

ภาคผนวก ข

เอกสารประกอบมาตรการป้องกันและ
แก้ไขผลกระทบสิ่งแวดล้อมและมาตรการติดตาม
ตรวจสอบคุณภาพสิ่งแวดล้อม

ภาคผนวก ข-1

เอกสารการจัดทำ HAZOP ของโครงการ

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Project No. PHA TH 2019_002

PHA_TH_HYCO_issue

Leader: Taweewat M

Scribe: Taweewat M

Meeting Location: MTP1 Saikaew

First Meeting: 8/7/2019

Last Meeting: 13/9/2019

Meeting Days: 24

Site: MTP1

Plant: HYCO

September 2019

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Introduction

As part of Process Hazard Analysis (PHA) program a hazard and operability (HAZOP) study on the HYCO plant at Map Tha Phut site1 was carried out from 8-19 July, 13-23 Sep, 9-13 Sep 2019 at MTP1 site. The HAZOP study was conducted at the end of the basic engineering and was based on the current piping and instrumentation diagrams (P&ID's).

The overall objectives of the HAZOP study on the HYCO were:

- to check the current design for possible deficiencies which could lead to hazards or operability problems;*
- to identify possible hazards or operability problems which need to be addressed in more detail;*
- to make recommendations for specific design aspects or safety measures which should be considered or installed.*

Including in scope of HAZOP

- ISBL & OSBL sections*
- Utility system*
- Past major incident, Past high risk incident review*

Excluding from scope of HAZOP

- All metering stations*
- New water pretreatment plant. This unit was replaced in 2018. HAZOP was conducted at that time. Pls refer to separated HAZOP report of new water pretreatment system*
- Decommissioned equipment which mentioned in design content of each node section.*
- LP, HP CO2 tank and N2 tank section are remained per original HAZOP report*

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Table 1 Drawings Used in the Analysis

| Type | Number | Title | Revision | Revision Date | Document Location |
|------|---------|-----------------------|----------|---------------|-------------------|
| P&ID | 10PFP01 | Feedgas preheating I | 14 | | |
| P&ID | 10PFP02 | Feedgas preheating II | 13 | | |
| P&ID | 10PFP03 | Desulfuization | 14 | | |
| P&ID | 10PFP04 | Stream/ Feed control | 12 | | |
| P&ID | 10PFP05 | Stream/ Feed Mixing | 15 | | |
| P&ID | 10PFP06 | CO2/ Feed control | 15 | | |
| P&ID | 10PFP07 | H2 Recycle compressor | 12 | | |
| P&ID | 11PFP01 | Steam drum | 15 | | |
| P&ID | 11PFP02 | Prereforming | 14 | | |
| P&ID | 11PFP03 | Reformer tubes | '09 | | |
| P&ID | 11PFP04 | Burner Connections | 11 | | |
| P&ID | 11PFP05 | Reformer box | 13 | | |
| P&ID | 11PFP06 | Waste Heat Recovery | 09 | | |
| P&ID | 11PFP07 | Combustion Air Blower | 09 | | |
| P&ID | 11PFP08 | Fuel gas system I | 15 | | |
| P&ID | 11PFP09 | Fuel gas system II | 11 | | |
| P&ID | 11PFP10 | Fuel Gas Control | 11 | | |
| P&ID | 12PFP01 | Gas Cooling I | 11 | | |
| P&ID | 12PFP02 | Gas Cooling II | 15 | | |
| P&ID | 13PFP01 | BFW pumps | 11 | | |
| P&ID | 13PFP02 | Deaerator | 12 | | |
| P&ID | 13PFP03 | Steam Heater | 10 | | |
| P&ID | 14PFP01 | CO2 removal | 14 | | |
| P&ID | 14PFP02 | MDEA Regeneration I | 16 | | |
| P&ID | 14PFP03 | MDEA Regeneration II | 10 | | |
| P&ID | 14PFP04 | MDEA Regeneration III | 13 | | |
| P&ID | 14PFP05 | CO2 Compressor I | 10 | | |
| P&ID | 14PFP06 | CO2 Compressor II | 12 | | |
| P&ID | 15PFP01 | Syngas Condensation | 10 | | |
| P&ID | 15PFP02 | Drying station I | 10 | | |
| P&ID | 15PFP03 | Drying station II | 15 | | |
| P&ID | 15PFP04 | Drying station III | 12A | | |
| P&ID | 16PFP01 | CO Expander | 12 | | |
| P&ID | 16PFP02 | Coldbox I | 11 | | |
| P&ID | 16PFP03 | Coldbox II | 10 | | |
| P&ID | 16PFP04 | Coldbox III | 12 | | |
| P&ID | 16PFP05 | Coldbox IV | 09 | | |
| P&ID | 16PFP06 | Methane pump | 10 | | |
| P&ID | 16PFP07 | CO Compressor I | 13D | | |

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| Type | Number | Title | Revision | Revision Date | Document Location |
|-----------|-----------------------|--------------------------------------|----------|---------------|-------------------|
| P&ID | 16PFP08 | CO Compressor II | 12G | | |
| P&ID | 16PFP09 | CO Evaporator | 09 | | |
| P&ID | 16PFP10 | Coldbox outlet | 12 | | |
| P&ID | 16PFP13 | Common Header of NG system | 09 | | |
| P&ID | 16PFP14 | CO metering station | 05 | | |
| P&ID | 18PFP01 | PSA-Plant | 16B | | |
| P&ID | 18PFP02 | PSA-Plant | 05 | | |
| P&ID | 18PFP03 | PSA-Plant | 06 | | |
| P&ID | 18PFP04 | PSA-Plant | 06 | | |
| P&ID | 89PFP01 | Gas Detectors | 10 | | |
| P&ID | 90PFP01 | Warm gas flare system I | 13F | | |
| P&ID | 90PFP02 | Warm gas flare system II | 10 | | |
| P&ID | 91PFP01 | Cold gas flare system | 09 | | |
| P&ID | 92PFP01 | Cooling water system | 13 | | |
| P&ID | 94PFP01 | N2 system and Drinking water system | 13 | | |
| P&ID | 95PFP01 | Instrument Air system | 09 | | |
| P&ID | 98PFP01 | Analyzer cabinet I | 11 | | |
| P&ID | 98PFP02 | Analyzer cabinet II | 09 | | |
| P&ID | 98PFP03 | Analyzer cabinet III | 09 | | |
| P&ID | 98PFP04 | Analyzer cabinet IV | 09 | | |
| OSBL P&ID | 030109-087 | Package boiler | 01 | | |
| OSBL P&ID | 16001330-T-D-101-01 | H2 supply system for SPE-II DOW | 04 | | |
| OSBL P&ID | 16002312-T-D-101-01 | NG supply system | 04 | | |
| OSBL P&ID | 16002312-T-D-101-02 | NG compressor | 01 | | |
| OSBL P&ID | 16002312-T-D-101-03 | NG compressor flare header | 01 | | |
| OSBL P&ID | 4507-T-D-102-01 | LPG distribution system | 10 | | |
| OSBL P&ID | 637400-01-02 | Process Gas | 7 | | |
| OSBL P&ID | B050.001 | Vendor package NG booster compressor | 16 | | |
| OSBL P&ID | H0202-T-D-101-01 | Liquid Nitrogen tank for Coldbox | 06 | | |
| OSBL P&ID | H0202-T-D-104-01 | CO2 tank and import | 09 | | |
| OSBL P&ID | H0202-T-D-105-01 | Feed H2 supply system | 06 | | |
| OSBL P&ID | H0202-T-D-110-01 | Cooling tower | 06 | | |
| OSBL P&ID | H0202-T-D-115-01 | Fuel gas supply system | 13 | | |
| OSBL P&ID | I3-1102.02-0330-1-301 | NG supply line | 00 | | |
| OSBL P&ID | 549908 | Demineral plant | 04 | | |

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Table 2 Team Members

| First Name | Last Name | Company | Job Title | Role |
|------------|------------------|-----------|-------------------------------------|--------------|
| Napakorn | Chalee | Linde plc | On-Site Plant Technician MTP1 | HAZOP member |
| Sunchai | Chaleerin | Linde plc | Area manager automation maintenance | HAZOP member |
| Santi | Chonabot | Linde plc | Area manager Mechanical maintenance | HAZOP member |
| Pipat | Lubiam | Linde plc | Area Manager electrical maintenance | HAZOP member |
| Taweewat | Mingkaew | Linde plc | Process Safety & Behavioral Safety | HAZOP Leader |
| Tidarat | Pattanothai | Linde plc | MTP1 Site manager | HAZOP member |
| Preecha | Sangpim | Linde plc | Sr. On-Site Plant Engineer | HAZOP member |
| Somchai | Thavonrattavanit | Linde plc | HyCO Technology Manager, ASEAN | HAZOP member |

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Table 4 List of Sections

| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|--|--|---|---|-----------|---|
| 1 | Tank/Vessel, Line/Pipe, Heat exchanger | NG supply | NG feed from PIC90308, desulphur to HV10025 | <ul style="list-style-type: none"> - H2+NG is used as feed. Discharge from NG booster teperature at 80 C pressure 45 barg pass to E1015 temp for feed preheating to 350 C and pass thorough desulpherization unit and untill feed shut off valve before stream mixing - Hydrogen recycle line from tube back 140 barg PCV75B-3 letdown pressure 38 barg connect to downstream of FV10002 | Blue | 10PFP02 10PFP01 10PFP03 10PFP04 10PFP05 10PFP07 16002312-T-D-101-01 16002312-T-D-101-02 H0202-T-D-115-01 16001330-T-D-101-01 |
| 2 | Line/Pipe, Heat exchanger, Tank/Vessel, Reactor, continuous | Pre-reformer & Reformer + Gas Cooling + Waste heat boiler | Pre-reformer & Reformer + Gas Cooling + Waste heat boiler | Feed gas after de-sulphurization unit will be mixed with steam at desired S:C ratio before receiving heat from flue gas section E-1126A/B then heated steam drum D-1131 before entering Pre-reformer to have 10% of reforming reaction then pass to E-1115 feed superheat then enter to reformer. Then reformed gas exist reformer and pass waste heat boiler E1122 and pass thorough E1015 for heating feed and pass E1011 to heat boiler feedwater at E1212 then pass through process gas cooling E-1412 knockout drum D1231 back to E1212 ==>E-1216 end node at XV12001 Note: 1. Feed is considered as NG. Prereformer process is considered endothermic reaction 2. Combustion session is in Node no.5 | Green | 10PFP01 10PFP02 10PFP05 10PFP06 11PFP02 11PFP01 11PFP03 11PFP05 12PFP01 14PFP02 12PFP02 |
| 3 | Line/Pipe, Tank/Vessel | Stream drum + steam system + Steam back up from package boiler | Waste heat (Water side) + Steam drum + Steam system + Steam back up from package boiler | <ul style="list-style-type: none"> - Steam is generated from [1] Waste heat boiler (E1122) recieve heat of reform gas [2] Steam drum (E1122) receives excess heat recover from flue gas by steam feed mixing (E1126A/B). - BFW is supplied from boiler feed water pump (P1371A/B) to D1131 and heat up residual heat from process gas which is pass E1212. - 41.5 barg HP steam from D1131 is supplied to steam header for suplying to Steam feed mixing (FV10011, FV10012), let pressure 5.5 barg for LP steam supply to UT stations. - Another high pressure steam sapply to E1521 (Heating regeneration gs for absorber), E1412 (MDEA reboiler) - Excess steam is to be vented off by PV13006 through atmosphere at N1161 | Orange | 10PFP05 11PFP01 12PFP01 13PFP01 13PFP02 13PFP03 14PFP02 15PFP03 |
| 4 | Line/Pipe, Furnace | Fuel gas system | NG from metering/ PSA purge gas until burner+Flue system | <ul style="list-style-type: none"> - Combusion air from blower C-1009 pass thorough E1121 for receiving heat from flue gas hat up to 400 c and pass to 10 burners. - Fuel <ul style="list-style-type: none"> - NG from PTT metering 29 barg letdown by PV1901303 to 23 barg and pass FV11004 and pass to burner - Tail gas from CB from FV11005 and Purge gas from PSA unit FV11006 supply valve and pass to fuel header to burner - Hot Flue gas after combustion passes through flue stack give heat to E1115, | Pink | 11PFP02 11PFP04 11PFP05 11PFP06 11PFP07 11PFP08 11PFP09 H0202-T-D-115-01 |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|--|---|---|---|-----------|--|
| | | | | E1126A/B, E1121 then pass through Induce fan of flue gas (C1107) then pass to stack N1163 and release to ATM | | 16002312-T-D-101-01 |
| 5 | Line/Pipe, , Tank/Vessel | Deareator | Deareator | <p>Demin Water section:</p> <ul style="list-style-type: none"> - Demin water receive from demin tank (Pump P90916A/B) run 1 unit stand 1 unit. Pump (Pump P90916A/B) then pass LV13005 A/B then mix with steam to control temperature nearly to boiling point before entry deareator (During start up) <p>Condensate recovery</p> <ul style="list-style-type: none"> - Hot condensate from D1231 (140 c) entry deareator - Cold condensate from D1232 (40-50c) to mix with demin water at mixer (YM001) before entry deareator - Condensate return from E-1521 <p>Control</p> <ul style="list-style-type: none"> - low pressure steam feed into the deareator under the stripping section and control the pressure in deareator at SP of 0.3 barg to achieve the full stripping, resulted in temperature in Deareator at 106 deg.C. <p>BFW pump</p> <ul style="list-style-type: none"> - BFW from P1317 recirculated by min flow to deareator | Purple | <p>13PFP01</p> <p>13PFP02</p> <p>13PFP03</p> <p>14PFP01</p> <p>14PFP02</p> <p>14PFP03</p> <p>14PFP04</p> <p>14PFP05</p> <p>14PFP06</p> <p>15PFP01</p> <p>15PFP02</p> <p>15PFP03</p> <p>15PFP04</p> |
| 6 | Line/Pipe, Tank/Vessel, Heat exchanger, Pump | MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum | MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum | <p>Carbon dioxide removal from Reform Gas</p> <ul style="list-style-type: none"> - Reform gas from D1232 coming to MDEA wash column T1401 and be adsorbed carbon dioxide with lean MDEA coming to top of T1401 by low temp (50 c) and high pressure (32 barg). Then, syngas will go up to top of column T1401. <p>Carbon dioxide removal from Rich MDEA</p> <ul style="list-style-type: none"> - Rich MDEA is taken out from T1401 and receive heat at E1413A/B then enter T1404 at top and desorb carbon dioxide by high temp (100 c Middle of column) and low pressure (0.5 barg) condition. Then, carbon dioxide will go up to top of T1404 to carbon dioxide compressor. Lean MDEA will pass through E1413A/B (Rich MDEA), E1414 (Cooling water) to cooldown and pump by P1474A/B then 10% of total lean MDEA will pass through side steam filter S1451, S1452 and another 90% will bypass filter. 100% MDEA enter T1401 as reflux for scrubbing 'CO2 with reform gas. <p>MDEA reboiler</p> <ul style="list-style-type: none"> - Reform gas from E1212 pass through E1412 to heat up to rich MDEA to boiling point. Boiled water in MDEA will return to T1404. 'CO2 will be also desorbed then go up to top of T1404 while remain MDEA will go down to bottom. <p>'CO2 knockout drum (D1441)</p> <ul style="list-style-type: none"> - To knock water and mist MDEA out from 'CO2 gas. Condensate will be pumped by P1473A/B to T1404 as reflux. | Royal | <p>12PFP02</p> <p>14PFP01</p> <p>14PFP02</p> <p>14PFP03</p> <p>14PFP04</p> <p>14PFP05</p> <p>15PFP01</p> |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|---|--|--|--|-----------|--|
| 7 | Line/Pipe, Tank/Vessel, Heat exchanger | Drier (TSA) | Drier (TSA) A1501A/B | <ul style="list-style-type: none"> - Syngas from MDEA T1401 Pressure 31 barg temperature 35 c passes through A1501A/B to absorb 'CO₂ and 'H₂O. Flow direction is from bottom to top then passes E1526 for cooldown then goes to XV15002 feed isolation valve before coldbox. - A1501A/B condition: (MAWP 35 barg, Design temp 190 c) - Adsorbent material : Molecular sieve, Silica gel - Adsorb temperature at 35 c pressure , desorb temperature 175 c pressure Pressure 30 barg | Salmon | 15PFP01 15PFP02 15PFP03 15PFP04 |
| 8 | Line/Pipe, Heat exchanger, Tank/Vessel | Regeneration gas + hydrogen fraction bypass | Regeneration gas + Hydrogen fraction bypass | <ul style="list-style-type: none"> - Crude hydrogen gas leave coldbox at temp 35 c. - Warm hydrogen pass through KV15015 and E1521 to get heat then goes to TSA as the regeneration gas for heating step - In cooling step, hydrogen shall pass KV15017 instead of KV15015 - Exhaust gas from TSA shall be tied in with hydrogen fraction bypass line TSA - Hydrogen fraction bypass TSA shall pass through E1522 then knock moisture at D1541 then goes to FV18001 | Blue | 16PFP02 15PFP02 15PFP03 15PFP04 18PFP01 |
| 9 | Line/Pipe, Column, Heat exchanger, Pump | Coldbox (T1601: Methan wash column) | Coldbox (T1601: Methan wash column) | 1. Syngas pressure 30 barg, temp 35 c, flowrate 3500 kg/hr enter E1611, E1612 to get cold energy to -181.3 c then pass to T1601 2. T1601 (MAWP 35 barg, Max T= 50 Min T = -196 c) <ul style="list-style-type: none"> - Syngas will be pass to top of column then Liquid CO (Temp -183 pressure 1.5 barg) from T1603 (N7) to condense CO and Methane and some hydrogen. - Hydrogen which is not condensed will be scrubbed by Liquid methane - Residual H₂ will exist through top of T1601 as the Hydrogen fraction to E1612, E1611 to give cold energy then exit coldbox 3. Liquid methane <ul style="list-style-type: none"> - Liquid methane from P1671A/B will pump at pressure 32 barg temp -180 c and enter T1601 (Node end at pump discharge valves) | Sunrise | 16PFP02 16PFP03 16PFP04 16PFP05 16PFP06 16PFP10 |
| 10 | Line/Pipe, Column, Heat exchanger, Pump | Coldbox (T1602 : hydrogen stripper column) | Coldbox (T1602 : hydrogen stripper column) | T1602 (MAWP= 11 barg Min/Max temp = -196/+50 c) <ul style="list-style-type: none"> - Crude Liquid CO from bottom T1601 (LV16001,2) to enter T1602 (Pressure 30 bar temp -170 c) - CO, CH₄ is scrubbed in T1601 by Liquid CH₄. Tail gas will exit top of T1602 end at FN11005 as fuel gas to reformer - Liquid CO/ Methane exit T1602 bottom enter to T1603 through LV16003, HV16009 | Sunrise | 16PFP02 16PFP03 16PFP04 16PFP05 16PFP06 |
| 11 | Line/Pipe, Column, Heat exchanger, Pump | Coldbox (T1603 : CO methane separation column) | Coldbox (T1603 : CO methane separation column) | <ul style="list-style-type: none"> - T1603 : MAWP 4 barg, Min/Max temp -196/+50 c - E1615 : MAWP 4/30 barg Min/Max temp -195/+50 c - CO/CH₄ from T1602 is controlled by LV16003 feed to T1603, HV16009 will control by temperature of CH₄ suction pump passing through E1615 then feeding to T1603. - Low pressure CO will exit top of T1603 as product to C1608 - 'HP CO product are fed to T1603 as reflux | Sunrise | 16PFP02 16PFP03 16PFP05 16PFP06 16PFP10 16PFP04 |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|---------------------------------|--------------------------------|--------------------------------|---|-----------|---|
| | | | | and reboil. Temp -181.5 c / -140 c Pressure 26.3 barg - MP CO product are fed to T1603 as reboil. Temp -130 C Pressure 13 barg - Liquid nitrogen is used for start up at pressure 15 barg | | |
| 12 | Line/Pipe, Pump, Heat exchanger | Coldbox (Liq Methane pump) | Coldbox (Liq Methan pump) | - Process description : LCH4 from bottom T1603 pass E1615 and enter P1671A/B. Discharge pressure LCH4 pressure 35 barg, Temp -187 c to E1612 to give cold energy then supply as reflux to T1601, T1602. Residual LCH4 is recycled back to E1615 to give cold energy. Exit from T1603 and recycled stream will enter P1671A/B suction. - Equipment details - E1612 MAWP (N1/N2)= 35 barg, MDT = -196 c - E1615 MAWP (N7/N8/N9) = 4 barg, MDT = -196 c - P1671 Discharge 35 barg Temp = -196, Suction 4 bar Temp = -196 c, flow rate = 1642 kg/hr | Sunrise | 16PFP02 16PFP04 16PFP05 16PFP06 |
| 13 | Line/Pipe, Pump, Heat exchanger | Coldbox (CO turbine) | Coldbox (CO turbine) | Process descriptions - 'HP CO from CO compressor pressure 26.5 barg Temp 35 c enter to E1611 to get cold energy until temp -109 c and enter turbine suction to expand. Outlet temp is -130 c pressure 13 bar as MP CO - MP CO exit turbine 13 barg temp -130 c to enter E1611 and enter CO compressor stage 3 until manual valve suction of stage 3rd compressor - 'LP CO 1.5 barg from seal gas back to CO compressor suction - Bypass turbine 'HP CO to MP CO - Start up line - Start up line CO turbine (PFP02) - Start up line 'HP CO to T1601 feed (PFP02) - Start up line hydrogen fraction to MP CO (PFP10) - Seal gas; 'HP CO 26.5 barg from exit 'CO2 absorber - Cooling water | Sunrise | 16PFP08 16PFP01 16PFP02 |
| 14 | Compressor, Line/Pipe | CO compressor + CO supply line | CO compressor + CO supply line | - Operating condition - CO suction pressure 1.5 bar, Temp 35 C - Discharge 3rd stage 12.9 bar, Temp 35 c, flow rate 1903 Nm3/hr - Discharge 4th stage 26.5 bar, Temp 35 c, flow 4472 Nm3/hr - Compressor design data - Compressor shut off pressure = xxx Barg - Casing MAWP stage 1,2,3,4 = 9,15,27,60 barg - Carbon dioxide absorber A1651 MAWP = 35 barg MDT = 190 c | Sunrise | 16PFP10 16PFP07 16PFP08 16PFP13 16PFP14 |
| 15 | Line/Pipe, Tank/Vessel | PSA plant (A1,2,3) | PSA plant (Node7) | Adsorption step (A1,2,3) - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with | Yellow | 18PFP03 18PFP01 |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|------------------------|-------------------------------|--------------------|---|-----------|--|
| | | | | <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | |
| 16 | Line/Pipe, Tank/Vessel | PSA plant Node (E1/R1) | PSA plant (Node1) | Adsorption step (E1,R1) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C - Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | Yellow | 18PFP03 18PFP01 |
| 17 | Line/Pipe, Tank/Vessel | PSA plant Node (E2/R2) | PSA plant (Node2) | Adsorption step (E2,R2) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C - Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | Yellow | 18PFP03 18PFP01 |
| 18 | Line/Pipe, Tank/Vessel | PSA plant (P1/PP1 and P5/PP5) | PSA plant (Node3) | Adsorption step (P1/PP1 and P5/PP5) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C - Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | Yellow | 18PFP03 18PFP01 |
| 19 | Line/Pipe, Tank/Vessel | PSA plant (D) | PSA plant (Node 4) | Adsorption step (D) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C - Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | Yellow | 18PFP03 18PFP01 |
| 20 | Line/Pipe, Tank/Vessel | PSA plant (R0/R01) | PSA plant (Node6) | Adsorption step (R0/R01) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C - Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | Yellow | 18PFP03 18PFP01 |
| 21 | Line/Pipe | Warm, Cold Flare | Warm, Cold Flare | Cold flare <ul style="list-style-type: none"> - All liquid drain valves from coldbox, Heat exchanger - Safety valves from coldbox section - Pressure control valves from coldbox section All pipelines connects with header and D9131 for liquid knockout. MDT -196 C , MAWP 4 barg. Warm flare <ul style="list-style-type: none"> - All vent valves from process connect to | Coral | 90PFP01 90PFP02 91PFP01 H0202-T-D-115-01 16002312-T-D-101-03 |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|-----------------------|---------------------------------|---------------------------------|--|-----------|---|
| | | | | header and pass thorough stand pipe from trapping condensate. Design temp 250 c MAWP 4 barg NG fuel for pilot - Receiving 5 barg NG from NG metering PCV1311 and regulates pressure to 1.5 barg by PV90004 Note : Flare design for flow condition that PV16004, PV 16035, PV18002, PV18003 can relief simultaneously at heat release 1.26e8 KJ/hr flow 9,508.8 Nm3/hr which is less than SV16006 capacity. so, flare design can refer to SV1606 capacity at 10,821 Nm3/hr heat release 1.32e8 KJ/ hr. | | |
| 22 | Line/Pipe | Package boiler | Package boiler | NG fuel - NG metering supply 21 barg pass through valve PCV1301A/B to reduce pressure to 3 barg and let down pressure to 90 mbar by PCVxxx Diesel fuel - T1203 cap 15000 L. Diesel pump supply 3 barg diesel to burner. - PSV202 recirculate fuel back to tank at pressure xxx barg Dearator - Demineral from demineral unit. Max flow rate 4.5 M3/hr pressure 5 barg - Chemical treatment unit contains ;NH3OH and Eliminox Boiler - Operating pressure 41.5 bar, temp 250 c - Design pressure 45 barg, flowrate 4 ton/hr temp 258 c - Water tube type | Salmon | H0202-T-D-115-01 030109-087 |
| 23 | Line/Pipe | NG compressor + NG supply line | NG compressor + NG supply line | NG supply - NG from PTT metering 39 barg then pass thorough M10594 for removing oil then letdown pressure to 27 bar by PCV10594-1 before enter compressor suction. Discharge pressure 45 barg pass through PCV901308 to letdown pressure to 42 barg then enter HYCO as a feed - C10501, C10502 Design pressure 47 barg, design temp 78 c, capacity 2119 kg/hr | Salmon | 16001330-T-D-101-01 637400-01-02 B050.001 H0202-T-D-115-01 H0202-T-D-101-01 H0202-T-D-105-01 |
| 24 | Line/Pipe | Hydrogen mix feed to NG booster | Hydrogen mix feed to NG booster | hydrogen from pipeline system at 29 barg pass through PCV301 letdown pressure to 28.6 barg. FCV10595-1 controls flow rate to mixing with NG at such of NG booster. | Salmon | 16001330-T-D-101-01 H0202-T-D-105-01 |
| 25 | Line/Pipe, Compressor | Carbon dioxide compressor | Carbon dioxide compressor | C1408 ; Max flow rate = 3032 kg/h, Design pressure 47 barg/ Temp 170 c, operating discharge pressure 39 barg, suction pressure 0.4 barg - Boost up carbon dioxide pressure from 0.5 barg to 36 barg for injecting to feedgas outlet prereformer at FV10016.B | Salmon | 14PFP04 14PFP05 14PFP06 10PFP06 12PFP02 94PFP01 |
| 26 | Line/Pipe | CO2 tank low pressure tank | CO2 tank low pressure tank | Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | Salmon | H0202-T-D-104-01 |
| 27 | Line/Pipe | CO2 pump (P851A/B) | CO2 pump (P90851A/B) | Pump data - Flow rate 4000 kg/hr, Design Pressure | Salmon | H0202-T-D-104-01 |

