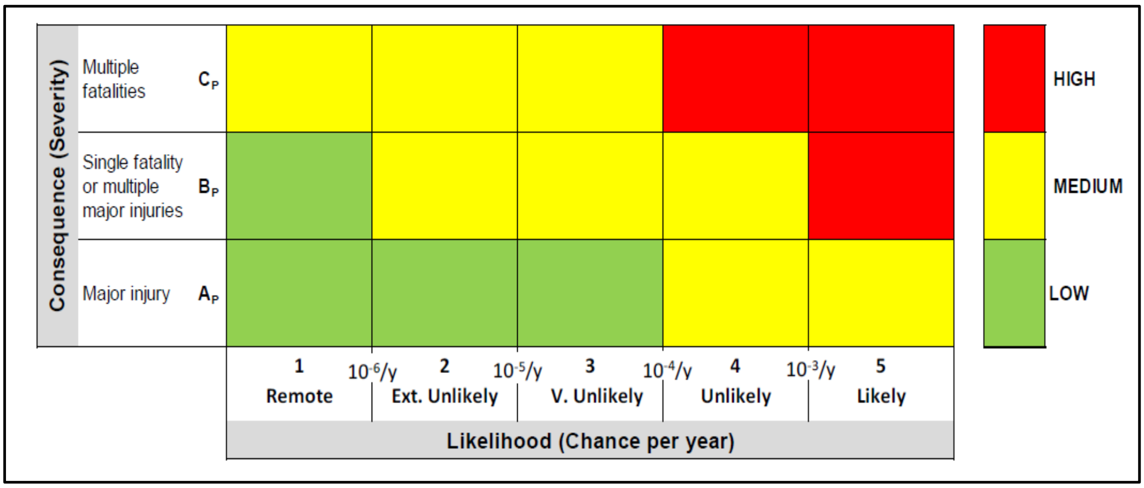
(f) **Risk Assessment**. In this, Risk and Severity related to each deviation is assessed using Risk matrix. It is one of the quantitative methods to find the how sever the deviation is along with the associated risk. This step is generally not the part of all HAZOP assessments. Risk assessment is the most important part of analysis where we identify hazards, their consequences, likelihood and severity of each hazard and finally implement control measures for the same.

(g) **Propose improvements**. Possible actions or improvements to prevent the deviations/ hazards/ accident to occur or to mitigate the consequences are recorded here. Name of point of contact/ person responsible can also be entered in one column where the follow of the deviations/ proposed improvement can be tracked.

RISK MATRIX

3. Risk matrix is a tool used in carrying out risk assessment analysis to evaluate and prioritise the risk/ hazards based on factors namely Likelihood (Probability of the even happening) and Severity (the potential impact or consequences of the risk). This helps in determining which risk requires more attention and guides in decision making on implementation control measures.

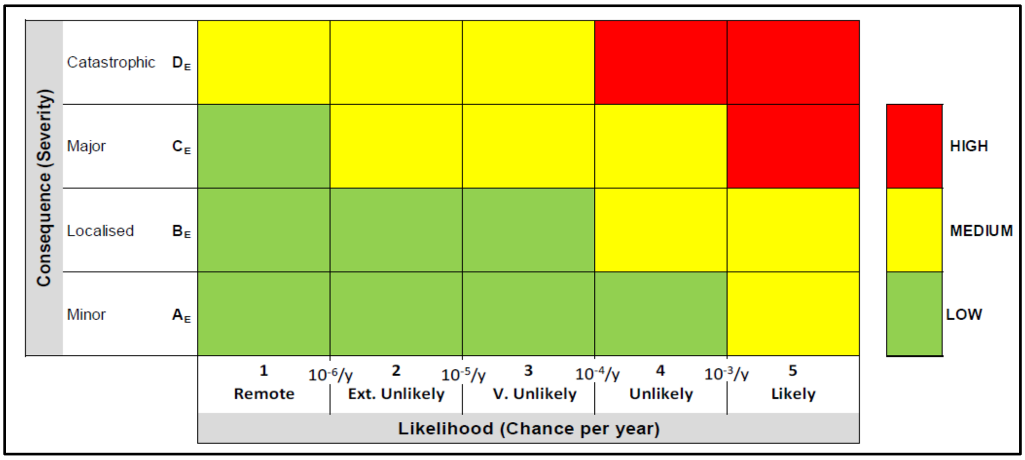
4. **RISK MATRIX: PERSON ONBOARD**



Rating and Risk Criteria

Low Risk - A_P1, A_P2, A_P3 & B_P1
Medium Risk - A_P4, A_P5, B_P2, B_P3, B_P4, C_P1, C_P2 & C_P3
High Risk - B_P5, C_P4 & C_P5

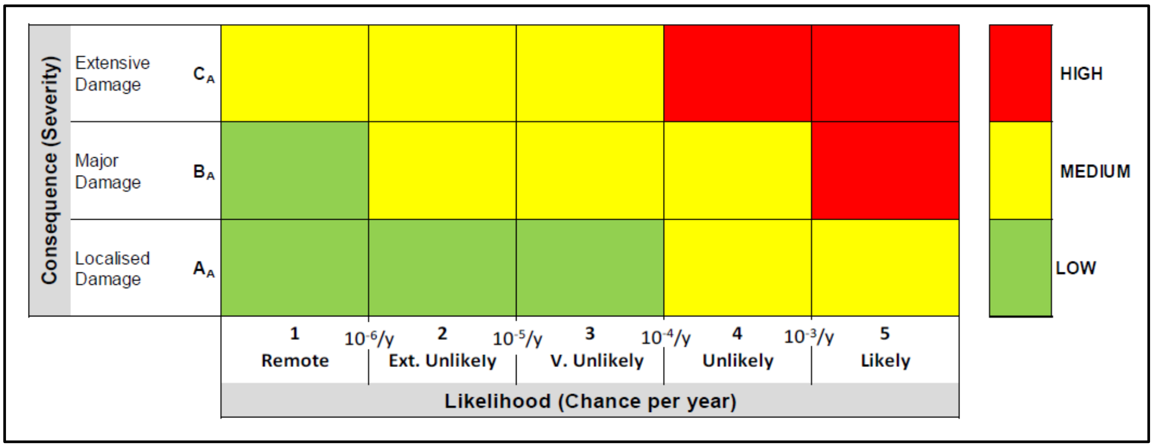
5. **RISK MATRIX: ENVIRONMENT**



Risk Rating

Low Risk - A_E1, A_E2, A_E3, A_E4, B_E1, B_E2, B_E3 & C_E1
Medium Risk - A_E5, B_E4, B_E5, C_E2, C_E3, C_E4, D_E1, D_E2 & D_E3
High Risk - C_E5, D_E4 & D_E5

6. **RISK MATRIX: ASSETS**



(a) **Risk Rating**

Low Risk – A_A1, A_A2, A_A3 & B_A1
Medium Risk – A_A4, A_A5, B_A2, B_A3, B_A4, C_A1, C_A2 & C_A3
High Risk – B_A5, C_A4 & C_A5

CARBON CAPTURE & STORAGE ONBOARD (CCS)

7. A Carbon Capture and Storage (CCS) system on ships is used to absorb the CO2/ Green House Gas emissions produced from various machinery/ equipment's to reduce greenhouse gas emissions, particularly CO_2, by capturing it from the ship's exhaust gases before it is released into the atmosphere. This system has been installed onboard marine vessels to comply with the IMOs regulations discussed previously in this report.

8. **Working of the CCS**. To carry out the HAZOP analysis, the detail working of the CCS system must be understood. The working of the CCS installed onboard various ships consists of various step, from treating the exhaust gas to separating and storing the separated elements. The detail working of the process have been enumerated below: -

CO2 Capturing Process

(a) **Exhaust Gas Collection**. Exhaust gas from the main engine is routed through the quencher (part of scrubber) by an external blower, where the temperature of the flue gas is brought down drastically. Quencher can be cooling water type or fin type, depending on the system design. This rapid cooling condenses the gases, reduce the volume and help remove any solid particulates if present.