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| No. | Type | Name | Description | Design Intent | Highlight | Drawings |
|-----|---------------------------|---|--|---|-----------|--|
| | | | | 42 barg, Temperature -20 c - Operating; Liquid from T85A pumped to 42 barg for filling T85B. Recycle valve PCV90851-1 used for recycle back to T85A to prevent over pressure downstream before relief valve pop up. | | |
| 28 | Line/Pipe | CO2 tank High pressure | CO2 tank High pressure | Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | Salmon | H0202-T-D-104-01 |
| 29 | Line/Pipe | CO2 vaporizer E852 | CO2 vaporizer E852 | Carbon dioxide from high pressure tank - Pressure 40 barg pass through vaporizer coil. Vaporizer coils - MAWP 3000 psi, capacity 4500 kg/hr Demin water - Demin water used for fill up to vaporizer bath Steam heating - Steam from boiler package feed to vaporizer bath at pressure through PCV90102 for letting down pressure from 41 barg to 17.24 barg at flowrate of 500 kg/hr | Salmon | H0202-T-D-104-01 |
| 30 | Line/Pipe, Tank/Vessel | Liquid Nitrogen tank for Coldbox | Liquid Nitrogen tank for Coldbox | Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | Salmon | H0202-T-D-101-01 |
| 31 | Utilities and services | utilities and services | Utilities and services supporting the process | | Salmon | |
| 32 | | previous incidents | Review of previous incident reports | | Salmon | |
| 33 | | Cooling water treatment chemicals | Cooling water treatment chemicals | | Salmon | 92PFP01 H0202-T-D-110-01 4507-T-D-102-01 |

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Table 5 LE Matrix from LS905-01 2015 Used in Analysis

| | 1-Negligible Injury to Personnel (first party): No injuries Fatalities (first party): None Public (third party): No impact Environment (water, air, soil): No release expected | 2-Minor Injury to Personnel (first party): Slight and reversible injuries Fatalities (first party): None Public (third party): No impact Environment (water, air, soil): on-site: Small contained release or reversible soil contamination | 3-Moderate Injury to Personnel (first party): Irreversible injuries like burns or inhalation of toxic gases causing partial disability (<20%) Fatalities (first party): None Public (third party): No injuries, minor impact | 4-Serious Injury to Personnel (first party): Serious permanent injuries or total disability (>75%) to max. two persons Fatalities (first party): Single fatality (1-2) Public (third party): Injuries, major nuisance Environment (water, air, soil): Moderate release or temporary harmful environmental affects (e. g. agricultural areas cannot be used at least one year for cultivation). | 5-Major Injury to Personnel (first party): Heavy permanent injuries or total disability to several persons (=3) Fatalities (first party): Multiple fatalities (=3) Public (third party): One or more fatalities Environment (water, air, soil): Off site: Large uncontained release off-site or permanently high harmful environmental affects |
|---|--|--|---|--|--|
| 6-Probable More than once per year | Acceptable, No Action | SIL-1: Low | SIL-3: High | Unacceptable, QRA/ Change of Design | Unacceptable, QRA/ Change of Design |
| 5-Likely Once per year | Acceptable, No Action | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) | SIL-2 SIL-2: Medium | SIL-3 SIL-3: High | Unacceptable, QRA/ Change of Design |
| 4-Possible Once in a turnaround period | Acceptable, No Action | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) | SIL-1: Low | SIL-2: Medium | SIL-3: High |
| 3-Unlikely Once in plant lifetime | Acceptable, No Action | Acceptable, No Action | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) | SIL-1: Low | SIL-2: Medium |
| 2-Very Unlikely Once in lifetime of 10 plants | Acceptable, No Action | Acceptable, No Action | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) | SIL-1: Low |
| 1-Highly Unlikely Once in lifetime of 100 plants | Acceptable, No Action | Acceptable, No Action | Acceptable, No Action | Acceptable, No Action | Transition: Protection/Mitigation until ALARP (i.e., trip function in BPCS, control valve to be closed via solenoid, high priority alarm) |
| 0-Extremely Unlikely Once in lifetime of 1000 plants | Acceptable, No Action | Acceptable, No Action | Acceptable, No Action | Acceptable, No Action | Acceptable, No Action |

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Table 6 5x5 from IMS-36-18 Risk Matrix Used in Analysis

| | Minor Minor Injury - First Aid, No damage to Environment, Minimal quality impact, No damage to property, equipment or production | Moderate Minor injury – medical Treatment (with no lasting effect), Moderate damage with no long-term affects (temporarily exceed regulatory limits or products spilled on site), Potential out of spec product in process, Minor property, equipment or a brief loss of production or use of equipment (several hours) | Serious Serious injury Lost Time Cases and injuries resulting in low level disability. Regulatory fine or non-conformance, Serious damage but may be corrected (a localized incident causing serious ecological damage to the environment, but which may be quickly treated and eliminated), Potential out of spec product to customer no recall, Major property/equipment damage or loss of production or use of equipment (several days). | Major Potential single fatality, Serious and long-term damage (incident causing serious and long-term damage to the site and surrounding areas). Such as significant chemical spills, Potential out of spec product/material to customer requiring recall, Major property damage/equipment that results in an extended loss of production or use of equipment (several weeks to months). | Catastrophic Major incident with potential multiple fatalities, Ecological disaster, Potential customer product run out, Massive destruction to property, equipment or facilities or total loss of production (permanent shut-down). |
|---|---|--|--|---|---|
| Frequent An event that has happened at the site or several times in Linde | P3 MEDIUM | P3 MEDIUM | P2 HIGH | P2 HIGH | P1 Extremely HIGH |
| Occasional An event that has happened within Linde | P4 LOW | P3 MEDIUM | P3 MEDIUM | P2 HIGH | P1 Extremely HIGH |
| Possible A rare event that has occurred in the Industrial Gases Industry | P4 LOW | P3 MEDIUM | P3 MEDIUM | P2 HIGH | P2 HIGH |
| Remote An event that has occurred in the world but requires a combination of rare events | P4 LOW | P4 LOW | P3 MEDIUM | P3 MEDIUM | P2 HIGH |
| Improbable There are no known events of this kind. | Insignificant Extremely LOW | P4 LOW | P4 LOW | P3 MEDIUM | P3 MEDIUM |