(b) **Scrubbing**. This form the most important part of CCS system where the cooled flue gases are treated to remove the pollutants. The CO2 thus separated is processed to remove moisture and impurities, which would interfere with the storage later. Scrubbing can be achieved using the following methods: -

(i) **Chemical Absorption**. A lime-based solution generally containing *Soda Lime* (NaOH + Ca (OH)3 is the best CO2 absorbent) is present in the scrubber. This absorbs the maximum CO2 from the exhaust gases, thus making it cleaner and GHG free. High Efficiency of CO2 collected and established absorption system are the two important factor that allows this method to be the most suited for onboard ship installation. The chemical equation governing the reaction are: -

$$CO_2 + Ca\,(OH)_2 \rightarrow CaCO_3 + \text{Water}$$
$$CO_2 + 2NaOH \rightarrow Na_2CO_3 + \text{Water}$$

(ii) **Membrane Separation**. Separating CO2 from exhaust gases is an efficient and scalable process. This process requires passing of CO2 from a specially selected membrane viz a viz polymeric membranes, inorganic membranes (such as zeolites and silica), or mixed-matrix membranes (which combine polymers with inorganic filters. CO_2 molecules permeate through the membrane faster than N_2 and O_2 due to their higher solubility and diffusivity in the membrane material. Pressure gradient across the membrane allows the CO2 pass through the membrane. Purity of CO2, fouling and degradation of membrane and pressure gradient requirement are few aspects where this process is not much suitable for installation onboard ship.

(iii) **Cryogenic Distillation**. This process involves cooling of exhaust gases to extremely low temperature, thus condensing CO2 from other pollutants and hence cleaning the flue gases of GHGs. CO2 has high boiling points from other gages and hence it condenses faster than other gases. The process involves initial cooling and compression making it easier to condense CO_2 later in the process. After precooling, the exhaust gas mixture is cryogenically cooled up to -50 to -70 degree using specialised refrigeration system thus condensing CO_2 while other gases remain in gaseous forms. This is carried out in stages to avoid using high energy. High purity of Co_2 extracted, high energy demand and not suitable for low CO_2 concentration make it one of the suitable options to be fitted onboard.

(c) **Regeneration Process**. Regeneration is the process of extracting CO_2 back from the products of absorption process. CO_2 rich solvent is boiled to high temperatures where CO_2 evaporates and keep the residual solvent behind. The CO_2 steam is sent for Liquefaction process and residual solvent is sent to absorption tower for reuse. In order for efficient liquefaction, the generated CO_2 steam is cooled and condensed in reflux drum (horizontal or vertical drum which separates two fluids based on their density differences) where additional moisture is separated, and pure CO_2 is extracted.

CO2 Liquefaction

(d) **CO2 Compression**. Liquefaction is a process of liquifying a gas by cooling it below its condensation point under high pressure. Hence, CO_2 post regeneration is pressurised to 70 bar @room temp using CO_2 compressor and liquified. Compression makes it easier to cool the CO_2 to liquid state.

(e) **Dehumidification & Refrigeration**. Before the CO_2 is refrigerated, it is passed through a dehumidifier and condenser to remove any residual moisture created during the process of compression. Post dehumidification, the CO_2 is refrigerated, which cools it until it gets liquified.

(f) **Condensation**. Cooled CO_2 is finally again passed through a condenser to finally liquify it and make it ready for storage. Any leftover impurities/ gases are vented out as they wont get separated further.

Storage

(g) **Storage Tanks**. The liquified CO_2 is transferred to the storage tanks. These are designed to keep liquid CO_2 at required pressure and temperature. These tanks have pressure gauges, monitoring instrumentation, relief valves, level indicators for safe control and monitoring of the liquid CO_2. Tanks are insulated to avoid any heat transfer which can lead to unwanted heating and pressure built up.