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| | | | |
|---|------|------|------------------------|
| Linde PLC | HYCO | MTP1 | Name: NG supply |
| Design Intent: - H2+NG is used as feed. Discharge from NG booster temperature at 80 C pressure 45 barg pass to E1015 temp for feed preheating to 350 C and pass through desulphurization unit and until feed shut off valve before stream mixing - Hydrogen recycle line from tube back 140 barg PCV75B-3 letdown pressure 38 barg connect to downstream of FV10002 | | | |
| P&ID: 10PFP02, 10PFP01, 10PFP03, 10PFP04, 10PFP05, 10PFP07, OSBL P&ID: 16002312-T-D-101-01, 16002312-T-D-101-02, H0202-T-D-115-01, 16001330-T-D-101-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Pipat Lubiam (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|--|--|----------|-----------|-------------------|------------|--------------|
| 1.1 | High level (NA) | | | | | | | | |
| 1.2 | Low level (NA) | | | | | | | | |
| 1.3 | High interface level (NA) | | | | | | | | |
| 1.4 | Low interface level (NA) | | | | | | | | |
| 1.5 | High temperature | 1. High discharge temperature from NG booster (need to link from NG booster node) (see 23.5) | 1. Fire from pipe/ vessel rupture due high temperature | 1. High discharge after cooler (TT10543, 44) NG booster set at 55 C | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. High temperature from reaction from Olefin, Oxygen, CO in feed in desulphurization unit (Now there is no Olefin mix in feed gas due to we use NG) (see 1.18) | 1. Fire from pipe/ vessel rupture due high temperature | 2. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Production interruption | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Catalyst damage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. TV10003 failed closed | 1. Fire from pipe/ vessel rupture due high temperature | 2. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 3. 'TAH10003 high temp alarm at 390 c 4. 'TAH10014 high temp | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|---|--|--|----------|------------|-------------------|------------|--|
| | | | | alarm at 400 c | | | | | |
| | | 4. TT10003 malfunction | 2. Production interruption | 2. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 4. 'TAH10014 high temp alarm at 400 c 5. TV10003 to control outlet temperature of feed from E1015 control at 350 c by selector switch between TT10003, TT10014A 6. 'TAH10017 high temp alarm at 400 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. TT10014.A malfunction | 1. Fire from pipe/ vessel rupture due high temperature | 2. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 5. TV10003 to control outlet temperature of feed from E1015 control at 350 c by selector switch between TT10003, TT10014A 6. 'TAH10017 high temp alarm at 400 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Catalyst damage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. High concentration of contaminants (see 1.9) | | | | | | | |
| 1.6 | Low temperature | 1. Feed preheater has fouling causing low temperature to desulphur unit | 1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulphur, sulphure break through Prereformer/ Reformer (see 2.10) | 1. Offline cleaning during TA every 2 years 5. Quaterly total Sulphur analysis for inlet and outlet of desulphur 6. Work intrusion troubleshooting for detecting hydrogen sulfide is avialable | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 17. To calculate approach temeprature of E1015 after cleaning and compare with condition before shutting down to be the data base for next cleaning next 2 years P3 CAR 21. To review troubleshooting of desulphurization unit in case low inlet temperature |
| | | 2. Bypss valve of E1015 fail open (TV10003) | 1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulphur, sulphure break | 2. Maintenance PM and stroke check (Yearly) 3. Calibration valves and | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 21. To review troubleshooting of desulphurization unit in case low inlet temperature |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|---|---|-------------|----------------|----------------------|------------|---|
| | | | through Prereformer/ Reformer (see 2.10) | temp transmitter done every TA (Yearly) 4. TAL10003 setting 300 c 5. Quaterly total Sulphur analysis for inlet and outlet of desulphur 6. Work intruction troubleshooting for detecting hydrogen sulfide is avialable | | | | | |
| | | 3. Tempeature control error reading low (TIC10003) | 1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulpher, sulphere break through Prereformer/ Reformer (see 2.10) | 3. Calibration valves and temp transmitter done every TA (Yearly) 5. Quaterly total Sulphur analysis for inlet and outlet of desulphur | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 21. To review troubleshooting of desulphurization unit in case low inlet temperature |
| | | 4. Tempeature control error reading low (TIC10014A) | 1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulpher, sulphere break through Prereformer/ Reformer (see 2.10) | 3. Calibration valves and temp transmitter done every TA (Yearly) 4. TAL10003 setting 300 c 5. Quaterly total Sulphur analysis for inlet and outlet of desulphur | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 18. To add TAL10014 setting 300 c same as TAL10003 P3 CAR 21. To review troubleshooting of desulphurization unit in case low inlet temperature |
| 1.7 | High pressure | 1. Pressure control valve malfunction fully open (PCV901308) | 1. Pipe/ vessel rupture create fire and explosion | 3. PSV-1301 set at 46 barg 4. Yealy PM to calibration PCV901308 in yearly basis | 5 X 5 LG | Major | Possible | P2 | P3 CAR 2. Implement 2oo3 voting with PT901308 and PT10002A/B for control PV901308 P3 CAR 3. To set limit of set point for 'PIC901308 to be 45 barg P3 CAR 122. Check relief capacity of SV1301 to cover full flow from PV901308 full open at upstream pressure at 50 barg - trip set point of NG compressor (Refer valve data sheet maximum flow rate 2,130 Nm3/hr at 45 barg. it is subjected to be much higher flowrate at 50 barg) |
| | | | 2. High flow (see 1.16) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|-------|----------|----|---|
| | | | 3. High flow - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.1) | | | | | | |
| | | | 4. High pressure - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.8) | | | | | | |
| | | 2. Feed shut off valve malfunction fully close (HV10025) while booster compressor running | 1. Pipe/ vessel rupture create fire and explosion | 3. PSV-1301 set at 46 barg 5. SV-1001 setting 47 barg design for external fire case of R-1001. Relief capacity 1673 Nm3/hr | 5 X 5 LG | Major | Possible | P2 | P3 CAR 122. Check relief capacity of SV1301 to cover full flow from PV901308 full open at upstream pressure at 50 barg - trip set point of NG compressor (Refer valve data sheet maximum flow rate 2,130 Nm3/hr at 45 barg. it is subjected to be much higher flowrate at 50 barg) |
| | | | 2. High flow (see 1.16) | | | | | | |
| | | 3. External fire | 1. Pipe/ vessel rupture create fire and explosion | 5. SV-1001 setting 47 barg design for external fire case of R-1001. Relief capacity 1673 Nm3/hr | 5 X 5 LG | Major | Possible | P2 | |
| | | 4. PIC901308 error reading low | 1. Pipe/ vessel rupture create fire and explosion | 4. Yealy PM to calibration PCV901308 in yearly basis | 5 X 5 LG | Major | Possible | P2 | P3 CAR 2. Implement 2oo3 voting with PT901308 and PT10002A/B for control PV901308 P3 CAR 3. To set limit of set point for 'PIC901308 to be 45 barg |
| | | | 2. High flow (see 1.16) | | | | | | |
| | | | 3. High flow - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.1) | | | | | | |
| | | | 4. High pressure - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.8) | | | | | | |
| | | 5. PVC75B-3 fail fully open (H2 feed) | 1. Pipe/ vessel rupture create fire and explosion | 7. SV1006 setting 43 barg and its capacity (605.3 kg/hr) can support PCV75B-3 fail fully open (571.78 | 5 X 5 LG | Major | Possible | P2 | P2 CAR 1. PT10019 (PAH = 44 barg, PAHH = 45 barg - existing function trip Hydrogen recycle compressor B), Now site use |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|---|--|----------|-----------|----------------------|------------|--|
| | | | | kg/hr) | | | | | <p>this transmitter for hydrogen feed at suction of NG compressor which operate at 30 barg and has 'PSV setting at 43 barg (SV1006). To re-adjust value of high pressure alarm to be 40 barg and install second PT with 1002D</p> <p>P3 CAR 7. To remove PAHH10019 and concerned logics of Hydrogen recycle compressor</p> |
| | | 6. Low/no flow (Normal+Steam operation) - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.2) | | | | | | | |
| | | 7. High pressure - NG compressor + NG supply line (see 23.7) | | | | | | | |
| 1.8 | Low pressure | 1. No production, No hazard issue | 1. Low pressure - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.9) | | | | | | |
| 1.9 | High concentration of contaminants | 1. High concentration of Olefin in feedgas | 1. High temperature at R1001 (see 1.5) | 1. Currently, Plant uses NG feed which is not possible to have Olefin to contaminate (Original designis Tail gas from Olefin plant) | LE3 | 4-Serious | 0-Extremely Unlikely | Acceptable | |
| | | | 5. High temperature expose to downstream of R1001 | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. LPG line leak to NG feed | 2. Plant condition upset | 2. Line from LPG feed is blinded and LPG tank is now emptied | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 4. To raise EMOC to cover disconnection of LPG feed |
| | | 3. High concentration of Oxygen in feedgas (see 1.13) | 3. Fire at CoMo catalyst in R1001 and damage to downstream equipment | <p>3. Purging procedure during start up process</p> <p>4. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1)</p> <p>5. Operating practice is recommended to start up plant with Nitrogen before introduce NG</p> | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 5. Check procedure for back purge at desulpherization unit in case of high temperature 'TSHH 10014 active and PV10009 is interlock close to prevent high temperature expose to downstream and flare header |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|-----------|----------------------|------------|--|
| | | | | 10. PV1009 to close due to high temperature of R1001 | | | | | |
| | | | 5. High temperature expose to downstream of R1001 | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. High concentration of CO in feedgas | 1. High temperature at R1001 (see 1.5) | 4. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 7. Online GC analyzer for CO, carbon dioxide, nitrogen | LE3 | 4-Serious | 0-Extremely Unlikely | Acceptable | |
| | | | 5. High temperature expose to downstream of R1001 | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. High concentration of Sulphur in feedgas (see 1.19) | 1. High temperature at R1001 (see 1.5) | 4. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) | LE3 | 4-Serious | 0-Extremely Unlikely | Acceptable | |
| | | | 4. CoMo Catalyst degradation | | 5 X 5 LG | Major | Remote | P3 | |
| | | 6. Different source of supply from NG supplier | 2. Plant condition upset | 7. Online GC analyzer for CO, carbon dioxide, nitrogen 8. Routine sampling by Dragger tube by weekly (Sulphur, Chloride, Mercaptan) 9. Routine sampling by laboratory every 3 monthly (H2, nitrogen, CO,CO2, Methane, Olefin, Total Sulpher) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. High concentration of Chloride in feedgas | 2. Plant condition upset | 8. Routine sampling by Dragger tube by weekly (Sulphur, Chloride, Mercaptan) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 9. High concentration of Mercaptan in feedgas | 2. Plant condition upset | 8. Routine sampling by Dragger tube by weekly (Sulphur, Chloride, Mercaptan) | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 23. Implement Dragger tube for meassuring Methyl Mercaptans (NG feed from PTT has Mercaptan). According to Dragger tube data sheet is for Ethyl mercaptans. If dragger tube to be used for meassring Methyl mercaptans, correction factor 0.7 is required to apply. |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------------------|--|--|---|----------|----------|--------|----|--|
| | | | 4. CoMo Catalyst degradation | | 5 X 5 LG | Major | Remote | P3 | |
| | | 10. Deviation during startup - NG compressor + NG supply line -> nitrogen contaminated from NG booster (see 23.11) | | | | | | | |
| 1.10 | Internal coil leak or rupture (E1015) | 1. Corrosion from Chloride + Oxygen + Moisture in feed (see 1.9) | 1. Feed leak into reform gas cause carbon dioxide break through and 'H2S contain in MDEA solution | 2. PM Hydrostatic test and Cleaning every 2 years | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 6. To implement measurement of 'H2S in 'CO2 in 'CO2 recycle to reformer |
| | | | 2. High temperature outlet E1015 causing plant trip due to TSHH-10014 at 420 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.11) | | | | | | |
| | | | 4. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| | | 3. High temperature from upstream | 2. High temperature outlet E1015 causing plant trip due to TSHH-10014 at 420 | 4. TT10014 2oo4 vote set at 420 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.11) | | | | | | |
| | | | 4. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| | | | | | | | | | |
| | | 4. Improper maintenance | 1. Feed leak into reform gas cause carbon dioxide break through and 'H2S contain in MDEA solution | 2. PM Hydrostatic test and Cleaning every 2 years | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. High temperature outlet E1015 causing plant trip due to TSHH-10014 at 420 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------------|---|--|--|----------|----------|--------|----|---|
| | | | knockout drum (see 6.11) | | | | | | |
| | | | 4. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| | | 5. High pressure in feed | 1. Feed leak into reform gas cause carbon dioxide break through and 'H2S contain in MDEA solution | 1. SV1001 Set point 47 barg | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 121. SV-1001 has capacity at 1,673 Nm3/hr while max capacity of FV-10002 could be higher. Need to confirm releif capcity of SV-1001 at 45 barg compared to maximum flow rate from FV-10002 |
| | | | 2. High temperature outlet E1015 causing plant trip due to TSHH-10014 at 420 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.11) | | | | | | |
| | | | 4. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| | | 6. Erosion (see 1.16) | 1. Feed leak into reform gas cause carbon dioxide break through and 'H2S contain in MDEA solution | 2. PM Hydrostatic test and Cleaning every 2 years 3. Design of equipment is covered 100% load | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. High temperature outlet E1015 causing plant trip due to TSHH-10014 at 420 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.11) | | | | | | |
| | | | 4. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| 1.11 | Internal leak or rupture (NA) | | | | | | | | |
| 1.12 | Loss of containment | 1. High pressure (if the overpressure cause exceeds | 1. Large NG leakage and fire happen | 1. SV1001 set 46 barg, PSV1301 set 46 barg | 5 X 5 LG | Major | Remote | P3 | P3 CAR 1. PAH-901308 to be implemented. Setting at 45 |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--|--|---|---|----------|----------|--------|----|---|
| | | the equipment pressure rating) | | 2. High pressure alarm PIC10009 set 41 Barg | | | | | barg |
| | | 2. Corrosion from Moisture in feed | 2. Small NG leakage | 3. Plant patrol Shift wise/LLF | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. External fire | 1. Large NG leakage and fire happen | 4. Emergency response 5. Fire water system 6. LEL detector with alarm to CCR | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Gasket, packing, or seal failure | 2. Small NG leakage | 3. Plant patrol Shift wise/LLF 7. Yearly Pressure test | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. Improper maintenance | 1. Large NG leakage and fire happen | 3. Plant patrol Shift wise/LLF 7. Yearly Pressure test | 5 X 5 LG | Major | Remote | P3 | |
| 1.13 | Deviation during startup | 1. Water leak from cooler into booter compressor (to link from NG booster compressor node) (see 23.11) | 2. CoMo catalyst damage | 1. Procedure to drain water from booster during start up 2. Cooler Sight glass is monitored during start up 3. PDAH10022 set point 25 mBarg 4. TI10014 monitor during start up | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Incomplete purging | 1. High concentration of contaminants (see 1.9) | | | | | | |
| 1.14 | Deviation during shutdown/ maintenance | 1. Air ingress to system and react with CoMo catalyst | 1. Fire and Explosion | 1. Purging procedure (local WI No.11-0012) 2. Gas detector calibration 3. Dilution tube for measuring hydrocarbon in nitrogen | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Hydrogen misdirected flow to NG line during shutdown | 1. Fire and Explosion | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Used/ unloading CoMo catalyst with out Nitrogen (Loss of Nitrogen supply) | 1. Fire and Explosion | 2. Gas detector calibration 4. Nitrogen is supplied through pipeline | 5 X 5 LG | Major | Remote | P3 | P3 CAR 27. To convert method statement for load/unloading CoMo catalyst to operating procedure P3 CAR 28. Confirm vendor's |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|--|---|----------|----------|--------|----|---|
| | | | | | | | | | approved procedure is acceptable for diposal of used catalyst. Reconfirm with site safety coordinator |
| 1.15 | Deviation during sampling | 1. Leakage during sapling prereform gas | 1. Operator expose to Flammable/ Toxic gases | 1. Personal gas detector 2. Sampling proccedure (WI I-HYCO 027) 3. Sampling point is spefically design for closed loop to prevent release of flammable/ Toxic 4. There is sample cooler installed at sampling point where high temperature is expected to see 5. I-HYCO-013 Bomb sampling procedure | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Bomb leak during transportation from plant to laboratory | | | | | | | P3 CAR 30. Review procedure for bomb transportation to laboratory |
| 1.16 | High flow | 1. Control valve PV901308 failure fully open | 1. Erosion developped due to high velocity (see 1.10) | 1. Control valve FV10002 | | | | | |
| | | | 2. Deviation downstream S : C ratio at reformer (See at Pre-reformer & Reformer) (see 2.1) | | | | | | |
| | | 2. Control valve FV10002 failure fully open | 1. Erosion developped due to high velocity (see 1.10) | 2. Control valve PV901308 | | | | | |
| | | | 2. Deviation downstream S : C ratio at reformer (See at Pre-reformer & Reformer) (see 2.1) | | | | | | |
| | | 3. Low pressure downstream | 1. Erosion developped due to high velocity (see 1.10) | | | | | | |
| | | 4. High pressure (see 1.7) | 1. Erosion developped due to high velocity (see 1.10) | | | | | | |
| | | | 2. Deviation downstream S : C ratio at reformer (See at Pre-reformer & Reformer) (see 2.1) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|--|---|---|----------|------------|-----------------|------------|---|
| 1.17 | Low/no flow | 1. Control valve PV901308 failure fully close | 1. Plant process upset | 1. FI10003A Flow alarm low setting 8 Nm3/hr 2. PAL12001A | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Low pressure - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.9) | | | | | | |
| | | 2. Control valve FV10002 failure fully close | 1. Plant process upset | 1. FI10003A Flow alarm low setting 8 Nm3/hr 2. PAL12001A | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Low pressure - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.9) | | | | | | |
| | | 3. (H2 Feed) Upstream valve close | 2. Composition deviation (see 1.19) | | | | | | |
| | | 4. (H2 Feed) low/No pressure | 2. Composition deviation (see 1.19) | | | | | | |
| 1.18 | High reaction rate | 1. High concentration of contaminants (see 1.9) | 1. High temperature (see 1.5) | | | | | | |
| 1.19 | Composition deviation | 1. Less hydrogen in feed | 1. Hydrogenation reaction incomplete (See consequence of CoMo degradation) (see 1.9) | | | | | | P3 CAR 8. To remove hydrogen recycle C1008A from service and pipeline connecting to existing hydrogen feed. To be done by approved EMOC |
| | | 2. Low/no flow (see 1.17) | 1. Hydrogenation reaction incomplete (See consequence of CoMo degradation) (see 1.9) | | | | | | |
| 1.20 | Low reaction rate | 1. CoMo catalyst deactivated due to Non Sulfided condition because too low sulphur in feed for long time | 1. Sulphur breakthrough (see 2.10) | 1. Check dragger tube for 'H2S and Mercaptan in weekly basis 2. Quarterly total Sulphur analysis for inlet and outlet of desulphur 3. Troubleshooting procedure for 'H2S and Sulphur breakthrough | LE3 | 3-Moderate | 2-Very Unlikely | Transition | P3 CAR 20. To improve NG feed sampling test by including Methyl mercaptan, Ethyl mercaptan and hydrogen sulfide |
| | | | 2. High concentration of | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|--------|------------|-----------------|------------|--------------|
| | | | contaminants - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.10) | | | | | | |
| | | 2. Zinc oxide bed fully absorb 'H ₂ S after life time design | 1. Sulphur breakthrough (see 2.10) | 1. Check dragger tube for 'H ₂ S and Mercaptan in weekly basis 2. Quarterly total Sulphur analysis for inlet and outlet of desulphur 3. Troubleshooting procedure for 'H ₂ S and Sulphur breakthrough | LE3 | 3-Moderate | 2-Very Unlikely | Transition | |
| | | | 2. High concentration of contaminants - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.10) | | | | | | |