(h) **Pumps**. Spray pumps and transfer pumps are used for internal circulation of CO_2 to avoid stratification (process of layer formation in fluids due to heating/ cooling). Transfer pumps may also be required to transfer the CO_2 from onboard storage tanks to shore establishments.

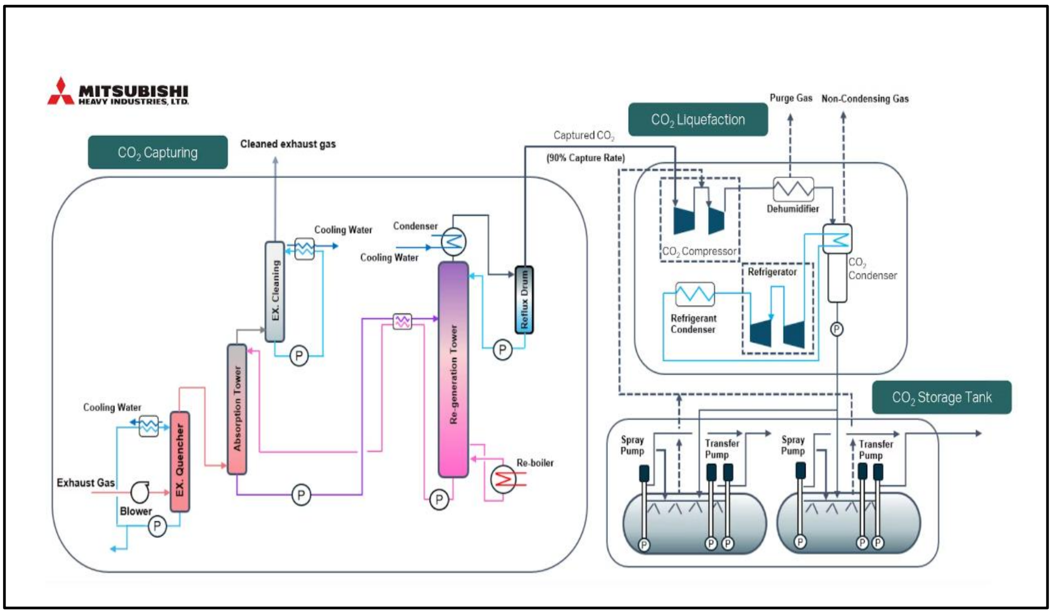


Fig 8. Process Flow of a Carbon Capture and Storage system onboard
https://www.zerocarbonshipping.com/publications/the-role-of-onboard-carbon-capture-in-maritime-decarbonization/

HAZOP Table for Carbon Capture and Storage System

Node/ Equipment	Sub Equipment	Para meter	Guide word	Deviation	Causes	Consequences/ Hazards	Risk Analysis			Safeguard	Recommendations (additional measures)
							Ppl.	***Env.***	***Ast.***		
Exhaust gas handling unit	Exhaust Gas Ducts	Exhaust gas flow rate	No FLow	No flow through the exhaust duct	Exhaust duct blockage due to debris and corrosion	Increased backpressure, engine damage, reduced CO2 capture efficiency	BP4	DE3	CA4	Flow monitoring sensors with alarms	Install differential pressure sensors to detect early signs of blockage (pre-warning function) Implement a routine maintenance for internal inspection & cleaning of duct
		Exhaust gas flow rate	More Flow	Excessive Exhaust Flow rate	Damper malfunction, fan over-speed	Overloading of downstream equipment, inefficient CO2 capture	BP2	CE3	BA4	Flow monitoring sensors with alarms, Damper position feedback control, Fan speed control system	Implement automatic damper cleaning system before & after system operation, Install stand-by fan
	Duct Fan (Exh. Gas suction fan)	Exhaust gas flow rate	No Flow	No flow through Duct Fan	Electrical failure of Fan motor or mechanical failure of impeller unit	No gas-flow to CCS system, overheating of equipment	BP2	DE3	CA4	Interlock system to shut down CCS in case of fan failure	Backup power supply for fans, Install stand-by fan
		Exhaust gas flow rate	More Flow	More Flow through the Duct Fan	Fan over-speed	Overpressure in duct, equipment damage	BP2	DE3	BA2	Fan motor speed control using VFD & monitoring system	Implement shut down system for fan overspeed
	Damper	Position	Fail	Damper Fails to open	Mechanical failure, actuator failure	Bypass of exhaust gases without capturing CO2	BP2	DE4	AA5	Redundant control systems	Install manual overrides for dampers and test actuator performance regularly, Implement automatic damper cleaning system before & after system operation
		Position	More	Damper opening excessive	Control system malfunction	Excessive exhaust flow through the system	BP2	DE3	BA2	Damper position feedback control	Regular testing of damper control systems
Absorption Unit	Absorber Column	Gas flow	No Flow	No flow of exhaust gas	Blockage in inlet piping, fan failure	No CO_2 capture, **increased emissions**	BP2	DE3	CA4	Flow monitoring sensors, Interlock system to shut down CCS in case of fan failure	Install differential pressure sensors for column to detect blockages early and trigger alarms