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| | | | |
|--|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: Pre-reformer & Reformer + Gas Cooling + Waste heat boiler |
| Design Intent: Feed gas after de-sulphurization unit will be mixed with steam at desired S:C ratio before receiving heat from flue gas section E-1126A/B then heated steam drum D-1131 before entering Pre-reformer to have 10% of reforming reaction then pass to E-1115 feed superheat then enter to reformer. Then reformed gas exist reformer and pass waste heat boiler E1122 and pass thorough E1015 for heating feed and pass E1011 to heat boiler feedwater at E1212 then pass through process gas cooling E-1412 knockout drum D1231 back to E1212 ==>E-1216 end node at XV12001 Note: 1. Feed is considered as NG. Prereformer process is considered endothermic reaction 2. Combustion session is in Node no.5 | | | |
| P&ID: 10PFP01, 10PFP02, 10PFP05, 10PFP06, 11PFP02, 11PFP01, 11PFP03, 11PFP05, 12PFP01, 14PFP02, 12PFP02 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Pipat Lubiam (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------------------|---|---|--|----------|-------|--------|----|--------------|
| 2.1 | High flow | 1. Control valve FV10011, FV10012 fully open in internal mode | 2. High S:C ratio caused lower yield of CO | 1. FV10011 & FV10012 designed to fix rate of change in value 3. S.O.P 11-0012 to ensure mode change | 5 X 5 LG | Minor | | | |
| | | | 5. Low temperature control at reformer (lower than 700) can caused carbon deposit (hot tube then damage) | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 7. Steam drum low pressure lead to low/no of steam (see 3.2) | | | | | | |
| | | 2. High pressure upstream (see 1.7) | 2. High S:C ratio caused lower yield of CO | 4. Alarm tube DP PDI11028 | 5 X 5 LG | Minor | | | |
| | | | 3. Low S:C ratio caused incompleted reforming reaction lead to carbon deposite on catalyst in which overheated tube in long run | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Catalyst chattering due to suddenly expendation from pressure drop | | 5 X 5 LG | Major | Remote | P3 | |
| | 3. High flow - NG supply (see 1.16) | 3. Low S:C ratio caused incompleted reforming reaction lead to carbon deposite on catalyst in which overheated tube in long run | | | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|----------|-------|--------|----|---|
| | | 4. wrong input value of HIC10517 and HIC10535 | 2. High S:C ratio caused lower yield of CO | | 5 X 5 LG | Minor | | | P3 CAR 19. Limit set point of HIC10517 and HIC10535. S:C input to be in range of 2.2 to 2.5 |
| | | | 3. Low S:C ratio caused incompleted reforming reaction lead to carbon deposite on catalyst in which overheated tube in long run | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. PV12001 fully open due to mechanical failure (spring broken), mis-operation | 3. Low S:C ratio caused incompleted reforming reaction lead to carbon deposite on catalyst in which overheated tube in long run | 2. Every T/A calibration PT12001 and function test PV12001 | 5 X 5 LG | Major | Remote | P3 | P3 CAR 9. Review set point of PDI11028 (existing 40 Barg) to be varied by plant load P3 CAR 22. Study implementation interlock permissive open FV10002 with reformer temperature at 700 c during start up and interlock for close one shot action to close FV10002 when TT11011 goes below 780 c with ramping FV10002 in 10 mins |
| | | | | | 5 X 5 LG | Major | Remote | P3 | |
| | | | | | 5 X 5 LG | Major | Remote | P3 | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | 6. PV12001 fully open due to pressure transmitter read high | 3. Low S:C ratio caused incompleted reforming reaction lead to carbon deposite on catalyst in which overheated tube in long run | 2. Every T/A calibration PT12001 and function test PV12001 5. TALL11011 temp low alarm 6. PDAH12001 to cross check and switching selection of transmitter | 5 X 5 LG | Major | Remote | P3 | P3 CAR 9. Review set point of PDI11028 (existing 40 Barg) to be varied by plant load P3 CAR 19. Limit set point of HIC10517 and HIC10535. S:C input to be in range of 2.2 to 2.5 P3 CAR 22. Study implementation interlock permissive open FV10002 |
| | | | | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------------------------|--|--|---|----------|-----------|-------------------|------------|---|
| | | | | | | | | | with reformer temperature at 700 c during start up and interlock for close one shot action to close FV10002 when TT11011 goes below 780 c with ramping FV10002 in 10 mins |
| | | | 4. Catalyst chattering due to suddenly expensation from pressure drop | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 5. Low temperature control at reformer (lower than 700) can caused carbon deposit (hot tube then damage) | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 8. Low pressure in process (see 2.9) | | | | | | |
| | | 7. Carbon dioxide feed upset from upstream control | 5. Low temperature control at reformer (lower than 700) can caused carbon deposit (hot tube then damage) | 5. TALL11011 temp low alarm | 5 X 5 LG | Major | Remote | P3 | P3 CAR 10. Add alarm High carbon dioxide feed at FIC10016D setting 4,500 Nm3/hr |
| | | | 9. Reverse flow - CO2 vaporizer E852 (see 29.3) | | | | | | |
| 2.2 | Low/no flow (Normal+Steam operation) | 1. XV12001 fail closed | 2. No production no safety issue | 6. Yealy PM stroke test | | | | | |
| | | | 4. High pressure of upstream of HV10025 (see 1.7) | | | | | | |
| | | 2. HV10025 fail partital closed | 1. Process upset | 1. See safeguard in high pressure of NG supply node 6. Yealy PM stroke test | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. High pressure of upstream of HV10025 (see 1.7) | | | | | | |
| | | 3. HV10025 fail fully closed | 5. High temperature in reformer tube. Reformer tube leak and damage. Leak of combustibile gas damage insulation and reformer box | 2. TAHH11011A/B/C (2oo3 SIL1) set 900 c with delay 5 sec 3. FI10002A/B/C (2oo3) 6. Yealy PM stroke test | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. PV10009 fail open | 1. Process upset | 2. TAHH11011A/B/C (2oo3 | 5 X 5 | Moderate | Remote | P4 | P3 CAR 11. Check actual |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------------------|---|---|----------|------------|-------------------|------------|--|
| | | | | SIL1) set 900 c with delay 5 sec 4. Interlock PV10009 lock close with burner on (HA11035) 6. Yealy PM stroke test | LG | | | | interlock function of PV10009 lock close with burner management system to remain close during burner is on regardless with operation mode P3 CAR 16. Install proximity at close position at PV10009 to show open - close position in DCS. Create in standard operating procedure to manage situation in case valve PV10009 is fail open. Operator need to close manual valve. Training to all operators accordingly |
| | | | 5. High temperature in reformer tube. Reformer tube leak and damage. Leak of combustible gas damage insulation and reformer box | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. Low pressure upstream (see 1.17) | | | | | | | |
| | | 6. FV10011 fail closed(Steam feed) | 1. Process upset | 5. Ratio FFI10518A/B/C set Low 1.72, Low low 1.62 mol/mol, Burner management system trip 6. Yealy PM stroke test 7. FFI10506A/B/C set Low 2.17, Low low 2.08 mol/mol, Burner management system trip | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Low temperature control at reformer (lower than 700) can caused carbon deposit (hot tube then damage) (see 2.7) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 7. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|----------|------------|-------------------|------------|--------------|
| | | | flammable gas emission | | | | | | |
| | | 7. FV10012 fail closed (Steam feed) | 1. Process upset | 6. Yealy PM stroke test 7. FFI10506A/B/C set Low 2.17, Low low 2.08 mol/mol, Burner management system trip | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Low temperature control at reformer (lower than 700) can caused carbon deposit (hot tube then damage) (see 2.7) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 7. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 8. Carbon dioxide feed valve (FV10016) closed | 6. Process fluctuation, lower production rate | 8. FFI10516 Ratio 'CO2 : Feed set Low = 2.0 Low Low = 1.8 | 5 X 5 LG | Minor | | | |
| | | 9. Low pressure steam drum | 7. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | 5. Ratio FFI10518A/B/C set Low 1.72, Low low 1.62 mol/mol, Burner management system trip 7. FFI10506A/B/C set Low 2.17, Low low 2.08 mol/mol, Burner management system trip 9. PAL11027 steam drum pressure low 10. Back up into steam system by package boiler | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 10. Low pressure - Stream drum + steam system + Steam back up from package boiler (see 3.2) | 1. Process upset | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. No production no safety issue | | | | | | |
| | | | 7. Inadequate steam for reaction, lead to carbon | | LE3 | 3- | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------------|--------------------------------|--|--|--------|-----------|-------------------|------------|--------------|
| | | | deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | | Moderate | Unlikely | | |
| 2.3 | Low/no flow (Nitrogen mode) | 1. XV12001 fail closed | 1. No safety issue | 6. E1216, E1115 design temperature design 675 c Mat'I SS/SA213TP304H, outlet pipeline design at 660 c | | | | | |
| | | 2. PV12001 fail partial closed | 2. No nitrogen media flow to cooldown reformer tube during reformer warm up phase (see 2.6) | 1. 'FAL10001 = 700 kg/hr 'FALL1001 = 600 kg/hr trip burner management system 2. 'TAH11009 Setting 590 c 3. 'TAH11015 setting 760 c 4. TAH11002D setting 530 c TAL = 370 c 5. TSHH11028 (SIL1) setting 900 delay 5 sec 6. E1216, E1115 design temperature design 675 c Mat'I SS/SA213TP304H, outlet pipeline design at 660 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. PV12001 fail fully closed | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.6) | 1. 'FAL10001 = 700 kg/hr 'FALL1001 = 600 kg/hr trip burner management system 3. 'TAH11015 setting 760 c 6. E1216, E1115 design temperature design 675 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 4.4) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------------------------------|--|--|--------|-----------|-------------------|------------|--------------|
| | | | | Mat'I SS/SA213TP304H, outlet pipeline design at 660 c | | | | | |
| | | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 4.4) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. HV10025 fail partial closed | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.6) | 2. 'TAH11009 Setting 590 c 3. 'TAH11015 setting 760 c 4. TAH11002D setting 530 c TAL = 370 c 5. TSHH11028 (SIL1) setting 900 delay 5 sec 6. E1216, E1115 design temperature design 675 c Mat'I SS/SA213TP304H, outlet pipeline design at 660 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 4.4) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. HV10025 fail fully closed | 2. No nitrogen media flow to cooldown reformer tube during reformer warm up phase (see 2.6) | 3. 'TAH11015 setting 760 c 6. E1216, E1115 design temperature design 675 c Mat'I SS/SA213TP304H, outlet pipeline design at 660 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.6) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------|--|---|--------|-----------|-------------------|------------|---|
| | | | to downstream equipment (see 4.4) | | | | | | |
| | | 6. PV10009 fail open | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.6) | 2. 'TAH11009 Setting 590 c 3. 'TAH11015 setting 760 c 4. TAH11002D setting 530 c TAL = 370 c 5. TSHH11028 (SIL1) setting 900 delay 5 sec 6. E1216, E1115 design temperature design 675 c Mat'l SS/SA213TP304H, outlet pipeline design at 660 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 16. Install proximity at close position at PV10009 to show open - close position in DCS. Create in standard operating procedure to manage situation in case valve PV10009 is fail open. Operator need to close manual valve. Training to all operators accordingly |
| | | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 4.4) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 7. No Nitrogen pressure | 2. No nitrogen media flow to cooldown reformer tube during reformer warm up phase (see 2.6) | 1. 'FAL10001 = 700 kg/hr 'FALL1001 = 600 kg/hr trip burner management system 2. 'TAH11009 Setting 590 c 3. 'TAH11015 setting 760 c 4. TAH11002D setting 530 c TAL = 370 c 5. TSHH11028 (SIL1) setting 900 delay 5 sec 7. Change E1115 every 15 years according to limited lift time of material since it is operated at design temperature | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.6) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and | | LE3 | 4-Serious | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|---|---|---|----------|-----------|-------------------|------------|---|
| | | | its downstream pipelines / damage material / leakage to downstream equipment (see 4.4) | | | | Unlikely | | |
| 2.4 | Reverse flow (NA) | | | | | | | | |
| 2.5 | Misdirected flow | 1. HV11001 fail open | 3. No safety issue | | | | | | |
| | | | 4. Process upset | | 5 X 5 LG | Minor | | | |
| | | 2. TV11002A fail open | 1. High temperature prereformer inlet, Pipe failure due to flue gas approach temp > 600 c while pipe design 540 c (see 2.6) | 1. Interlock TV11002B to open and TV11002A to close due to high temperature detect at TSHH11028C,D (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | Rec 1. To study reliability for control of TIC11002 by using voting between TT11002 and TT11028 |
| | | 3. TV11002B fail open | 2. Low temperature reform gas and incompleted reaction | 1. Interlock TV11002B to open and TV11002A to close due to high temperature detect at TSHH11028C,D (SIL1) | | | | | Rec 1. To study reliability for control of TIC11002 by using voting between TT11002 and TT11028 |
| | | | 4. Process upset | | 5 X 5 LG | Minor | | | |
| | | 4. LV12003 malfunction due to Level indicator error | 5. Reformed gas pass through deaerator. Reform gas vent to atmosphere | 2. LV12003 fail closed 4. 'LSLL 12003 (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. LV12006 malfunction due to Level indicator error | 5. Reformed gas pass through deaerator. Reform gas vent to atmosphere | 3. LV12006 fail closed 5. 'LSLL 12006 (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 6. TT11002 error reading low value | 1. High temperature prereformer inlet, Pipe failure due to flue gas approach temp > 600 c while pipe design 540 c (see 2.6) | 1. Interlock TV11002B to open and TV11002A to close due to high temperature detect at TSHH11028C,D (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 7. LT12003 error read high value (see 2.15) | 5. Reformed gas pass through deaerator. Reform gas vent to atmosphere | 4. 'LSLL 12003 (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 8. LT12004 error read high value (see 2.15) | 5. Reformed gas pass through deaerator. Reform gas vent to atmosphere | 5. 'LSLL 12006 (SIL1) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|---|--|--------|------------|-------------------|------------|--|
| 2.6 | High temperature | 1. Temperature sensor of reformer (TIC11010) error reading low value | 1. High temperature at reformer resulting tube damage and fire in reformer box (see 2.16) | 1. TT11011 A/B/C 2oo3 (TSHH11011 set at 900 c SIL1) burner management system trip 3. Selector for average control by either TI11010 or TI11011B or TI11011C range 700 - 1000 c | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. Burner improper adjustment | 2. Localized overheat on some reformer tube that fuel concentrated on lead to skin temperature over design. Reduce tube life time and is possible for tube damage in future | 4. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. Catalyst deactivation | 3. Higher skin temperature and Lower conversion at same exit reformer temperature. Hot tube | 4. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting 6. Visual inspection of tube condition 3 times/week 7. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor 8. AT15003 online analyzer for Methane measurement (TSA outlet) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 4. Improper catalyst loading (Void, Bridge, Debris, Block) | 4. Create hot spot at reformer tube | 6. Visual inspection of tube condition 3 times/week 9. Proper catalyst loading provide to contractor. DP catalyst tube loading measurement documents is method statement. 10. Trouble shooting in case tube get hot spot included in operating procedure | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 13. DP catalyst tube loading measurement procedure to be converted from method statement to local procedure |
| | | 5. Carbon deposition in reformer tube | 3. Higher skin temperature and Lower conversion at same exit reformer temperature. Hot tube | 6. Visual inspection of tube condition 3 times/week 10. Trouble shooting in case | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 14. Review and separate steaming procedure from plant start up procedure |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|--------|------------|-------------------|------------|---|
| | | | | tube get hot spot included in operating procedure 11. Steaming procedure carbon elimination | | | | | |
| | | | 4. Create hot spot at reformer tube | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 6. Burner damage causing flame impingement to reformer tube | 2. Localized overheat on some reformer tube that fuel concentrated on lead to skin temperature over design. Reduce tube life time and is possible for tube damage in future | 5. Monitor flame shape Monitor flame shape 3 times/week 12. LLF check shift wise around reformer box 13. Design for reformer box insulation is 1200- 1400 c can resist flame impingement within short time 15. Offline inspection during turnaround by Mech team 16. Offline cleaning by production team | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 4. Create hot spot at reformer tube | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Reformer insulation damage causing hot spot at reformer furnace side wall. Fire could expose to personnel | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 7. PSA/Coldbox upset cause to high fuel to burner, resulting in NG fuel close and no control over temperature of reformer exit | 1. High temperature at reformer resulting tube damage and fire in reformer box (see 2.16) | 1. TT11011 A/B/C 2oo3 (TSHH11011 set at 900 c SIL1) burner management system trip 14. Pressure differential fuel line PI11013 A/B/C 'PAH setting 140 mbar 'PSHH 160 mbar burner management system trip 17. Troubleshooting in Fuel loop control operating procedure | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 15. To put alarm of opening on FIC10004 NG trim fuel during normal operation if opening is lower than 5% |
| | | 8. Cooling fan (E1216 A/B) fan dirtiness | 6. High temperature outlet gas. No water condense or | 18. TI12007 to close valve XV12001 'TAH = 65 'TSHH = | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|---|---|---|--------|-----------|-------------------|------------|--------------|
| | | | condesate high temperature to dearetor, high temperature to MDEA unit (see 6.5) | 90 c A/B/C 2oo3 (SIL1) to close valve XV12001 | | | | | |
| | | 9. E1216 A/B motor not function/ Impeller damage | 6. High temperature outlet gas. No water condense or condeseate high temperature to dearetor, high temperature to MDEA unit (see 6.5) | 19. Every 2 years preventive maintenance during major turnaround | | | | | |
| | | 10. Misdirected flow (see 2.5) | | | | | | | |
| | | 11. Low/no flow (Nitrogen mode) (see 2.3) | | | | | | | |
| | | 12. Low/no flow (Nitrogen mode) (see 2.3) | | | | | | | |
| | | 13. TV11001 fail fully open | 7. Reform gas outlet from E1122 high temperature (600 - 700 c) over pipe design rating. Fire and explosion could be expected | 20. TAH11001 set point 430 c 21. TSHH11024 (SIL1) set point 440 c to close TV11001 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 14. TIC11001 error reading low | 7. Reform gas outlet from E1122 high temperature (600 - 700 c) over pipe design rating. Fire and explosion could be expected | 21. TSHH11024 (SIL1) set point 440 c to close TV11001 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 2.7 | Low temperature | 1. Low/no flow (Normal+Steam operation) (see 2.2) | | | | | | | |
| 2.8 | High pressure | 1. High pressure - NG supply (see 1.7) | | | | | | | |
| | | 2. High pressure - Stream drum + steam system + Steam back up from package boiler (see 3.1) | | | | | | | |
| | | 3. Deviation during maintenance (see 2.13) | | | | | | | |
| 2.9 | Low pressure | 1. High flow due to PV12001 fully open due | 1. No production. No safety issue | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|--|---|--------|------------|-------------------|------------|--------------|
| | | to mechanical failure (spring broken), mis-operation or pressure transmitter read high (see 2.1) | | | | | | | |
| | | 2. Low pressure - NG supply (see 1.8) | 1. No production. No safety issue | | | | | | |
| | | 3. Low/no flow - NG supply from Control valve PV901308 failure fully close or Control valve FV10002 failure fully close (see 1.17) | 1. No production. No safety issue | | | | | | |
| 2.10 | High concentration of contaminants | 1. High concentration of contaminants upstream (see 1.9) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | 1. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting 2. Visual inspection of tube condition 3 times/week 3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor 4. AT15003 online analyzer for Methane measurement (TSA outlet) 5. Trouble shooting in case tube get hot spot included in operating procedure 6. Steaming procedure carbon elimination | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. Low temperature - NG supply (see 1.6) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. Low reaction rate in desulphurization unit resulted in sulphur break through Prereformer/ Reformer, CoMo deactivate (see 1.20) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | 1. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting 2. Visual inspection of tube | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|---|--------|-------------|-------------------|------------|--------------|
| | | | | condition 3 times/week 3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor 4. AT15003 online analyser for Methane measurement (TSA outlet) 5. Trouble shooting in case tube get hot spot includeds in operating procedure 6. Steaming procedure carbon elimination | | | | | |
| | | | 2. Prereformer catalyst deactivation lead to lower prodction. (No safety issue) (see 2.18) | | | | | | |
| | | 4. Low reaction rate in desulphurization unit resulted in sulphur break through Prereformer/ Reformer, Zinc Oxide saturated (see 1.20) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | 1. Meassure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting 2. Visual inspection of tube condition 3 times/week 3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor 4. AT15003 online analyser for Methane measurement (TSA outlet) 5. Trouble shooting in case tube get hot spot includeds in operating procedure 6. Steaming procedure carbon elimination | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Prereformer catalyst deactivation lead to lower prodction. (No safety issue) (see 2.18) | | | | | | |
| | | 5. Preformer expose to | 3. R1105 Weakening carbon | 7. Currently outlet of | LE3 | 4-Serious | 0- | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------------|---|--|--|----------|------------|--------------------|------------|--|
| | | HTHA (High temperature Hydrogen Attack) (High hydrogen partial pressure + high temperature) | steel material (Decarburization and Fissuring). Vessel damage leakage of flammable gas and toxic gas | Prereformer Hydrogen fraction is 8.3% mol at 38.3 barg (partial pressure 46 psig) at temperature of 460 c which is satisfied condition for this material 8. Control hydrogen flow rate refer to design (8 kg/hr) FI10595 high flow alarm 18 kg/hr | | | Extremely Unlikely | | |
| | | 6. High concentration of contaminants - Hydrogen sulfide contain in carbon dioxide recycle and feed in to reformer (see 6.11) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 6. To implement measurement of 'H2S in 'CO2 in 'CO2 recycle to reformer |
| | | 7. Low/no flow - Hydrogen mix feed to NG booster (see 24.2) | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.18) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Prereformer catalyst deactivation lead to lower production. (No safety issue) (see 2.18) | | | | | | |
| 2.11 | Deviation during startup | 1. Oxygen residual in process | 1. Form explosive mixture in pipeline | 1. Standard operating procedure for oxygen purge in place and practice 2. Normal start up procedure during nitrogen start up from ambient to 400 C 3. Standard operating procedure to purge any of feedline to be free oxygen below 1%/ standard operating procedure to purge oxygen out from steam line for more than 30 mins | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Rate of temperature heating up too fast (More than 50 c per hour) | 2. Lead to stress from thermal expansion leading to flanges damage and flammable gas leak out | 4. Plant start up procedure for heat up rate 5. Rate of change temperature alarm from TI11011A/B/C | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Remormer tube got | | 5 X 5 | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|---|----------|----------|----------|----|---|
| | | | thermal stress and crack. Fire happens in reformer box | | LG | | | | |
| | | | 4. Refractory inside furnace crack | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. High different pressure across isolation XV11001 (inlet prereformer) | 5. Valve actuator damage | | 5 X 5 LG | Minor | | | |
| | | 4. Improper condensate drain at FV10011, FV10012 | 6. Condensate contact to prereformer catalyst/ catalyst breakage due to rapid change of temperature | 6. Plant start up procedure for condensate drain | 5 X 5 LG | Major | Remote | P3 | |
| | | | 7. Condensate ingress to feed super heater (E1115) and damage tube. Solid accumulation block | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Steam introduction into any equipment when temp is below condensation point | 6. Condensate contact to prereformer catalyst/ catalyst breakage due to rapid change of temperature | 7. Plant start up procedure for steam introduction must be introduced above temperature of 450 c | 5 X 5 LG | Major | Remote | P3 | |
| | | | 8. Condensate contact to reformer catalyst/ catalyst breakage due to rapid change of temperature | | 5 X 5 LG | Major | Remote | P3 | |
| | | 6. Feed steam into prereformer too long without hydrogen or hydrocarbon | 9. Prereformer catalyst degrade and process upset | 8. Interlock trip burner management system when feed steam more than 10 mins | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. NG introduction below 700 c | 10. Carbon deposit in reformer tube. Catalyst damage immediately | 9. Plant start up procedure for introducing NG at above temperature of 700 c | 5 X 5 LG | Major | Remote | P3 | P3 CAR 22. Study implementation interlock permissive open FV10002 with reformer temperature at 700 c during start up and interlock for close one shot action to close FV10002 when TT11011 goes below 780 c with ramping FV10002 in 10 mins |
| | | 8. No carbon dioxide feed due carbon dioxide compressor shutdown and No source from carbon dioxide import | 11. NG steam mixing feed back flow to carbon dioxide feeding line. High temperature exposes to pipeline causing stress corrosion cracking due to carbon dioxide touching with | 10. FV10016A,B closed when carbon dioxide not using 11. Check valve XAE010 at import line 12. Check valve at carbon | 5 X 5 LG | Serious | Possible | P3 | P3 CAR 12. Check carbon dioxide injection pipe by non-destructive testing at all welding joint due to it is possible to subject with reverse NG+Steam mixing to |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|---|---|----------|----------|----------|----|--|
| | | | steam/ carbon dioxide in water corrosion on carbon steel | dioxide compressor XAE009 13. Carbon dioxide Pipeline design for auto drain, No pocket | | | | | this pipeline |
| 2.12 | Deviation during shutdown | 2. Cold down rate more 50 c per hour | 1. Lead to stress from thermal expansion leading to flanges damage and flammable gas leak out | 2. Standard operating procedure for cooldown tempeature rate 3. Rate of change temperature alarm from TI11011A/B/C | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Remormer tube got thermal stress and crack. Fire happens in reformer box | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Pressure ramp down rate too fast (0.5 barg/ min) | 1. Lead to stress from thermal expansion leading to flanges damage and flammable gas leak out | 4. Program for ramp pressure down (0.5 bar/ min) | 5 X 5 LG | Major | Remote | P3 | P3 CAR 24. Create standard operating procedure for plant shutdown for purging after shutdown. Precuation for hazard of Nikel carbonyl hazard to be mentioned for open/ access to equipment |
| | | | 2. Remormer tube got thermal stress and crack. Fire happens in reformer box | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. No nitrogen purge to refromer after electrical power loss for more than 30 min | 4. Carbon will deposit in catalyst inside reformer tube and leading to catalysy shattering | 1. Standard operating procedure for purging during shutdown 6. Standard operating procedure for purging during emergency shutdown | 5 X 5 LG | Major | Remote | P3 | P3 CAR 26. Review and update emergency shutdown to inlcude Nitrogen purging reformer within 30 mins to be done to avoid catalyst damage |
| | | 6. Inadequate steam purge after trip by any reason | 4. Carbon will deposit in catalyst inside reformer tube and leading to catalysy shattering | 6. Standard operating procedure for purging during emergency shutdown 7. Limit flow steam at not less than 220, 820 kg/hr by limit valve (FV10011, 10012) by mechanical lock | 5 X 5 LG | Major | Remote | P3 | |
| | | 7. No condensate drain | 3. Corrsion at low point due to condensate as(CO2 + H2O) of equipment and pipeline | 5. Precedure for condeseate draining shutdown | 5 X 5 LG | Moderate | Possible | P3 | P3 CAR 25. Need to list low point drain location and update to shutdown procedure |
| 2.13 | Deviation during | 1. improper manage Used catalyst (Nikel) i.e. | 2. Generate hazardous waste. Impact to company | 1. Company is only | 5 X 5 | Major | | | P3 CAR 28. Confirm vendor's approved procedure is |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|--|--|----------|----------|----------|----|--|
| | maintenance | improper purging, improper disposal method | permit license in case violation to regulatory of environment management | authorised vendor | LG | | | | acceptable for diposal of used catalyst. Reconfirm with site safety coordinator |
| | | 2. New catalyst handling | 3. Casinogenic agent | 2. PPE (Air line, Chemical resistance grove, Tyvex suite) 3. JSA | 5 X 5 LG | Serious | | | |
| | | 3. Nikel carbonyl (see 2.12) | | | | | | | |
| | | 4. Deviation during shutdown/ maintenance - NG supply (see 1.14) | | | | | | | |
| 2.14 | Deviation during sampling | 1. Reform gas Leak during sampling activity | 1. Personnel Expose to flammable and toxic gas | 1. Sampling point is spefically design for closed loop to prevent release of flammable/ Toxic | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Injury from hot burning | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Prereform gas Leak during sampling activity | 1. Personnel Expose to flammable and toxic gas | 1. Sampling point is spefically design for closed loop to prevent release of flammable/ Toxic 3. I-HYCO-013 Bomb sampling procedure | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Injury from hot burning | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Cold/ Hot Condensate sampling at D1231, 1232. Currently collect at bottom at sight glass | 3. Possibe to have toxic gas and hot water exposure | | 5 X 5 LG | Moderate | Possible | P3 | P3 CAR 29. Review point of sampling condeseate drain and sampling procedure at D1231, D1232. To install sample panel with cooler |
| | | 4. Bomb leak during transportation from plant to laboratory | 1. Personnel Expose to flammable and toxic gas | | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 30. Review procedure for bomb transportation to laboratory |
| | | 1. Condesate in knockout drum low level (D-1231, D1232) | 1. Misdirected flow (see 2.5) | | | | | | |
| | | | 2. Misdirected flow (see 2.5) | | | | | | |
| 2.16 | Internal leak or | 1. Reformer tube life | 1. Contamination of other | 4. Eddy current test at | 5 X 5 | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|----------|--------|----|--------------|
| | rupture | | fluid | reformer test per Linde standard PdM 5. Replica test at reformer tube/ Hot collector every year 6. Visual inspection 3 time/ week | LG | | | | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Equipment life time | 1. Contamination of other fluid | 7. Offline inspection following Linde's standard | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. High temperature → High temperature at reformer resulting tube damage and fire in reformer box (see 2.6) | 1. Contamination of other fluid | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Corrosion from condensate not draining (see 2.12) | 1. Contamination of other fluid | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Cold down rate more 50 c per hour (see 2.12) | 1. Contamination of other fluid | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | 6. carbon dioxide pipeline damage from misdirected flow (see 2.11) | 1. Contamination of other fluid | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|----------|--------|----|--------------|
| | | 7. Carbulization of metal tube due to over operating design temperature (Cooling media level low in waste heat boiler) | 1. Contamination of other fluid | 8. Metal design condition and material 9. Offline inspection by RFT 10. Maintain optimum S:C ratio to prevent carbon formation in reform gas | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Release of toxic and flammable gas when steam venting at steam heading and dearerator vent | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 8. Ceramic ferrule crack due to too high temperature condition | 1. Contamination of other fluid | 11. Changed material to Inconel 12. Yearly visual inspection. Repair when require | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Release of toxic and flammable gas when steam venting at steam heading and dearerator vent | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 9. Refractory cracking lead to carbon steel damage (Heating rate not respected) | 1. Contamination of other fluid | 12. Yearly visual inspection. Repair when require 13. Measurment waste heat boiler surface every shift wise | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Release of toxic and flammable gas when steam venting at steam heading and dearerator vent | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 10. Hot collector cracking | 2. Release of toxic and flammable gas. Fire and explosion risk | 5. Replica test at reformer tube/ Hot collector every year | 5 X 5 LG | Major | Remote | P3 | |
| | | 11. High corrosive ambient condition damage cooling fin fan E1216 | 2. Release of toxic and flammable gas. Fire and explosion risk | 12. Yearly visual inspection. Repair when require | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------|--|--|---|----------|------------|-------------------|------------|--------------|
| | | 12. Support for pipeline and equipment for thermal expansion failure due to rust, resistance, dust, blocking etc | 1. Contamination of other fluid | 15. Insert teflon at support and LLF check for comparing hot and cold position movement 16. Spring hangers | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Release of toxic and flammable gas. Fire and explosion risk | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Release of toxic and flammable gas when steam venting at steam heading and deaerator vent | | 5 X 5 LG | Serious | Remote | P3 | |
| 2.17 | High reaction rate (NA) | 1. No issue found | | | | | | | |
| 2.18 | Low reaction rate | 1. Higher S:C ratio (low production of CO, No safety issue) | | | | | | | |
| | | 2. Low temperature (low production of CO, No safety issue) | | | | | | | |
| | | 3. Lifetime of catalyst | 1. Reformer catalyst deactivation lead to reformer hot tube and flammable gas release | 1. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting 2. Visual inspection of tube condition 3 times/week 3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor 4. AT15003 online analyzer for Methane measurement (TSA outlet) 5. Trouble shooting in case tube get hot spot included in operating procedure 6. Steaming procedure carbon elimination | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 4. High concentration of contaminants -> | | 1. Measure skin temperature 3 times/week | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--------------|--|--------|---|----|----|--------------|
| | | Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.10) | | <p>and record kept. Any defect, operator will take action by adjusting</p> <p>2. Visual inspection of tube condition 3 times/week</p> <p>3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor</p> <p>4. AT15003 online analyser for Methane measurement (TSA outlet)</p> <p>5. Trouble shooting in case tube get hot spot included in operating procedure</p> <p>6. Steaming procedure carbon elimination</p> | | | | | |
| | | 5. High concentration of contaminants --> Prereformer catalyst deactivation lead to lower production. (No safety issue) (see 2.10) | | <p>1. Measure skin temperature 3 times/week and record kept. Any defect, operator will take action by adjusting</p> <p>2. Visual inspection of tube condition 3 times/week</p> <p>3. Online reform gas quality measurement AP12001 (HC C1-6, carbon dioxide, CO) for operator to monitor</p> <p>4. AT15003 online analyser for Methane measurement (TSA outlet)</p> <p>5. Trouble shooting in case tube get hot spot included in operating procedure</p> <p>6. Steaming procedure carbon elimination</p> | | | | | |

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| | | | |
|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: Stream drum + steam system + Steam back up from package boiler |
| Design Intent: - Steam is generated from [1] Waste heat boiler (E1122) receive heat of reform gas [2] Steam drum (E1122) receives excess heat recover from flue gas by steam feed mixing (E1126A/B). - BFW is supplied from boiler feed water pump (P1371A/B) to D1131 and heat up residual heat from process gas which is pass E1212. - 41.5 barg HP steam from D1131 is supplied to steam header for supplying to Steam feed mixing (FV10011, FV10012), let pressure 5.5 barg for LP steam supply to UT stations. Another high pressure steam supply to E1521 (Heating regeneration gas for absorber), E1412 (MDEA reboiler) - Excess steam is to be vented off by PV13006 through atmosphere at N1161 | | | |
| P&ID: 10PFP05, 11PFP01, 12PFP01, 13PFP01, 13PFP02, 13PFP03, 14PFP02, 15PFP03 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|--|---|--|--------|-----------|-------------------|------------|--------------|
| 3.1 | High pressure | 1. High temperature in waste heat boiler (E1122) (see 2.6) | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 1. 'PSV1101A/B/C/D setting 47 barg, 2x100% capacity. There is diverter valve for PSV1101 (A,C)/ (B,D) 2. PAH11027 setting 45 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. PV13006 fail close | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 1. 'PSV1101A/B/C/D setting 47 barg, 2x100% capacity. There is diverter valve for PSV1101 (A,C)/ (B,D) 2. PAH11027 setting 45 barg 11. Steam control valves are plan overhaul, stroke test is done fully every year | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High pressure in high pressure steam header | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. PIC13006 error reading low | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 1. 'PSV1101A/B/C/D setting 47 barg, 2x100% capacity. There is diverter valve for PSV1101 (A,C)/ (B,D) 2. PAH11027 setting 45 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High pressure in high pressure steam header | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. TIC11001 error reading high | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 1. 'PSV1101A/B/C/D setting 47 barg, 2x100% capacity. There is diverter valve for PSV1101 (A,C)/ (B,D) 2. PAH11027 setting 45 barg 3. PIC13006 setting 42 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|--------|-----------|-------------------|------------|--|
| | | | | 4. PIC11027 setting 41.5 barg | | | | | |
| | | 5. Reform gas from E1126A misdirected flow cause high heat generate at D1131 | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 1. 'PSV1101A/B/C/D setting 47 barg, 2x100% capacity. There is diverter valve for PSV1101 (A,C)/ (B,D) 2. PAH11027 setting 45 barg 3. PIC13006 setting 42 barg 4. PIC11027 setting 41.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 6. PIC13004 error reading low | 3. High pressure in high pressure steam header | 3. PIC13006 setting 42 barg 5. Setpoint of package boiler is 41.5 barg 11. Steam control valves are plan overhaul, stroke test is done fully every year | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | 7. PV13004 fail open | | 3. PIC13006 setting 42 barg 5. Setpoint of package boiler is 41.5 barg 6. Steam control valves are regularly done every 2 years 11. Steam control valves are plan overhaul, stroke test is done fully every year | | | | | |
| | | 8. PV13005 fail open | 4. High pressure in low pressure steam header | 7. 'PSV1304 setting 7 barg 8. PAH13005 setting 6 barg 11. Steam control valves are plan overhaul, stroke test is done fully every year | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 9. PIC13005 error readig low | 4. High pressure in low pressure steam header | 3. PIC13006 setting 42 barg 7. 'PSV1304 setting 7 barg 8. PAH13005 setting 6 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 10. Misoperation start up valve left open from package boiler | 3. High pressure in high pressure steam header | 3. PIC13006 setting 42 barg 7. 'PSV1304 setting 7 barg 8. PAH13005 setting 6 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. High pressure in low | | LE3 | 4-Serious | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|---|--------|------------|-------------------|------------|--|
| | | | pressure steam header | | | | Unlikely | | |
| | | 11. Impulse line PIC11027 blockage by solid from chemical in steam (HP steam) | 2. High pressure in steam drum and steam system. Pipe could be ruptured and steam release | 3. PIC13006 setting 42 barg 9. Yearly scale removal implulse line by steam injection 10. Switch using TI11002 instead | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High pressure in high pressure steam header | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. High pressure in low pressure steam header | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 12. Impulse line PIC13005 blockage by solid from chemical in steam (LP steam) | 4. High pressure in low pressure steam header | 7. 'PSV1304 setting 7 barg 9. Yearly scale removal implulse line by steam injection | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 13. High pressure supply from package boiler (see 22.7) | | | | | | | |
| 3.2 | Low pressure | 1. TV11001 fail open | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 2. Back up steam from package boiler 3. PAL11027 setting 38 barg 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively 9. PAL13009 setting 38 barg | | | | | |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damange. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. TIC11001 error reading low | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 2. Back up steam from package boiler 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr | | | | | P3 CAR 31. To implement automatic open of steam import to mixing feed XV13001 in early condition from PAL11027 warning alarm |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|--------|------------|-------------------|------------|--|
| | | | | repectively 5. PAL11027 setting 38 barg and auto select to temperature control by TI11001 instead 9. PAL13009 setting 38 barg | | | | | P3 CAR 32. To show limit opening of PV11027 (5-7%) for interlocking with TV11001 in PID P3 CAR 33. To revise Note13 in PID 11PFP01 to specific HIC11027 set point at 5% then system will use TIC11001 function instead of PIC |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. Leakage through TV11001 | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 3. PAL11027 setting 38 barg 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively 6. TV11001 is included to PM and spare part for offline maintenance 7. Maintain optimization S:C to reduce carbon formation by optimization of NG composition adjustment 9. PAL13009 setting 38 barg | | | | | |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 4. Reformer Low temperature than required | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 2. Back up steam from package boiler 3. PAL11027 setting 38 barg 8. Master loop of reformer | | | | | P3 CAR 34. To transfer cascade set point TIC11010 following load from ALC to DCS |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------------------------------|--|---|--------|------------|-------------------|------------|--|
| | | | | exit is cascaded with plant load by ALC (auto load control program) 9. PAL13009 setting 38 barg | | | | | |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 5. PIC13006 error reading high | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 3. PAL11027 setting 38 barg 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively 9. PAL13009 setting 38 barg | | | | | |
| | | 6. PV13006 fail open | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 3. PAL11027 setting 38 barg 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively 9. PAL13009 setting 38 barg 12. steam control valves are plan overhaul, stroke test is done fully every year | | | | | |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 7. PV11027 fail open | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 2. Back up steam from package boiler 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively | | | | | P3 CAR 31. To implement automatic open of steam import to mixing feed XV13001 in early condition from PAL11027 warning alarm |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|----------|------------|-------------------|------------|---|
| | | 8. PIC11027 error reading high | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 4. FALL 10508A/B/C, FALL10008A/B/C (total steam flow low-low) setting 1,000 kg/ hr, 1,100 kg/hr repectively 9. PAL13009 setting 38 barg | | | | | P3 CAR 31. To implement automatic open of steam import to mixing feed XV13001 in early condition from PAL11027 warning alarm |
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damange. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 9. PV13005 fail close | 4. Low pressure and loss steam to downstream equipment (Not consider safety issue in this node) | 12. steam control valves are plan overhaul, stroke test is done fully every year | | | | | |
| | | 10. PIC13005 error reading low | 4. Low pressure and loss steam to downstream equipment (Not consider safety issue in this node) | | | | | | |
| | | 11. High flow - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.1) | 4. Low pressure and loss steam to downstream equipment (Not consider safety issue in this node) | | | | | | |
| | | 12. Relief valve passing ('PSV1304) | 4. Low pressure and loss steam to downstream equipment (Not consider safety issue in this node) | 10. PIC13005 control pressure at 5 barg 11. PPEs | | | | | P3 CAR 35. Include PPE requirement for response with relief valve pop up at steam drum ie. Gloove, face shield, ear muff in existing WI |
| | | | 5. High noise from relief valve lifting | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 6. Hot condensate exposure | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 13. Relief valve passing ('PSV1101A/C, B/D) | 2. Low steam generation and low in steam drum. Inadequate steam supply to system (see 2.2) | 3. PAL11027 setting 38 barg 5. PAL11027 setting 38 barg and auto select to temperature control by TI11001 instead 11. PPEs | | | | | P3 CAR 35. Include PPE requirement for response with relief valve pop up at steam drum ie. Gloove, face shield, ear muff in existing WI |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|---|--|--|----------|------------|-------------------|------------|--------------|
| | | | 3. Inadequate steam for reaction, lead to carbon deposition in prereformer and reformer. Overheat is reformer tube lead to tube damage. Toxic and flammable gas emission | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 3.3 | High flow | 1. Low pressure (see 3.2) | | | | | | | |
| 3.4 | Low/no flow | 1. Low/no flow (Normal+Steam operation) - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.2) | | | | | | | |
| 3.5 | Reverse flow | 1. Misdirected flow - Package boiler (reverse flow through V-1208 opening) (see 22.4) | | | | | | | |
| | | 2. Steam from steam drum reverse back to demin pipeline | 1. Pipeline failure due to over steam is higher than temperature rating. Pipe could be rupture and steam release | 1. XAE008 chck valve with safety function (refer to RSP-1100) 2. Pump 1371A/B is 50 barg operation pressure. 3. XAE005 at P1371 discharge 4. Pump P1371A, B is redundancy with auto switching when running pump discharge pressure is low | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 3.6 | Misdirected flow (NA) | | | | | | | | |
| 3.7 | High temperature | 1. Personal exposure to high temperature when blowdown | 1. Injury from hot burning | 3. PPE requirement | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Personal exposure to high temperature when sampling | 1. Injury from hot burning | 3. PPE requirement 4. Sample cooler | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Personal exposure to high temperature nearby uninsulated pipeline and equipment | 1. Injury from hot burning | 1. Insulation on hot pipeline and hot equipment 2. Safety barricade with precaution signage | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---|--|---|----------|-------------|-------------------|------------|--------------|
| | | 4. Low level (see 3.16) | | | | | | | |
| 3.8 | Low temperature (NA) | | | | | | | | |
| 3.9 | High concentration of contaminants | 2. No continuous blowdown - High concentrated dosing chemical | 1. More suspended Salt on boiler, Forming, Boiler Water Entainment in Steam. Possible to damage Reformer, Prereformer catalyst due to salt solid leading tube damage if prolong, Hammer effect in steam pipeline | 1. Conductivity measurment AI11001 settting 50 micro S 2. Sampling water analysis from surface blowdown. Discussion with NALCO to manipulate continuous blowdown 4. NALCO check water quality 2 time/ weeks | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Total suspended solid increase. More fouling in system and could deposite in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condesate recycle at E1332 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. No intermitent blowdown | 2. Total suspended solid increase. More fouling in system and could deposite in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condesate recycle at E1332 | 1. Conductivity measurment AI11001 settting 50 micro S 2. Sampling water analysis from surface blowdown. Discussion with NALCO to manipulate continuous blowdown 3. Standard operating procedure minimum requirement 1 time/ day (Conductivity, pH) 4. NALCO check water quality 2 time/ weeks | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. Demin plant failure | 2. Total suspended solid increase. More fouling in system and could deposite in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condesate recycle at E1332 | 1. Conductivity measurment AI11001 settting 50 micro S 2. Sampling water analysis from surface blowdown. Discussion with NALCO to manipulate continuous blowdown 3. Standard operating | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|---|----------|-----------|-------------------|------------|---|
| | | | | procedure minimum requirement 1 time/ day (Conductivity, pH) 4. NALCO check water quality 2 time/ weeks | | | | | |
| | | | 3. Increase more chemical injection, more frequent blowdown | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 10. Internal coil leak or rupture (see 3.17) | | | | | | |
| | | 5. Catalyst powder from condensate | 4. Erosion at waste heat boiler tube (E1122), Steam leak to reform gas | 5. Limit ramp up, ramp down pressure during start up and shutdown 6. S:C ratio adjustment 7. Inspection during TA 8. Visual check sampling from deaerator for solid particle by NALCO 9. Boiler feed pump strainer (0.315 mm) with dP measurement | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 5. E1212 tube get erosion from powder particle, Steam leak to reform gas | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. Rust debris and particle from pipeline | 4. Erosion at waste heat boiler tube (E1122), Steam leak to reform gas | 9. Boiler feed pump strainer (0.315 mm) with dP measurement | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 5. E1212 tube get erosion from powder particle, Steam leak to reform gas | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. Carbon dioxide contamination due to low performance of deaerator | 6. Low pH condition in BFW create more consumption of Amine solution ofr adjusting pH | | 5 X 5 LG | Minor | | | |
| | | 8. High pH from chemical dosing (pH More than 11) | 7. Stress corrosion cracking on vessels i.e. E1122, D1131 | 1. Conductivity measurement AI11001 setting 50 micro S 2. Sampling water analysis from surface blowdown. Discussion with NALCO to manipulate continuous | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 118. Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|-------------|----------------|----------------------|------------|---|
| | | | | blowdown 3. Standard operating procedure minimum requirement 1 time/ day (Conductivity, pH) 4. NALCO check water quality 2 time/ weeks 7. Inspection during TA | | | | | |
| | | 9. Low pH condition from chemical dosing less than 8.5 | 8. General corrosion creates thinning material tendency to leak | 1. Conductivity measurment AI11001 settting 50 micro S 2. Sampling water analysis from surface blowdown. Discussion with NALCO to manipulate continuous blowdown 3. Standard operating procedure minimum requirement 1 time/ day (Conductivity, pH) 4. NALCO check water quality 2 time/ weeks 7. Inspection during TA | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 118. Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 |
| | | 10. High oxygen content in boiler feed water from low performace of dearator | 9. Oxygen pitting corrosion in D1331, E1122 | 10. Oxygen residual measurement from NACO Bi-yearly 11. Operating condition for steam feeding in control 12. Offline inspection of dearator packing every year 13. Offline inspection of internal surface of D1331 in year | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | 11. High concentration of contaminants - Deareator (see 5.11) | 2. Total suspended solid increase. More foulinng in system and could deposite in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condasate recycle at E1332 | | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------|---|--|---|----------|------------|-------------------|------------|--------------|
| | | | 3. Increase more chemical injection, more frequent blowdown | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 12. High concentration of contaminants - Deareator (see 5.11) | 2. Total suspended solid increase. More fouling in system and could deposit in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condensate recycle at E1332 | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Increase more chemical injection, more frequent blowdown | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 13. High concentration of contaminants - Deareator (see 5.11) | 9. Oxygen pitting corrosion in D1331, E1122 | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 3.10 | Loss of containment | 1. Thermal expansion | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 2. Replace teflon outlet piping at pipeshoe 3. Visual inspection every turn around | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Vent or drain valve leaking (Small valve) | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 1. Plugs in vent and drain valves 4. LLF everyshift | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Vent or drain valve leaking (Large valve) | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 5. Conduct yearly inspection/ overhaul (Steam) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|----------|--------|----|--------------|
| | | 4. Steam leak through pipeline | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 4. LLF everyshift 8. Pipe thickness, NDT inspection every turnaround | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. Condensate leak thorough pipeline | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 3. Visual inspection every turn around 5. Conduct yearly inspection/ overhaul (Steam) 8. Pipe thickness, NDT inspection every turnaround | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. Sample station valve leaking | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 4. LLF everyshift 6. PPE requirement | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. Erosion at outlet continuous blowdown valve | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 3. Visual inspection every turn around 5. Conduct yearly inspection/ overhaul (Steam) 9. Upgrade material of blowdown valve to alloy steel | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. Gasket, packing, or seal | 1. Steam/ hot condensate | 4. LLF everyshift | 5 X 5 | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|--|--|---|----------|----------|------------|----|--------------|
| | | failure | release (from piping) causng injury to people nearby | 6. PPE requirement | LG | | | | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 9. Corrosion | 1. Steam/ hot condensate release (from piping) causng injury to people nearby | 8. Pipe thickness, NDT inspection every turnaround | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Loss of containment | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Injury to working people | | 5 X 5 LG | Moderate | Remote | P4 | |
| 3.11 | Deviation during startup | 1. High Fe content in condensate | 1. Corrosion in system | 1. Start up procedure to measure Fe content | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High oxygen content in boiler feed water during failure to adjust dosing chemical | 1. Corrosion in system | 2. Start up procedure for control pH in BFW 3. Temperature monitor at D1331 during start up TI13002 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Remain condensate at low point | 2. Water hammering, Vibration causing pipeline damage | 4. Standard operating procedure for condensate draining befoe start up in place | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. No oxygen purge during start up. Remain oxygen with process steam to reformer | 3. Feed oxygen into prereformer and reformer. (No issue since the moment of first time feeding is next to nitrogen mode, No flammable gas) | 5. Purge system before startup with Niitrogen 6. Standard operating procedure purge at vent manual line of Steamdrum | | | | | |
| 3.12 | Deviation during shutdown | 1. Ramp down pressure | 1. Lead to stress from thermal expansion leading to flanges damage and flammable gas leak out | 1. Standard operating procedure for cooldown tempeature rate 2. Pressure ramp rating 0.5 barg / min alarm (PI13006) | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. System is not connctected to atmosphere. When temp ois lower than 100 c at 0 barg | 2. Full vacuum is total steam system | 3. All equipment is design for full vacuum condition | 5 X 5 LG | Serious | Improbable | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|--|---|--|----------|------------|-------------------|------------|--|
| 3.13 | Deviation during maintenance | 1. Flexible hose connection during maintenace causing steam/ hot condensate release during discopnnected flexible hose | 1. Hot condensate release to personel | 1. Vent valve at steam utility point (USNT01- -04) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Confined space work | 2. Ashyxiaition causing fatality | 2. Safety system of work implemented | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Solvent chemical for MPI work | 3. Personal injury | 3. Chemical is eleminated during cleaning before start up | 5 X 5 LG | Moderate | Remote | P4 | |
| 3.14 | Deviation during sampling | 1. Person expose to high temperature | 1. Injury | 1. PPEs 2. Sample cooler | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 39. Include condensate sampling procedure into I-HYCO-013 |
| 3.15 | High level | 1. LIC11001 error reading low | 1. Highl level in steam drum and water carried over to Prereformer damage catalyst | 2. Plant inspection shiftwise for checking level gauge at steam drum | 5 X 5 LG | Major | Remote | P3 | Rec 3. Install additional LT11001 and 1oo2 voting interlock either trip LV11001 or trip BFW pump. (P3 CAR issued during previous Process Safety audit) |
| | | | 2. Highl level in steam drum and water carried over to Reformer and causing reformer tube damage | | LE3 | 3-Moderate | 2-Very Unlikely | Transition | |
| | | 2. LV11001 fail open more | 1. Highl level in steam drum and water carried over to Prereformer damage catalyst | 1. LAH11001 at 70% 2. Plant inspection shiftwise for checking level gauge at steam drum | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Highl level in steam drum and water carried over to Reformer and causing reformer tube damage | | LE3 | 3-Moderate | 2-Very Unlikely | Transition | |
| 3.16 | Low level | 1. LV11001 fail close | 1. Steam drum high temperature and may over deisgn temperature leading to rupture. | 1. LAL11001 at 50% level 2. LSL11002 A/B/C 2oo3 SIL1 rated to burner management system trip | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. No water remain in waste heat boiler and high temperature leading to rupture. Fire and explosion happen dure to flammable gas realease outside | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|---|----------|------------|-------------------|------------|--------------|
| | | | 3. High temperature (see 3.7) | | | | | | |
| | | | 4. Overheat and damage coil. Steam ingress to reformer tube and causing damage to reformer tube | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Overheat and damage coil. Steam ingress to prereformer catalyst causing catalyst damage | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 6. Internal coil leak or rupture (see 3.17) | | | | | | |
| | | 2. LIC11001 error reading high | 1. Steam drum high temperature and may over design temperature leading to rupture. | 2. LSL11002 A/B/C 2oo3 SIL1 rated to burner management system trip | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. No water remain in waste heat boiler and high temperature leading to rupture. Fire and explosion happen due to flammable gas release outside | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High temperature (see 3.7) | | | | | | |
| | | | 4. Overheat and damage coil. Steam ingress to reformer tube and causing damage to reformer tube | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Overheat and damage coil. Steam ingress to prereformer catalyst causing catalyst damage | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 6. Internal coil leak or rupture (see 3.17) | | | | | | |
| | | 3. Steam drum tube leaking causing steam leak to reform gas | 1. Steam drum high temperature and may over design temperature leading to rupture. | 1. LAL11001 at 50% level 2. LSL11002 A/B/C 2oo3 SIL1 rated to burner management system trip 3. Yearly magitic team 100% welding joint at heater coils | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|----------|------------|-------------------|------------|--------------|
| | | | 2. No water remain in waste heat boiler and high temperature leading to rupture. Fire and explosion happen due to flammable gas release outside | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. Continuous blowdown valve remain fully open (No issue to low level cause) | | | | | | | |
| | | 5. Intermittant blowdown valve remains fully open | 4. Overheat and damage coil. Steam ingress to reformer tube and causing damage to reformer tube | 4. Spring return handle (Discontinue) 5. Yearly service inspection and hydro test | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Overheat and damage coil. Steam ingress to prereformer catalyst causing catalyst damage | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 6. Internal coil leak or rupture (see 3.17) | | | | | | |
| | | 6. BFW pump fail | 1. Steam drum high temperature and may over design temperature leading to rupture. | 1. LAL11001 at 50% level 2. LSL11002 A/B/C 2oo3 SIL1 rated to burner management system trip 6. Standby pump with auto switching, auto start up mode | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. No water remain in waste heat boiler and high temperature leading to rupture. Fire and explosion happen due to flammable gas release outside | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 4. Overheat and damage coil. Steam ingress to reformer tube and causing damage to reformer tube | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Overheat and damage coil. Steam ingress to prereformer catalyst causing catalyst damage | | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------------|--|---|------------|--------|---|----|----|--------------|
| | | | 6. Internal coil leak or rupture (see 3.17) | | | | | | |
| 3.17 | Internal coil leak or rupture | 1. Low level (see 3.16) 2. High concentration of contaminants (see 3.9) | | | | | | | |