		Gas flow	More Flow	Excess flow of exhaust gas	Damper malfunction, fan over-speed	Reduced CO_2 capture efficiency, **solvent flooding**	BP2	DE3	BA2	Fan speed control system, damper position feedback control	Implement automatic damper cleaning system before & after system operation, Install stand-by fan
		Gas flow	Less Flow	Less Flow	Partial blockage, fan failure	Reduced CO_2 capture efficiency, **increased emissions**	BP2	DE3	BA4	Regular fan maintenance schedule	Install airflow sensors to monitor real-time flow rates and alert operators of low flow conditions
		Gas pressure	High Pressure	High Pressure	Blockage in outlet piping	Equipment damage	BP2	DE3	BA3	Pressure relief valves on absorber column	Install pressure monitoring sensors with alarms to detect high pressure early
		Gas pressure	Low Pressure	Low Pressure	Leak in absorber column or piping	Inefficient CO_2 capture, loss of solvent	BP2	DE3	BA2	Leak detection systems	Conduct regular inspections for leaks and install automatic shutdown systems for leaks
	Solvent Circulation Pump	Solvent flow	No Flow	No Flow	Pump failure, clogging in solvent lines	No CO_2 absorption, solvent degradation	BP2	DE3	CA3	Stand-by pump	Install pump failure alarms and interlock system to stop process if solvent flow stops
		Solvent flow	More Flow	More Flow	Pump over-speed	Solvent flooding in absorber column, reduced capture efficiency	BP2	DE3	BA2	Pump motor speed control system	Install flow sensors and alarms for solvent circulation monitoring
		Solvent flow	Less Flow	Less Flow	Pump underperformance, partial blockage	Incomplete CO_2 absorption, reduced efficiency	BP2	DE3	BA4	Regular pump maintenance schedule	Install flow sensors and alarms for solvent circulation monitoring
	Heat Exchanger	Cooling efficiency	No Cooling	No Cooling	Cooling water failure	Overheating of solvent, reduced CO_2 absorption	AP1	DE3	BA3	Backup cooling system	Install temperature monitoring sensors with alarms and interlock systems to shut down process if cooling fails
	Cooling Pump	Cooling water flow	No Flow	No Flow	Pump failure, electrical failure, clogging in cooling water lines	Overheating of exhaust gases, reduced CO_2 absorption efficiency, solvent degradation	AP1	AE3	BA3	Backup pump, regular maintenance checks	Install pump failure alarms and interlock system to shut down process if cooling fails
		Cooling water flow	Low Flow	Low Flow	Partial blockage, pump underperformance	Incomplete cooling, overheating of exhaust gases, reduced CO_2 capture efficiency	AP1	AE3	BA2	Regular pump maintenance schedule	Install flow sensors and alarms for cooling water circulation monitoring
Regeneration Unit	Regenerator Heater	Temperature	Low Temp	No Heating	Heater failure, electrical fault	Solvent not regenerated, CO_2 remains in solvent, reduced CO_2 capture efficiency	AP1	AE3	BA4	Temperature monitoring sensors with alarms	Install backup heater to ensure continuous operation