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| | | | |
|--|------|------|------------------------------|
| Linde PLC | HYCO | MTP1 | Name: Fuel gas system |
| Design Intent: - Combustion air from blower C-1009 pass thorough E1121 for receiving heat from flue gas hat up to 400 c and pass to 10 burners. - Fuel - NG from PTT metering 29 barg letdown by PV1901303 to 23 barg and pass FV11004 and pass to burner - Tail gas from CB from FV11005 and Purge gas from PSA unit FV11006 supply valve and pass to fuel header to burner - Hot Flue gas after combustion passes through flue stack give heat to E1115, E1126A/B, E1121 then pass though Induce fan of flue gas (C1107) then pass to stck N1163 and release to ATM | | | |
| P&ID: 11PFP02, 11PFP04, 11PFP05, 11PFP06, 11PFP07, 11PFP08, 11PFP09, OSBL P&ID: H0202-T-D-115-01, 16002312-T-D-101-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|------------------------------------|--|---|--------|------------|-------------------|------------|--------------|
| 4.1 | High flow | 1. FV11004 fail open (NG) | 1. High temperature in reformer | 1. PSHH11020 A/B/C (SIL1) setting 2100 mbar trip burner management system 2. 'PAH11020 setting 1900 mbar 3. SV10003 setting 6 barg 4. 'TSHH11011 A/B/C (SIL1) setting 900 c trip burner management system 5. Oxygen measurement controller AIC11003 (1oo2) setting 1.5 - 4% follow by load 8. AIC11003 Oxygen alarm low = 1% 'Low low = 0.5% | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer exit temp fluctuation. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. FIC11004 error reading low (NG) | 1. High temperature in reformer | 1. PSHH11020 A/B/C (SIL1) setting 2100 mbar trip burner management system 2. 'PAH11020 setting 1900 mbar | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|--------|------------|-------------------|------------|--------------|
| | | | | 3. SV10003 setting 6 barg 4. 'TSHH11011 A/B/C (SIL1) setting 900 c trip burner management system 5. Oxygen measurement controller AIC11003 (1oo2) setting 1.5 - 4% follow by load 8. AIC11003 Oxygen alarm low = 1% 'Low low = 0.5% | | | | | |
| | | | 2. Reformer exit temp fluctuation. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. FV11005 fail open (TG) (max flow from coldbox is 60 kg/hr which could not lead to severe effect to reformer) | 2. Reformer exit temp fluctuation. | 5. Oxygen measurement controller AIC11003 (1oo2) setting 1.5 - 4% follow by load 8. AIC11003 Oxygen alarm low = 1% 'Low low = 0.5% | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 4. FV11006 fail open (PG) | 1. High temperature in reformer | 5. Oxygen measurement controller AIC11003 (1oo2) setting 1.5 - 4% follow by load 6. PSHH11007A/B/C (2oo3) SIL1 setting 0 mbarg 7. 'PAH11007 -0.5 mbarg 8. AIC11003 Oxygen alarm low = 1% 'Low low = 0.5% 9. 'PSHH11013 A/B/C (2oo3) SIL 1 setting 160 mbarg 10. 'PAH11013 = 140 mbarg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|--------|------------|-------------------|------------|--|
| | | | 2. Reformer exit temp fluctuation. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 5. TIC11010 error reading low (Reformer exit temp) | 1. High temperature in reformer | 4. 'TSHH11011 A/B/C (SIL1) setting 900 c trip burner management system | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 6. FIC11002 erro reading low | 4. Reformer box pressure too high. Fire and heat expose to personal duing inspection/ damage reformer insulation/ Over design pressure of reformer box damage integrity of reformer box (see 4.7) | 6. PSHH11007A/B/C (2oo3) SIL1 setting 0 mbarg 7. 'PAH11007 -0.5 mbarg 11. Communication with boardman to ensure condition is under control before open peep door | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 40. Provide fire apron for operators for inspecting inside reformer |
| | | 7. Upset PSA causes high amount of 'PG to reformer/ cause high flow 'PG to reformer but low flow NG | 1. High temperature in reformer | 4. 'TSHH11011 A/B/C (SIL1) setting 900 c trip burner management system 5. Oxygen measurement controller AIC11003 (1oo2) setting 1.5 - 4% follow by load 6. PSHH11007A/B/C (2oo3) SIL1 setting 0 mbarg 7. 'PAH11007 -0.5 mbarg 8. AIC11003 Oxygen alarm low = 1% 'Low low = 0.5% 9. 'PSHH11013 A/B/C (2oo3) SIL 1 setting 160 mbarg 10. 'PAH11013 = 140 mbarg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer exit temp fluctuation. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|---|--|--|----------|------------|-------------------|------------|--------------|
| | | | 3. Incomplete combustion in reformer box might lead to after burn effect if Oxygen ingress into flue gas stack and damage to equipment | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 5. Low/no flow- high flow 'PG to reformer but low flow NG (see 4.2) | | | | | | |
| | | 8. Upstream pressure high due to by pass valve at PTT NG meter open too fast and PCV901303 cannot control pressure (In case NG compressor trip) | 1. High temperature in reformer | 1. PSHH11020 A/B/C (SIL1) setting 2100 mbar trip burner management system 2. 'PAH11020 setting 1900 mbar 3. SV10003 setting 6 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer exit temp fluctuation. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 4.2 | Low/no flow | 1. FV11004 fail close (NG) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 2. PDALL11021A/B/C 2oo3 SIL1 setting 1.5 mbar trip BMS 3. PDAL11021 = 2.5 mbarg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 2. FIC11004 error reading high (NG) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 2. PDALL11021A/B/C 2oo3 SIL1 setting 1.5 mbar trip BMS 3. PDAL11021 = 2.5 mbarg 4. 'PAL11007 = -3 mbarg 5. 'PSLL11007 A/B/C 2oo3 (SIL1) = -5 mbarg trip BMS | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 | Minor | | | |
| | | | | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|----------|------------|-------------------|------------|--|
| | | | | | LG | | | | |
| | | 3. FV11005 fail close (TG) | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 4. FV11006 fail close (PG) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 4. 'PAL11007 = -3 mbarg 5. 'PSLL11007 A/B/C 2oo3 (SIL1) = -5 mbarg trip BMS 6. 'PSLL11014A/B/C 2oo3 (SIL1) = 2.5 mbarg 7. 'PAL11014 = 3.5 mbarg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 5. TIC11010 error reading high (Reformer exit temp) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 8. TI11010 and TT11011B/C reading deviation alarm | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 6. FIC11002 erro reading high suddenly. PIC11009 cannot follow (combustion air) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 4. 'PAL11007 = -3 mbarg 5. 'PSLL11007 A/B/C 2oo3 (SIL1) = -5 mbarg trip BMS 9. AIC11013 exccess oxygen low | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | P3 CAR 40. Provide fire apron for operators for inspecting inside reformer |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | | 4. Incomplete combustion leading high NOx, SOx in flue gas stack | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. High flow - High flow 'PG to reformer but low flow NG (see 4.1) | 5. Cause NG fuel to reformer FIC11004 to close, reformer temperature cannot be control and high temperature exit reformer | 10. Limited flow FIC11004 at minimum 65 kg/hr in cascade mode | LE3 | 3-Moderate | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|----------|-------------|-------------------|------------|--------------|
| | | | causing tube damage | | | | | | |
| | | 8. Misdirected flow (see 4.4) | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 9. Burner tip blockage from carbon deposit | 3. Process upset | 11. 'PSHH11013 A/B/C SIL1 trip burner management system | 5 X 5 LG | Minor | | | |
| | | 10. Low pressure upstream (NG metering) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 2. PDALL11021A/B/C 2oo3 SIL1 setting 1.5 mbar trip BMS 3. PDAL11021 = 2.5 mbarg 4. 'PAL11007 = -3 mbarg 5. 'PSLL11007 A/B/C 2oo3 (SIL1) = -5 mbarg trip BMS | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 11. Low pressure upstream (PSA trip) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 1. 'TAL11011 setting 780 c (reformer exit) 4. 'PAL11007 = -3 mbarg 5. 'PSLL11007 A/B/C 2oo3 (SIL1) = -5 mbarg trip BMS 6. 'PSLL11014A/B/C 2oo3 (SIL1) = 2.5 mbarg 7. 'PAL11014 = 3.5 mbarg | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Reformer box pressure low | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Process upset | | 5 X 5 LG | Minor | | | |
| | | 12. High flow - PSA plant (P1/PP1 and P5/PP5) -> PV18003 fail open (see 18.1) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 12. TIC11010 | LE3 | 3- Moderate | 1-Highly Unlikely | Acceptable | |
| | | 13. High flow - PSA plant (D) (see 19.1) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|---|--|---|--------|------------|-------------------|------------|--------------|
| | | 14. Low/no flow - PSA plant (P1/PP1 and P5/PP5) → PSA (P1 step no purge gas to drum) (see 18.2) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 12. TIC11010 | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 15. Low/no flow - PSA plant (D) (see 19.2) | 1. Reformer temperature low leading to carbon deposition damage reformer tube | 12. TIC11010 | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 4.3 | Reverse flow (NA) | | | 1. | | | | | |
| 4.4 | Misdirected flow | 1. Air preheater (E1121) leakage | 1. Combustion air pass through flue stack and pass flue gas blower. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water), Corrosion in pipeline and equipment (No safety issue) (see 4.6) | 2. AIC11013 excess oxygen low alarm L=1% low level=0.5% oxygen 3. 'TI11019 setting 'TAH=200 c, 'TAL=110 c (Inlet Flue gas blower) | | | | | |
| | | | 2. Lower capacity of flue gas due to replace capacity by air (No safety issue) | | | | | | |
| | | | 3. Incompleted combustion in case no combustion air to burner. Flammable gas accumulated in reformer box and causes after burn effect | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 6. Tube leak or rupture (see 4.15) | | | | | | |
| | | 2. E1115 leakage | 1. Combustion air pass through flue stack and pass flue gas blower. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water), Corrosion in pipeline and equipment (No safety issue) (see 4.6) | 2. AIC11013 excess oxygen low alarm L=1% low level=0.5% oxygen 4. 'TAH11015 setting = 760 c 5. 'TAH11016 setting = 680 c 6. LLF every shift 7. Preventive maintenance to replace as per life time | | | | | |
| | | | 4. Reform gas leak through | | LE3 | 4-Serious | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|---|--------|-----------|-------------------|------------|--------------|
| | | | flue path and it may catch fire if oxygen can leak into reformer box and flue stack. | | | | Unlikely | | |
| | | | 6. Tube leak or rupture (see 4.15) | | | | | | |
| | | 3. E1126 A/B leakage | 1. Combustion air pass through flue stack and pass flue gas blower. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water), Corrosion in pipeline and equipment (No safety issue) (see 4.6) | 2. AIC11013 excess oxygen low alarm L=1% low level=0.5% oxygen 4. 'TAH11015 setting = 760 c 5. 'TAH11016 setting = 680 c 6. LLF every shift 7. Preventive maintenance to replace as per life time | | | | | |
| | | | 4. Reform gas leak through flue path and it may catch fire if oxygen can leak into reformer box and flue stack. | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 6. Tube leak or rupture (see 4.15) | | | | | | |
| | | 4. Overheat coil (1126A/B, E1115) at flue gas stack and its downstream pipelines / damage material / leakage to downstream equipment (see 2.3) | 1. Combustion air pass through flue stack and pass flue gas blower. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water), Corrosion in pipeline and equipment (No safety issue) (see 4.6) | | | | | | |
| | | | 4. Reform gas leak through flue path and it may catch fire if oxygen can leak into reformer box and flue stack. | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 6. Tube leak or rupture (see 4.15) | | | | | | |
| | | 5. ECV11057 fail open to flare (NG) | 5. Low/no flow (see 4.2) | 1. Insert spectacle blinded in normal operation | | | | | |
| | | 6. XV11005.c bleed valve fail open | 5. Low/no flow (see 4.2) | 8. Control loop is SIL1 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|---|----------|------------|-------------------|------------|--------------|
| | | | | 9. Yearly PM to function test | | | | | |
| | | 7. ECV11066 fail open to flare (PG+TG) | 5. Low/no flow (see 4.2) | 1. Insert spectacle blined in normal opeaiton | | | | | |
| | | 8. XV11004.c fail open (PG+TG) | | 8. Control loop is SIL1 9. Yearly PM to function test | | | | | |
| | | 9. ZV11004 left open (nitrogen purge line) | 5. Low/no flow (see 4.2) | 1. Insert spectacle blined in normal opeaiton 10. ZS11004 interlock with start up sequence | | | | | |
| 4.5 | High temperature | 1. High temperature combustion air causing flue gas high temperature | 1. Combustion air pipe leakage due to over design temperature and plant upset | 1. 'TAH11014 setting 420 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Incomplete combustion resulting high nOx, SOx emiss to atmosphere | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. High temperature due to too much Fuel (NG, TG, 'PG) causing high temperature in reformer box | 3. Over design temperature of burner block (Refractory) resulting collapse and flame impingement with catalyst tubes. Internal fire in housing | 2. TI11012,15,16,18,19 Flue stack high temperature alarms 3. Other safeguard refer to "High flow of fuel gas system" | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 4. Reformer box insulation may be damaged and fire can expose to personel working nearby | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. High flow (see 4.1) | | | | | | | |
| | | 4. High concentration of contaminants - PSA plant (A1,2,3) (see 15.9) | 3. Over design temperature of burner block (Refractory) resulting collapse and flame impingement with catalyst tubes. Internal fire in housing | 4. TIC11010 | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 4. Reformer box insulation may be damaged and fire can expose to personel working nearby | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | | | | | |
| 4.6 | Low temperature | 1. Low/no flow (all possible causes and safeguards) (see 4.2) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|---|--|---|----------|------------|-------------------|------------|--------------|
| | | 2. Misdirected flow → Combustion air pass through flue stack and pass flue gas blower (see 4.4) | 1. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water) (see 4.9) | | | | | | |
| | | 3. High concentration of contaminants - PSA plant (A1,2,3) (see 15.9) | 1. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water) (see 4.9) | | | | | | |
| | | 4. High temperature - PSA plant (A1,2,3) (see 15.5) | 1. Low temperature in flue gas tendency to have water condense together with carbon dioxide (Acid water) (see 4.9) | | | | | | |
| 4.7 | High pressure | 1. Burner tip blockage lead to carbon deposit at 'PG | 3. High pressure in fuel header and irregular flame shape causing flame impingement o reformer tube. Reduce lifetime | 2. 'PSHH11013A/B/C (SIL1) setting = 160 mbar | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. PCV901303 fail open causing 29 barg NG pass to lower pipe class section | 1. High pressure at fuel header lead to rupture. Large amout flammable gas release may cause fire and explosion | 1. 'PSV1303 setting 28 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. Flue gas blower (C1107) fail | 2. High reformer box pressure. Heat can expose to personel during open peep door | 3. Interlock flue gas blower stop and burner management system trip 4. 'PSHH1107 A/B/C (SIL1) setting 0 mbar trip burner management system 5. 'PAH11007 setting -0.5 mbar | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Flue gas penetration to outside | | 5 X 5 LG | Minor | | | |
| | | 4. High flow - FIC11002 erro reading low causing Reformer box pressure too high (see 4.1) | 2. High reformer box pressure. Heat can expose to personel during open peep door | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Dampers are left closed at combustion air header | 5. High pressure at combustion air header | 6. Combustion air header deign higher than blower max static pressure | 5 X 5 LG | Serious | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|--|--|----------|------------|-------------------|------------|--------------|
| | | | | 7. 'FALL11001 trip burner management system | | | | | |
| 4.8 | Low pressure | 1. Low/no flow (see 4.2) | | | | | | | |
| | | 2. C1109 fail while C1107 is running | 1. High vacuum in reformer box causing reformer housing collapse | 1. Seal inspection every year during turn around 2. Interlock between running signal C1109 to stop C1107 3. 'PSLL11007 A/B/C 2oo3 (SIL) setting -5 mbarg to stop C1107 4. PM yearly calibration and loop test of 'PI11007 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 4.9 | High concentration of contaminants | 1. High sulphur in NG | 1. More SO2 in flue gas and release to atmosphere | 1. Low sulphur content in NG 2. Low NOx SOx burner 3. Environmental control flue gas analysis by government bi yearly | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Create sulphur stress corrosion cracking at burner tip (Not immediate result plant shutdown) | | 5 X 5 LG | Minor | | | |
| | | 2. Rust from pipeline/ purge gas drum | 4. Block burner tip, extinguish flame at burner causing fuel distribution change Irregular flame shape causing hot spot at reformer tube | 4. Regular according to dP measuring and condition base 5. PSHH11013 A/B/C 2oo3, SIL1 to trip burner management system due to high pressure in fuel header | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. Low temperature - Acid causing corrosion in E1121 then combustion air leak in to flue gas (No safety issue) (see 4.6) | | | | | | | |
| | | 4. Dust contain in air | 5. Block air silencer of combustion air | 6. Enough gaps in silencer | | | | | |
| | | 5. Contaminated air from neighbour emission (Cl, hydrocarbon,Sulphur) | 6. Corrosion in burner, air preheater, reformer tubes | 7. Regular offline inspection during turnaround | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|--|--|---|----------|---------|------------|----|--------------|
| 4.10 | Loss of containment | 1. Vent or drain valve leaking (Link to cause Bleed valves fail open) (see 4.2) | | | | | | | |
| | | 2. High pressure → C1107 fail (see 4.7) | | | | | | | |
| 4.11 | Deviation during startup | 1. Burner ignition incomplete while fuel still feed to burner could lead to back draft | 1. Fire expose to personnel resulting severe burning | 1. Timer purge by Combustion air with flow more than 6,100 kg/hr for 10 mins, FIC11002 set 6,100 kg/hr (Operator input set point but limited by FIC) 2. Timer to isolate burner within 30 sec and restart tightness test | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 2. Reformer housing damage | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 2. Tightness test of double block and bleed system failure | 1. Fire expose to personnel resulting severe burning | 2. Timer to isolate burner within 30 sec and restart tightness test 3. Procedure tightness test I-HYCO-097 | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 2. Reformer housing damage | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 3. Oxygen remain in fuel ('PG+TG) line due to incomplete purge (req<1% Oxygen) | 3. Fire in fuel ('PG+TG) pipeline | 4. Start up procedure to check oxygen less than 1% | 5 X 5 LG | Major | Remote | P3 | |
| | | | | | | | | | |
| 4.12 | Deviation during shutdown | 1. Fuel (NG,TG,'PG) remains in pipeline | 1. Toxic and flammable gas exposure when working in reformer | 1. Standard operating procedure for residual gas measuring in pipeline 2. Correct standard operating procedure for physical isolation method 4. Standard operating procedure for shutdown includes PSA purge gas drum purging | | | | | |
| | | | 2. Fire and explosion risk | | | | | | |
| | | | 4. Deviation during | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|---|--|---|--------|---|----|----|---|
| | | | maintenance (see 4.13) | | | | | | |
| | | 2. System is not properly isolated | 1. Toxic and flammable gas exposure when working in reformer | 1. Standard operating procedure for residual gas measuring in pipeline 2. Correct standard operating procedure for physical isolation method 4. Standard operating procedure for shutdown includes PSA purge gas drum purging | | | | | |
| | | | 2. Fire and explosion risk | | | | | | |
| | | | 4. Deviation during maintenance (see 4.13) | | | | | | |
| | | 3. Nitrogen leakage from fuel line to burner (Connected from manual hoses) | 3. Asphyxiation exposure | 3. Checklist of installed flexible hoses | | | | | P3 CAR 41. To update existing Flexible hose & Blind checklist including flexible hose/ blind matrix for each confined space location. Matrix to be used for PTW supporting document for reformer confined space entry |
| 4.13 | Deviation during maintenance | 1. Deviation during shutdown (see 4.12) | | | | | | | |
| 4.14 | Deviation during sampling | 1. No additional hazard from NG sampling and purge/ tail gas from coldbox and PSA | | | | | | | |
| 4.15 | Tube leak or rupture | 1. Misdirected flow - Air preheater (E1121) leakage (see 4.4) | | | | | | | |