		Temperature	High	Overheating	Control system failure, sensor malfunction	Solvent degradation, potential damage to equipment due to high temperatures	AP1	AE3	BA3	Automatic temperature control system	Implement high-temperature shutdown interlock
	Regenerator Column	Pressure	High	High Pressure	Blockage in outlet piping or CO_2 compressor failure	Equipment damage, safety hazards	AP1	AE3	BA3	Pressure relief valves on regenerator column	Install pressure monitoring sensors with alarms to detect high pressure early
		Pressure	Low	Low Pressure	Leak in regenerator column or piping	Inefficient CO_2 release from solvent, loss of solvent	BP4	AE3	BA3	Leak detection systems	Conduct regular inspections for leaks and install automatic shutdown systems for major leaks
	Heat Exchanger	Temperature	No	No Cooling	Cooling water failure	Overheating of solvent during regeneration process, reduced CO_2 absorption efficiency in next cycle	AP1	AE3	BA2	Backup cooling system	Install temperature monitoring sensors with alarms and interlock systems to shut down process if cooling fails
		Temperature	More	More Cooling	Excessive coolant flow or low coolant temperature	Suboptimal regeneration due to low temperature, incomplete CO_2 release from solvent	AP1	-	AA3	Temperature control system	Implement automatic temperature control calibration during maintenance
	Reflux Drum	Separation efficiency	NA	No Separation	Overloading of CO_2 gas flow, improper cooling in condenser, fouling inside drum	Water carryover into CO_2 stream, corrosion in downstream equipment (compressors, pipelines)	AP1	-	BA3	Regular maintenance of condenser and reflux drum, temperature control system	Install liquid level sensors to detect improper separation and trigger alarms
		Liquid level	High	High Liquid Level	Excessive condensate return, blockage in liquid outlet line	Reduced efficiency in solvent regeneration, overflow	BP4	-	BA5	Level monitoring sensors with alarms	Install automatic shutdown system if liquid level exceeds safe limits
		Liquid level	Low	Low Liquid Level	Insufficient condensates return from condenser, leakage in reflux drum or piping	Inefficient solvent regeneration due to water imbalance, potential solvent degradation	AP1	-	BA4	Regular inspections for leaks, level monitoring system	Install low-level alarms and interlock system to shut down process if liquid level is too low
Chemical Solvent Storage Tank	Chemical tank	Level	More	Excessive level	Tank overpressure, sensor failure	Vapor release, toxic exposure to crew, leakage	BP3	CE3	BA3	Level sensor, sealed tank, ventilation, gas detector, PPE for crew	Regular inspection and apply condition monitoring on tank and ventilation