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| | | | |
|--|------|------|------------------------|
| Linde PLC | HYCO | MTP1 | Name: Deareator |
| <p>Design Intent: Demin Water section:</p> <ul style="list-style-type: none"> - Demin water receive from demin tank (Pump P90916A/B) run 1 unit stand 1 unit. Pump (Pump P90916A/B) then pass LV13005 A/B then mix with steam to control tempeature nearly to boiling point before entry dearator (During start up) <p>Condensate recovery</p> <ul style="list-style-type: none"> - Hot condensate from D1231 (140 c) entry deareator - Cold condensate rom D1232 (40-50c) to mix with demin water at mixer (YM001) before entry deareator - Condenstate return from E-1521 <p>Control</p> <ul style="list-style-type: none"> - low pressure steam feed into the deaerator under the stripping section and control the pressure in deaerator at SP of 0.3 barg to achieve the full stripping, resulted in temperature in Deaerator at 106 deg.C. <p>BFW pump</p> <ul style="list-style-type: none"> - BFW from P1317 recirculated by min flow to dareator | | | |
| <p>P&ID: 13PFP01, 13PFP02, 13PFP03, 14PFP01, 14PFP02, 14PFP03, 14PFP04, 14PFP05, 14PFP06, 15PFP01, 15PFP02, 15PFP03, 15PFP04</p> | | | |
| <p>Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Pipat Lubiam (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member)</p> | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|--------|------------|------------|------------|---|
| 5.1 | High flow | 1. High flow demin water from pump (90916A/B) running in parallel | 1. Over pressure in demin water pipeline (see 5.7) | 1. Pipe design 10 barg @ 60 c cover pump head at 9 barg 2. Min flow by manual control recircuation to demin tank 3. LIC13005 | LE3 | 3-Moderate | 3-Unlikely | Transition | P2 CAR 2. Some discrepancy in P&ID with actual installation found i.e. Min flow line, Demin pumps tag number. Need to update P&ID of demin section as per actual installation P2 CAR 3. Operation control discharge pressure of Demin pump (90916A/B) by manual throttle recirculation valve to control discharge pressure. Pump (90916A/B) shut off pressure is 22.4 barg more than downstream pipe design pressure of 19 barg. Also required flow rate for dearator is only 2.3 Nm3/hr but existing demin pump is max flowrate at 6 Nm3/hr that control is done by manually throttle recirculation valve back to tank. Recommend to install PCV at discharge |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|------------|----------------------|------------|--|
| | | | | | | | | | recirculation line and PSV to cover pump full flow |
| | | 2. LV13005A/B fail open more | 2. Over pressure in deaerator (D1331) (see 5.7) | 4. SV1301 setting 4 barg flow capacity 1400 kg/hr 5. LT13005 setting 'LAH = 80% | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. LT13005 error reading low | 2. Over pressure in deaerator (D1331) (see 5.7) | 4. SV1301 setting 4 barg flow capacity 1400 kg/hr 6. LI13003 log by operator shiftwise 7. LLF shiftwise | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 4. High level in deaerator (see 5.9) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. PT13003 error reading low | 3. High temperature (see 5.5) | 4. SV1301 setting 4 barg flow capacity 1400 kg/hr 8. Deaerator design temperature is 200 c while low pressure steam supply is 156 c (Refer saturated steam at 5 barg) | LE3 | 2-Minor | 0-Extremely Unlikely | Acceptable | |
| | | 5. PV13003 fail open | 2. Over pressure in deaerator (D1331) (see 5.7) | 4. SV1301 setting 4 barg flow capacity 1400 kg/hr 8. Deaerator design temperature is 200 c while low pressure steam supply is 156 c (Refer saturated steam at 5 barg) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 3. High temperature (see 5.5) | | LE3 | 2-Minor | 0-Extremely Unlikely | Acceptable | |
| | | 6. Expand orifice bore (BFW recirculation) | 4. High level in deaerator (see 5.9) | 3. LIC13005 5. LT13005 setting 'LAH = 80% 6. LI13003 log by operator shiftwise 7. LLF shiftwise | 5 X 5 LG | Serious | Remote | P3 | |
| | | 7. High consumption at upstream demin water | 5. Demin pump (P90916A/B) cavitation and damage pump component | 7. LLF shiftwise 9. Safe system of work | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|---|----------|----------|----------|----|--|
| | | 8. Safety valve at discharge demin pump (P90916A/B) passing | 6. Low level - BFW up pump damage (see 5.10) | 3. LIC13005 6. LI13003 log by operator shiftwise 7. LLF shiftwise 10. LSLL13004 trip P-1371A/B | 5 X 5 LG | Serious | Remote | P3 | |
| 5.2 | Low/ No flow | 1. No demin pump running | 1. Low level in D1331 - P1371 cavitationand damage (see 5.10) | 1. LSLL13004 trip P-1371A/B 2. LIC13005 3. LAL13005 setting = 40% 4. LI13003 log by operator shiftwise | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. LV13005A/B fail close | 1. Low level in D1331 - P1371 cavitationand damage (see 5.10) | 1. LSLL13004 trip P-1371A/B 3. LAL13005 setting = 40% 4. LI13003 log by operator shiftwise | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. LT13005 error reading high | 1. Low level in D1331 - P1371 cavitationand damage (see 5.10) | 1. LSLL13004 trip P-1371A/B 4. LI13003 log by operator shiftwise | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. PT13003 error reading high | 3. Low temperature - Oxygen residual + carbon dioxide in BFW (see 5.6) | 5. TI13002 logging by operator shiftwise 6. FI13006 logging by operator shiftwise | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 42. Implement FAL13006 follow by plant load |
| | | 5. PV13003 fail close | 3. Low temperature - Oxygen residual + carbon dioxide in BFW (see 5.6) | 5. TI13002 logging by operator shiftwise 6. FI13006 logging by operator shiftwise | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 42. Implement FAL13006 follow by plant load |
| | | 6. Blockage at orifice bore (BFW recirculation) | 1. Low level in D1331 - P1371 cavitationand damage (see 5.10) | 2. LIC13005 | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 43. To put pump alarm high pressure with set point of shut off pressure of P1371A/B at PI13017, PI13018 |
| | | | 2. High temp - Heat up water when there is no consumption, pump cavitate and damage (see 5.5) | | 5 X 5 LG | Serious | Possible | P3 | |
| | | 7. Safety valve at discharge demin pump | 5. High pressure (see 5.7) | 8. Manual throttle recirculation valve to control | | | | | P2 CAR 3. Operation control discharge pressure of Demin |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|------------------------------|---|--------|------------|-------------------|------------|---|
| | | block close | | discharge pressure | | | | | pump (90916A/B) by manual throttle recirculation valve to control discharge pressure. Pump (90916A/B) shut off pressure is 22.4 barg more than downstream pipe design pressure of 19 barg. Also required flow rate for dearator is only 2.3 Nm ³ /hr but existing demin pump is max flowrate at 6 Nm ³ /hr that control is done by manually throttle recirculation valve back to tank. Recommend to install PCV at discharge recirculation line and PSV to cover pump full flow |
| | | 8. No BFW pump running | 4. High level (see 5.9) | | | | | | |
| 5.3 | Reverse flow | 1. Steam back flow from LV11001 | 1. High pressure in dearator | 1. XAE005 at P1371A/B discharge 2. XAE008 at steam drum inlet pipe 3. SV1301, SV1302 setting 15 barg (double protection when check valve XAE005, 008 leak while suction valve closed) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. Reverse flow - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.3) | | | | | | | |
| 5.4 | Misdirected flow | 1. Low level in D1232 causes syn gas flow through deareator | 1. High pressure (see 5.7) | | | | | | |
| | | 2. Low level in D1231 causes syn gas flow through deareator | 1. High pressure (see 5.7) | | | | | | |
| 5.5 | High temperature | 1. High flow - PT13003 error reading low , PV13003 fail open (see 5.1) 2. Low/ No flow - Heat up water when there is no | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|--|--|---|--------|------------|-------------------|------------|--|
| | | consumption, pump cavitate and damage (see 5.2) | | | | | | | |
| 5.6 | Low temperature | 1. Low/ No flow - PT13003 error reading high , PV13003 fail close (see 5.2) | | | | | | | |
| 5.7 | High pressure | 1. Top vent valve of dearator close | 1. High pressure at dearator causing rupture and flying debris and hotwater expose to personel | 1. SV1301 setting 4 barg flow capaci 1400 kg/hr 2. PAH13003 setting 500 mbar | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. Misdirected flow - Low level in D1232 causes syn gas flow through deareator, Low level in D1231 causes syn gas flow through deareator (see 5.4) | | 1. SV1301 setting 4 barg flow capaci 1400 kg/hr 2. PAH13003 setting 500 mbar | | | | | |
| | | 3. High flow - Demin water from pump (90916A/B) running in pallellel (see 5.1) | | | | | | | |
| | | 4. High flow - LV13005A/B fail open / LT13005 error reading low (see 5.1) | 1. High pressure at dearator causing rupture and flying debris and hotwater expose to personel | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 5. Low/ No flow -> Safety valve at discharge demin pump block close (see 5.2) | 2. High pressure at downstream pipe demin pump causing pipe rupture | | LE3 | 2-Minor | 4-Possible | Transition | P2 CAR 3. Operation control discharge pressure of Demin pump (90916A/B) by manual throttle recirculation valve to control discharge pressure. Pump (90916A/B) shut off pressure is 22.4 barg more than downstream pipe design pressure of 19 barg. Also required flow rate for dearator is only 2.3 Nm3/hr but existing demin pump is max flowrate at 6 Nm3/hr that control is done by manually throttle recirculation valve back to tank. Recommend to install PCV at discharge recirculation line and PSV to |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---|---|--|----------|---------|--------|----|--|
| | | | | | | | | | cover pump full flow |
| 5.8 | Low pressure (NA) | | | | | | | | |
| 5.9 | High level | 1. High flow (see 5.1) 2. Low/ No flow (see 5.2) | | | | | | | |
| 5.10 | Low level | 2. Low/ No flow - Low level in D1331 (see 5.2) 3. High flow - Safety valve at discharge demin pump (P90916A/B) passing (see 5.1) | | | | | | | |
| 5.11 | High concentration of contaminants | 1. Demin water failure | 1. Corrosion at waste heat boiler and steam drum (see 3.9) | 1. Bi-Weekly water analysis by NALCO at Steam drum 2. Yearly recertify boiler per regulatory 3. AI13001 online conduct measures Demin water supply to Deaerator. Alarm at 0.9 micro-S/cm2 4. SiO2 analysis sampling at Demin water in daily basis by NALCO (<0.02 ppb) | | | | | |
| | | | 2. Fouling damage tube at waste heat boiler (see 3.9) | | | | | | |
| | | 2. Wrong adjustment of chemical dosing pump | 3. Impact to capacity of stripping oxygen in deareator. Corrosion deareator (see 3.9) | 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant patrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 8. TI13002 monitor by operator during plant patrol. Logsheet 4 times/day 9. PIC13003 | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 44. Implement steam drum pH online analysis with alarm to CCR |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|---------|--------|----|--------------|
| | | | 6. Deviation during startup (see 5.13) | | | | | | |
| | | 3. Contamination of condensate due to carbon, catalyst powder | 4. Under deposit corrosion at deareator | 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant partrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Contamination of carbon dioxide in condensate | 1. Corrosion at waste heat boiler and steam drum (see 3.9) | 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant partrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 8. TI13002 monitor by operator during plant patrol. Logsheet 4 times/day 9. PIC13003 | | | | | |
| | | | 5. Carbonic acid corrosion at Dearator | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Wrong concentration of chemical dosing (due to cheimcal preparation) | 1. Corrosion at waste heat boiler and steam drum (see 3.9) | 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant partrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|---------|--------|----|--------------|
| | | | 3. Impact to capacity of stripping oxygen in dearator. Corrosion deareator (see 3.9) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. Carbonic acid corrosion at Dearator | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. Low performance of dearator due to damage packing or trays | 1. Corrosion at waste heat boiler and steam drum (see 3.9) | 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant patrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 8. TI13002 monitor by operator during plant patrol. Logsheets 4 times/day 9. PIC13003 | | | | | |
| | | | 3. Impact to capacity of stripping oxygen in dearator. Corrosion deareator (see 3.9) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. Carbonic acid corrosion at Dearator | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 7. Low performance due to low/ no flow steam | 1. Corrosion at waste heat boiler and steam drum (see 3.9) | 4. SiO2 analysis sampling at Demin water in daily basis by NALCO (<0.02 ppb) 5. Bi-Weekly water analysis by NALCO at Deareator 6. Check pH and conduct at Dearator and steam drum and record in plant patrol checklist and excel sheet in share drive by operator daily 7. AI11001 online conduct measures BFW at steam drum. Alarm high at 50 micro-S/cm2 | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------|---|--|---|----------|----------|--------|----|---|
| 5.12 | Loss of containment | 1. Sight glass failure at NH3OH | | 8. TI13002 monitor by operator during plant patrol. Logsheet 4 times/day 9. PIC13003 10. PAL13003 setting 200 mbarg | | | | | |
| | | | 3. Impact to capacity of stripping oxygen in dearator. Corrosion deareator (see 3.9) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. Carbonic acid corrosion at Dearator | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Ammonia hydroxide/ Eleminox release during refill activity | 1. Chemical spillage | 3. Secondary bund in place | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 45. Check volume of secondary bund to cover 110% volume of chemical tank |
| | | | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Ammonia hydroxide/ Eleminox Tank leakage | 1. Chemical spillage | 1. NALCO's procedure 3. Secondary bund in place 4. PPE requirement 5. Emergency chemical spillage kit | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 36. Aspirator with proper cartridge must be provided for operators. Expiry date of cartridge to be checked and replace if required |
| | | | 3. Concentrated Chemical expose to personel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. 'NH3OH pump leak (P8250A/B) | 1. Chemical spillage | 3. Secondary bund in place 4. PPE requirement 5. Emergency chemical spillage kit | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 37. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM P3 CAR 38. Set schedule to replace new UPVC pipeline of dosing every 15 years |
| | | | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 1. Chemical spillage | 3. Secondary bund in place 4. PPE requirement 6. Yearly PM check pump condition and piping | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|--|---|---|----------|----------|------------|----|---|
| | | | | connection | | | | | |
| | | | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. 'Eliminox pump leak (P8260) | 1. Chemical spillage | 3. Secondary bund in place 4. PPE requirement 6. Yearly PM check pump condition and piping connection | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. UPVC Pipe damage due to aging | 1. Chemical spillage | 7. LLF daily 8. Schedule replacement new pipeline and tank every 15 years during relife activity | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | |
| 5.13 | Deviation during startup | 1. Water hammering from steam mixing | 1. Pipeline crack and steam release to personel | 1. LLF during start up 2. Operational control by experienced operators | 5 X 5 LG | Serious | | | |
| | | 2. Imporper pH adjustment during start up (Chemical dosing) (see 5.11) | | | | | | | |
| 5.14 | Deviation during shutdown | 1. Full vacuum due to steam or condense after stop unit | 1. Damage to deareator vessel | 1. Deareator vessel design for full vacuum (-1 barg) | 5 X 5 LG | Major | Improbable | P3 | |
| | | 2. To high chemical dosing since chemical pump not stop | 2. Corrode dearator vessel | 2. Interlock dosing pumps with BFW pump (P1371A/B) | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 46. Update shutdown procedure to include stop BFW pumps and chemical dosing pumps to prevent high chemical dosing to deareator |
| | | 3. Steam is left open to dearator due 'PCV13003 fail open | 3. Steam release through top vent. Possible to expose to personel | 3. PCV13003 is fail close | 5 X 5 LG | Serious | Remote | P3 | |
| 5.15 | Deviation during maintenance | 1. Lockout/tagout system not complete for BFW pump and demin pump | 1. Severe injury or Fatality | 1. PTW + Support documents 2. Contractor management | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|------------------------------------|--|----------|----------|--------|----|--|
| | | | | 3. Full time supervision | | | | | |
| | | 2. Equipment is not properly isolated during confined space entry | 1. Severe injury or Fatality | 1. PTW + Support documents 2. Contractor management 3. Full time supervision | 5 X 5 LG | Major | Remote | P3 | |
| 5.16 | Deviation during sampling | 1. Hot water sampling | | 1. Wear PPE when sampling taken | | | | | P3 CAR 29. Review point of sampling condensate drain and sampling procedure at D1231, D1232. To install sample panel with cooler |
| | | 2. Samling cooler cooling water is isolated | 1. Person expose to hot condensate | 1. Wear PPE when sampling taken | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 29. Review point of sampling condensate drain and sampling procedure at D1231, D1232. To install sample panel with cooler |