	Chemical tank	Level	Less	Low level	Leakage in pipe and pump malfunction	Inefficient operation	AP2	AE1	AA2	Level sensor	Pipeline & pump inspection, apply condition monitoring approach on storage tank
	Chemical tank	Pressure	More	More pressure inside the tank	Failure of the pressure relief valve, failure of the automatic pressure control	Vapor release, possible explosion, toxic exposure to crew	BP3	CE3	BA3	Pressure relief valves, tank venting, PPE for crew	Regular monitor of the pressure, conduct valve inspection
	Chemical Pipelines	Flow rate	High	Excessive flow	Failure overrun and flow control valve failure	Solvent flooding, tank & pump damage, toxic exposure	BP2	BE2	BA2	Flow meter, control system, high level alarms	Pump inspection, adjust calibration
	Chemical Pipelines	Flow rate	No	No flow	Failure of pump and flow control, clogged filter	Incomplete CO_2 absorption, operational inefficiency	-	-	AA2	Pressure gauge, low level alarms	Pump inspection, renew filters, adjust calibration, conduct pipe flushing
Chemical Solvent Pipeline System	Chemical Pipelines	Quality	Low	Welding defect	No regular visual inspection, poor quality of material and poor coating & welding	Leakage of toxic chemical causing **rashes** and **burning sensation**	BP2	BE2	BA2	Leak detection, corrosion-resistant materials, anti-corrosion coating, PPE for crew	Regular inspection and required painting/ coating during planned maintenance periods
Compression System	Compressor	Flowrate	Less	Low Flow rate of CO2 to the compressor	Blockage in the pipeline (upstream)	1. Dry running of compressor leading to seal failure and overheating of parts 2. Improper compression leading to low efficiency of Liquefaction	AP1		BA3	Low Pressure Cutout at inlet of Compressor will trip the compressor.	Regular clean ship of pipeline and condenser tubes as per maintenance schedules.
	Compressor	Flowrate	Less	Low Flow rate of CO2 to the compressor	Partial Blockage in Reflux drum or Condenser	Low CO2 pressure at the inlet of compressor leading to dry running and overheating of parts	AP1	AE1	BA2	Low Pressure Cutout at inlet of Compressor will trip the compressor.	Regular clean ship of pipeline and condenser tubes as per maintenance schedules.
	Suction Piping	Flowrate	No Flow	No flow of CO2 to the compressor	Valve malfunctioning	Low CO2 pressure at the inlet of compressor leading to dry running and overheating of parts	AP1	AE1	BA1	Low Pressure Cutout at inlet of Compressor will trip the compressor.	Functionality checks to be conducted regularly on prior operation of the plant
	Flowmeter	Flowrate	Erratic	Erratic Flowmeter reading	Faulty Flowmeter	Faulty flow reading leading to incorrect calculation in control system/ cut in-cutouts.			AA2	NA	A dual channel Flowmeter or two flow meter can be used for redundancy.

	Discharge Piping	Hight Pressure	High	High Pressure at downstream of Compressor	Discharge valve malfunction	Material damage at the downstream of compressor. Probable pipe rupture or compressor damage **injuring the person** nearby	BP2	CE2	BA2	1. High Pressure cutout at discharge of compressor with prior alarm. 2. Relief valve for release of over pressure to atmosphere.	Install additional relief valves at downstream and upstream of Compressor and Dehumidifier respectively.
	Dehumidifier	High Pressure	High	High Pressure at downstream of Compressor	Clogged Dehumidifier	Internal damage to dehumidifier, thus releasing CO2 outside	BP2	BE2	BA2		
	Compressor	High Pressure	High	High Pressure at downstream of Compressor	Control Failure	Inadvertent shutting of the compressor			AA1	Pressure transmitter, Gauges and Alarms	1.Additional pressure transmitter may be installed. 2. Annual calibration check of instrumentation should be carried out.
	Compressor	High Vibrations	High	High Vibration of the compressor	1. Misalignment 2. Looseness of parts 3. Mounts degradation 4. Bearing failure	1. Mechanical failure of parts, bearings or ceasing of compressor at worst cases. 2. Leakages of CO2 to atmosphere causing **Cold burn** or **Asphyxiation**	BP2	AE2	CA2	1. Shock and Vibration mounts. 2. Vibration dampers	1. Online vibration measuring sensor can be installed as pat of CBPM techniques. 2. Vibration analysis of the compressor can be done as part of maintenance routine. 3. Routine tightening and alignment of the compressor to be carried out.
	Compressor	High Temperatu re	High	High compressor temperature	Improper compressor cooling while running	Cooling Fan malfunctioning and Overheating may **cause burns**	AP1		AA1	High Temperature Cutout	Periodic maintenance of lub oil system and cooling fan impeller
	Compressor	High Temperatu re	High	High compressor temperature	Faulty lubricating oil pump	Bearing failure and compressor ceasing. Overheating may cause **burn**s.	AP1		BA2	Differential oil pressure cut out	
	Compressor	High Temperatu re	Erratic	High compressor temperature	Faulty RTD	Erratic temperature indication and control system failure			AA2	High Temperature Cutout	Annual calibration check of instrumentation should be carried out
	Compressor	Flowrate	Leak	CO2 leakage in system	1.Mechanical Seal Failure 2. Damaged gaskets	1. **Asphyxiation risk** 2. Freezing of pipeline leading to **cold burn**. 3. Environmental risk	BP2	BE2	AA2	CO2 leak detectors	1. Regular inspection of seals & Gaskets 2. Annual calibration of leak detectors.

	Piping	Flowrate	Leak	CO2 leakage in system	Corrosion and pipeline material degradation	Pipeline rupture and CO2 leakage.	CP1	CE2	AA2		Routine maintenance of pipeline like painting and clean ship.
Refrigeration System	Ref Compressor	Cooling Effect	Low	Insufficient Cooling in Refrigeration system	Low refrigerant or refrigerant leak	In sufficient cooling and Inefficient CO2 liquefaction	AP1	AE1	AA2	Refrigerant Leak Detector	Annual calibration check of instrumentation should be carried out
	Ref Compressor				Condenser clogged	In sufficient cooling and Inefficient CO2 liquefaction			AA2	Bypass condenser or redundant condenser	Routine cleaning of condenser as part of maintenance operations.
	Ref Compressor	Refrigerant Pressure	Low	1. Insufficient Cooling 2. Low refrigeration pressure	Low refrigerant or refrigerant leak	**Nausea** caused by Refrigerant leakage.	AP1	AE1	AA1	Low pressure transmitters and alarms	Periodic leak check of system and regular refrigerant charging as per operating parameters.
	Ref Compressor	Refrigerant temperature	Freeze	Freezing of compressor & Pipelines leading to blockage	Excess refrigerant charging	**Cold Burn** to Watchkeeper	AP2		AA2	Temperature monitoring	Regulate refrigerant level/ flow
	Ref Compressor	Refrigerant Pressure	High	1. Insufficient Cooling 2. High refrigerant pressure	Over charging and condenser blockage	1. Inefficient cooling and liquefaction of CO2 2. Overpressure can cause material failure	AP1	AE1	AA1	Relief valves, High Pressure cut outs, Pressure Transmitters	Relief valves, High Pressure cut out, Pressure Transmitters
CO2 Storage Tank	CO2 Storage Tank	Tank Level	Erratic	Erratic Tank Level indication	Sensor failure	Incorrect tank reading might lead to control system failure.	AP1	AE1	AA2	Level sensor/ Level gauge, High level alarm	Annual calibration check of instrumentation should be carried out
	CO2 Storage Tank	Tank Level	Low	Low tank level	Leakage in pipe leading	CO2 release to atmosphere	BP2	CE2	AA2	Level sensor/ Level Gauge, High level alarm	Inspection of pipeline and gaskets during maintenance periods.
	CO2 Storage Tank	Tank Pressure	High	More pressure inside the tank	Failure of the pump & pressure control	CO2 release, tank rupture	BP2	BE2	AA2	Pressure relief valves	Regular monitor of the pressure and periodic testing of Tank and relief valve for MAX WORKING PRESSURE
CO2 Pipeline System	Transfer Pipelines	Flow rate	High	Excessive flow of Liquid CO2	1. Over speeding of pump 2. Flow control valve failure	1. Pipeline rupture due to overpressure 2. CO_2 release	BP2	CE2	AA2	Flow meter, VFD for pumps control system, high level alarms	Pump inspection, testing of tank and pipeline till MAX Working pressure.
	Transfer Pipelines	Flow rate	No Flow	No flow through the CO2 transfer pipelines	Failure of pump and flow control, pipe blockage	Inefficiency in capture	AP2	AE2	AA2	Pressure gauge, low level alarms	Pump inspection, adjust calibration, conduct pipe flushing

Loading & Unloading of CO_2 Storage Portable Tank	CO_2 Storage Tanks	Tank Weight	Less	Expired Lifting Gears	Lack of preparation & hazard identification	Lifting injuries, damage to the tank, CO_2 leakage	CP4	DE4	BA3	Personal protective equipment (PPE)	Risk assessment & hazard identification of lifting need to be done, including checklist and inspection of lifting gears

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