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| | | | |
|---|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum |
| <p>Design Intent: Carbon dioxide removal from Reform Gas</p> <ul style="list-style-type: none"> - Reform gas from D1232 coming to MDEA wash column T1401 and be adsorbed carbon dioxide with lean MDEA coming to top of T1401 by low temp (50 c) and high pressure (32 barg). Then, syngas will go up to top of column T1401. <p>Carbon dioxide removal from Rich MDEA</p> <ul style="list-style-type: none"> - Rich MDEA is taken out from T1401 and receive heat at E1413A/B then enter T1404 at top and desorb carbon dioxide by high temp (100 c Middle of column) and low pressure (0.5 barg) condition. Then, carbon dioxide will go up to top of T1404 to carbon dioxide compressor. Lean MDEA will pass through E1413A/B (Rich MDEA), E1414 (Cooling water) to cooldown and pump by P1474A/B then 10% of total lean MDEA will pass thorough side steam filter S1451, S1452 and another 90% will bypass filter. 100% MDEA enter T1401 as reflux for scrubbing 'CO2 with reform gas. <p>MDEA reboiler</p> <ul style="list-style-type: none"> - Reform gas from E1212 pass thorough E1412 to heat up to rich MDEA to boiling point. Boiled water in MDEA will return to T1404. 'CO2 will be also desorbed then go up to top of T1404 while remain MDEA will go down to bottom. <p>'CO2 knockout drum (D1441)</p> <ul style="list-style-type: none"> - To knock water and mist MDEA out from 'CO2 gas. Condensate will be pumped by P1473A/B to T1404 as reflux. | | | |
| P&ID: 12PFP02, 14PFP01, 14PFP02, 14PFP03, 14PFP04, 14PFP05, 15PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|---|----------|---------|-------------------|------------|--------------|
| 6.1 | High flow | 1. Syngas High pressure upstream | 1. Overpressure at T1401 (upstream is 37 barg while T1401 design 35 barg) (see 6.7) | 1. SV1501 setting 35 barg 2. PV12001 setting cascade with plant load Max 100% opening is equal to 32.7 barg 24. PIC15001 setting 31.75 barg | LE3 | 2-Minor | 1-Highly Unlikely | Acceptable | |
| | | 2. PV15001 (Syngas vent valve upstream of TSA) fail open | 2. T1401 tray collapse | 3. PDSHH12004 (SIL1) setting 200 mbar. Permissive to open XV12001 4. Upstream pressure control | 5 X 5 LG | Major | Improbable | P3 | |
| | | | 3. Rich MDEA entrainment to downstream and recycle back to T1401 resulting reduce carbon dioxide adsorption loading in lean MDEA | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 3. PT15001 read high | 2. T1401 tray collapse | 3. PDSHH12004 (SIL1) setting 200 mbar. Permissive to open XV12001 4. Upstream pressure | 5 X 5 LG | Major | Improbable | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|--|----------|---------|------------|----|---|
| | | | | control 5. PDAH12004 setting 120 mbar 6. PDAH14003 setting 60 mbarg | | | | | |
| | | | 3. Rich MDEA entrainment to downstream and recycle back to T1401 resulting reduce carbon dioxide adsorbtion loading in lean MDEA | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 4. FV14002A/B (Lean MDEA reflux T1401) fail open | 4. Liquid flooding (No safety issue) (see 6.9) | | | | | | P3 CAR 47. Implement FAH14002 in case FV14002A/B error open more P3 CAR 49. Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) |
| | | | 5. P1474A/B cavitation and pump damage (see 6.8) | | 5 X 5 LG | Serious | Possible | P3 | |
| | | 5. FT14002 read low | 4. Liquid flooding (No safety issue) (see 6.9) | | | | | | P3 CAR 48. Install second flow transmitter at FE14002 to prevent flow transmitter fail reading low/ pump cavitation due to high flow P3 CAR 49. Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) |
| | | | 5. P1474A/B cavitation and pump damage (see 6.8) | | 5 X 5 LG | Serious | Possible | P3 | |
| | | 6. Misoperate manual adjustment valve at side steam filter | 6. Filter collapse. Filtration failure and reduce carbon dioxide adsorbtion capacity in T1401 (No safety issue) | 7. Procedure for oprrate side stream filter 8. FI14004 to be monitored during adjust valve at sidestream filter and comapre with total flow (FIC14002) to get 10% flowrate throught filter 9. Regalar sampling Fe in monthly basis by operator | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------|--|--|----------|-----------|------------|-------|---|
| | | | | 10. PDAH14004 alarm setting 2.2 barg | | | | | |
| | | | 7. Impurity of ferric iron will induce corrosion faster (No safety issue) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 8. Impurity of organic substance increase will cause Foaming/ MDEA entrainment (No safety issue) | | 5 X 5 LG | Minor | | | |
| | | 7. FV14001 fail open | 9. Lower MDEA concentration and carbon dioxide absorption capacity drop | 5. PDAH12004 setting 120 mbar 6. PDAH14003 setting 60 mbarg 10. PDAH14004 alarm setting 2.2 barg 11. LAH14003 setting 72.5% 25. LIC14003/ LV14003 in control, LIC14004 in control with FIC14006 Cascade to drain out extra amount of liquid to sewer | 5 X 5 LG | Serious | Remote | P3 | |
| | | | | 26. Total amount of liquid in system increase. High level in T1401/ T1404/ D1441 (No safety issue) (see 6.9) | | | | | |
| | | 8. FT14001 read low | 9. Lower MDEA concentration and carbon dioxide absorption capacity drop | 10. PDAH14004 alarm setting 2.2 barg 11. LAH14003 setting 72.5% 25. LIC14003/ LV14003 in control, LIC14004 in control with FIC14006 Cascade to drain out extra amount of liquid to sewer | 5 X 5 LG | Serious | Remote | P3 | |
| | | | | 26. Total amount of liquid in system increase. High level in T1401/ T1404/ D1441 (No safety issue) (see 6.9) | | | | | |
| | | 9. LV14003A/B fail open | 10. Syngas pass through T1404 and vent to atmosphere through PV14015 | 13. PIC14015 setting 0.7 barg (If D1531, D-1541 low-level switch is not | LE3 | 4-Serious | 3-Unlikely | SIL-1 | P3 CAR 50. Consult with LE for scenario of LV14003 A/B remain open when interlock |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|----------|-----------|-------------------|-------------|---|
| | | | (Vent is located at low level) → case LV14003A/B fail open | active) 14. LSLL14002A/B/ PT14003 2oo3 (SIL2) to close LV14003 17. Stroke test and function test every turnaround | | | | | functioning since in SDE1003 page 12 mention relief valve is not design for syngas (we could not put interlock of PV14015 close to prevent personnel exposure of CO and Flammable gas release). Any recommendation from LE to be implemented P3 CAR 51. To put closing positioner for LV14003A/B to feedback close/ open position to DCS |
| | | | 11. Over pressure at T1404 (design 4 barg) leading to rupture → case LV14003A/B fail open (see 6.7) | | LE3 | 4-Serious | 2-Very Unlikely | Transition: | |
| | | | 17. E1413A/B, E1414, E1415 may leakage | | LE3 | 4-Serious | 3-Unlikely | SIL-1 | |
| | | 10. LT14003 read high | 12. Syngas pas thorough T1404 and vent to atmosphere through PV14015 (low level vent) → case LT14003 reading high | 12. Low level alarm14003 setting 27.5% 14. LSLL14002A/B/ PT14003 2oo3 (SIL2) to close LV14003 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 13. Over pressure at T1404 (design 4 barg) leading to rupture → case LT14003 reading high (see 6.7) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 11. FV13002 fail open (Steam to syngas) | 14. High temperature - T1404 high temperature and MDEA + H2O carried over to carbon dioxide (No safety issue) (see 6.5) | | | | | | |
| | | 12. FT13002 read low (Steam to syngas) | 14. High temperature - T1404 high temperature and MDEA + H2O carried over to carbon dioxide (No safety issue) (see 6.5) | | | | | | |
| | | 13. LV14010A/B (level control knockout drum) fail open | 15. P1473A/B pump cavitate and damage | 15. LAL14010 setting 40% 16. LSLL14009 trip pump P1473A/B | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 52. To put interlock to close FV14006 drainline at discharge condensate pump P1473A/B when |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|----------|------------|-------------------|------------|--|
| | | | | 17. Stroke test and function test every turnaround | | | | | LSLL14009 to prevent gas leak into sewer |
| | | | 16. Low level in D1441, Carbon dioxide gas contain in D1441 might be leakout through FV14006 to atmosphere (see 6.10) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 14. LIC 14010 read high | 15. P1473A/B pump cavitate and damage | 16. LSLL14009 trip pump P1473A/B | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 16. Low level in D1441, Carbon dioxide gas contain in D1441 might be leakout through FV14006 to atmosphere (see 6.10) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 15. FV14006 (Drain carbon dioxide knock out drum drain condensate to waste) fail open | 18. Low concentration MDEA + condensate release to sewer | 15. LAL14010 setting 40% 16. LSLL14009 trip pump P1473A/B 18. Plant patrol 2 times /shift | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 19. T1404 low level (see 6.10) | | | | | | |
| | | 16. FIC14006 read low | 18. Low concentration MDEA + condensate release to sewer | 14. LSLL14002A/B/ PT14003 2oo3 (SIL2) to close LV14003 15. LAL14010 setting 40% 16. LSLL14009 trip pump P1473A/B | 5 X 5 LG | Serious | Improbable | P4 | P3 CAR 52. To put interlock to close FV14006 drainline at discharge condensate pump P1473A/B when LSLL14009 to prevent gas leak into sewer |
| | | | 19. T1404 low level (see 6.10) | | | | | | |
| | | 17. PV14026 fail open (N2 to T1404) | 20. Nitrogen mix to carbon dioxide causing product contamination (No safety issue) | 19. SV1402 setting 3.5 bar. 20. PV14026 size is less than capacity of SV1402 | | | | | |
| | | | 21. Over pressure at T1404 due to PV14026 fail open (design 4 barg) (see 6.7) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 18. PV14015 (CO2 vent suction carbon dioxide compressor) fail open | 22. CO2 release to atmosphere (No safety issue) | 21. Compressor control logic to open recycle valve to suction to maintain | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|--|---|----------|------------|-------------------|------------|--------------|
| | | | | suction pressure | | | | | |
| | | | 23. CO2 low suction and damage compressor (see 25.2) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 19. PIC14015 read high | 23. CO2 low suction and damage compressor (see 25.2) | 21. Compressor control logic to open recycle valve to suction to maintain suction pressure | 5 X 5 LG | Serious | Remote | P3 | |
| | | 20. TIC14006 read low (T1404 temperature control for steam) | 14. High temperature - T1404 high temperature and MDEA + H2O carried over to carbon dioxide (No safety issue) (see 6.5) | | | | | | |
| | | 21. TIC14003 (Temperature control T1404 bottom) read low | 14. High temperature - T1404 high temperature and MDEA + H2O carried over to carbon dioxide (No safety issue) (see 6.5) | | | | | | |
| | | 22. LT14004 read high (T1404 sump level control) | 16. Low level in D1441, Carbon dioxide gas contain in D1441 might be leakout through FV14006 to atmosphere (see 6.10) | 22. LSL14005 A/B/C 2oo3 to stop P1474A/B 23. LAL14004 setting 24.5% | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 25. P1474A/B loss suction causing pump damage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 23. SV1501 (Syngas to TSA) lifted before set point | 2. T1401 tray collapse | 3. PDSHH12004 (SIL1) setting 200 mbar. Permissive to open XV12001 4. Upstream pressure control | 5 X 5 LG | Major | Improbable | P3 | |
| | | | 3. Rich MDEA entrainment to downstream and recycle back to T1401 resulting reduce carbon dioxide adsorbtion loading in lean MDEA | | 5 X 5 LG | Major | Improbable | P3 | |
| 6.2 | Low/ No flow | 1. Syngas low pressure upstream | 1. No safety issue, plant upset | | | | | | |
| | | 2. PV15001 (vent valve upstream TSA) fail close when required | 2. High pressure T1401, pipeline (see 6.7) | 29. SV1501 setting 35 barg | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|---|----------|----------|--------|----|---|
| | | 3. PT15001 read low | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 4. LAH14004 setting 60.5% 5. AI15001 carbon dioxide in syngas online analyzer AAH = 15 ppm 6. LAL14003 setting 27.5% | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. FV14002A/B (MDEA circulation flow to T1401) fail close | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 1. Valve FV14002A/B open in parallel 2. FAL14002 warning setting 12000 kg/hr 3. FALL14002 10000 kg/hr trip P1474A/B, Close XV12001 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. FT14002 read high | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 4. LAH14004 setting 60.5% 5. AI15001 carbon dioxide in syngas online analyzer AAH = 15 ppm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. FV14001 (BFW to T1401) fail close | 4. MDEA carried over to syngas and pass to TSA to degrade molsieve | 7. D1531, LSH15002 warning 8. FAL14001 setting 180 kg/hr | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. FT14001 read high | 4. MDEA carried over to syngas and pass to TSA to degrade molsieve | 7. D1531, LSH15002 warning | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. LV14003A/B (Level control T1401) fail close | 5. High level - T1401 - 'Flooding in column, MDEA entrainment to syngas (see 6.9) | 31. LAL14004 (T1404) setting = 24.5% 32. 'LAH 14003 (T1401) setting = 72.5% 33. LV14003A/B redundance to each other operator to select when another valve has problem | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 6. Low level - T1404 - P1474 cavitate (see 6.10) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 9. LT14003 read low | 5. High level - T1401 - 'Flooding in column, MDEA entrainment to syngas (see 6.9) | 31. LAL14004 (T1404) setting = 24.5% | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 61. To create procedure for mitigation by manual local control with observe level sight glass in case LT14003 read low or read high (Abnormal) |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|---|----------|---------|--------|----|--|
| | | | | | | | | | P3 CAR 62. To keep spare pare of LT14003 to be avialble due to criticality |
| | | | 6. Low level - T1404 - P1474 cavitate (see 6.10) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 10. FV13002 fail close (Steam to syngas) | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 9. TAL12001 Reform gas after steam mixing to E1412 (setting 150 c) 10. TAL14006 setting 85 c (Middle column T1404) 27. AAH15001 setting 15 ppm 28. Bypass valve FV13002 is availavle | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 53. To re-adjust alarm set point low temperature alarm/High temperature alarm (TAH14006 130 c --> 110 c TAL14006 85 c --> 95 c, TAH14008 120 c --> 100 c) to corespose temperature indication correct temperature before 'CO2 break thorough P3 CAR 58. Create procedure for bypass FV13002 steam feed mixing valve |
| | | | 7. Low temperature (see 6.6) | | | | | | |
| | | 11. FT13002 read high (Steam to syngas) | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 9. TAL12001 Reform gas after steam mixing to E1412 (setting 150 c) 10. TAL14006 setting 85 c (Middle column T1404) 27. AAH15001 setting 15 ppm 28. Bypass valve FV13002 is availavle | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 58. Create procedure for bypass FV13002 steam feed mixing valve |
| | | | 7. Low temperature (see 6.6) | | | | | | |
| | | 12. LV14010A/B (level control carbon dioxide knockout drum) fail close | 6. Low level - T1404 - P1474 cavitate (see 6.10) | 11. LAH14010 setting 60% 12. 'LSHH 14008 stop 'CO2 compressor 13. LV14010 A/B in redundancy | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 8. MDEA condensate carried over carbon dioxide compressor and drop | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|----------|---------|--------|----|--------------|
| | | | performance of compressor (No safety issue) | | | | | | |
| | | 13. LIC 14010 read low | 6. Low level - T1404 - P1474 cavitate (see 6.10) | 11. LAH14010 setting 60% 12. 'LSHH 14008 stop 'CO2 compressor | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 8. MDEA condensate carried over carbon dioxide compressor and drop performance of compressor (No safety issue) | | | | | | |
| | | 14. PV14026 fail close during no operation (N2 to T1404) | 10. Low pressure - T1404 vacuum condition (see 6.8) | 14. All equipment at MDEA regeneration system are design for full vacuum 30. Regular non-destructive testing at pipeline and external of column | | | | | |
| | | | 11. Oxygen ingress due to vacuum condition through leaking joint MDEA degraded/ combustible mixer in reformer feed (see 6.8) | | | | | | |
| | | 15. FV14006 (Carbon dioxide knock out drum drain condensate to waste) fail close | 9. High level - T1404 (see 6.9) | 11. LAH14010 setting 60% 12. 'LSHH 14008 stop 'CO2 compressor | | | | | |
| | | 16. FIC14006 read high | 9. High level - T1404 (see 6.9) | 11. LAH14010 setting 60% 12. 'LSHH 14008 stop 'CO2 compressor | | | | | |
| | | 17. PV14015 (CO2 vent suction carbon dioxide compressor) fail close when required | 20. High pressure - at T1404 (see 6.7) | 15. PAH14015 setting 0.7 barg 16. SV1402 setting 3.5 barg | | | | | |
| | | 18. PIC14015 read low | | 16. SV1402 setting 3.5 barg | | | | | |
| | | 19. TIC14006 read high (T1404 temperature control for steam) | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 9. TAL12001 Reform gas after steam mixing to E1412 (setting 150 c) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 7. Low temperature (see 6.6) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|-------------|---------|--------|----|---|
| | | 20. TIC14003 (Temperature control T1404 bottom) read high | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 9. TAL12001 Reform gas after steam mixing to E1412 (setting 150 c) 10. TAL14006 setting 85 c (Middle column T1404) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 7. Low temperature (see 6.6) | | | | | | |
| | | 21. LT14004 read low (T1404 sump level control) | 3. Carbon dioxide break through TSA, Coolbox ice blocking in exchanger (see 7.9) | 17. LG14004 log by operator shiftwise | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 9. High level - T1404 (see 6.9) | | | | | | |
| | | 22. Block exchanger E1413A/B (Rich MDEA side) | 6. Low level - T1404 - P1474 cavitate (see 6.10) | 21. TAH14021 setting 60 c 25. TIC14006, TV14006 in control 26. TI14003A exit E1413 | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 54. Implement alarm PDAH14005, PAH14023 to predict blockage in E1413A/B P3 CAR 57. To configure alarm high temp of TI14003A at suitable set point |
| | | | 18. Higher temperature of lean MDEA exit E1413, higher loading in E1414/ require more cooling water to maintain same temperature (No safety issue) (see 6.5) | | | | | | |
| | | | 19. Lower temperature of rich MDEA feeding into T1404, required more steam feeding for regeneration (No safety issue) (see 6.6) | | | | | | |
| | | 23. Block exchanger E1413A/B, E1414(Learn MDEA side), | 12. P1474 cavitate and manage | 10. TAL14006 setting 85 c (Middle column T1404) 18. Redundnce E1413 for swtiching when required 19. PDI14005 log by operator shiftwise 25. TIC14006, TV14006 in control | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 57. To configure alarm high temp of TI14003A at suitable set point |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|--|--|---|----------|-----------|-----------------|-------------|---|
| | | | | 26. TI14003A exit E1413 | | | | | |
| | | | 18. Higher temperature of lean MDEA exit E1413, higher loading in E1414/ require more cooling water to maintain same temperature (No safety issue) (see 6.5) | | | | | | |
| | | | 19. Lower temperature of rich MDEA feeding into T1404, required more steam feeding for regeneration (No safety issue) (see 6.6) | | | | | | |
| | | 24. Block exchanger E1415 (Cooling water side) | 13. Higher exit temp from E1415 causing condensate carry over to 'CO2 compressor (see 6.5) | 20. TAH14012 seting 60 c at suction carbon dioxide compressor | 5 X 5 LG | Serious | Remote | P3 | |
| | | 25. Block exchanger E1414 (Cooling water side) | 14. Higher lean MDEA temp reduce carbon dioxide adsorption performance in T1404 (see 6.5) | 21. TAH14021 setting 60 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 26. Side stream filter blokage | 15. Impurity of organic substance increase will cause Foaming/ MDEA entrainment (No safety issue) | 22. Procedure for oprrate side stream filter 23. FI14004 to be monitored during adjust valve at sidestream filter and comapre with total flow (FIC14002) to get 10% flowrate throught filter 24. Regalar sampling Fe in monthly basis by operator | | | | | |
| | | | 16. Impurity of furrir iron will induce corrosion faster (No safefy issue) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 17. Impurity of organic substance increase will cause Foaming/ MDEA entrainment (No safety issue) | | | | | | |
| 6.3 | Reverse flow | 1. Syngas reverse to BFW line when BFW pump trip (T1401) | 1. Syngas reverse to steam drum. Toxic and flammable gas release to atmosphere through deareator | 1. Check valve at P1371A/B (Safety relevant lift check valve) | LE3 | 4-Serious | 2-Very Unlikely | Transition: | P3 CAR 55. Implement interlock close valve FV14001 when boths |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|---|----------|------------|-------------------|------------|--|
| | | | atmosphere vent (see 5.3) | 2. P1371A/B automatic swtiching | | | | | P1371A/B trip |
| | | 2. Syngas reverse to nitrogen line (T1404) through PCV14026 | 2. Reverse 'CO2+Steam to nitrogen line when no pressure, Corrosion in nitrogen pipe | 3. Check valve upstream PCV14026/ material of branch line from column T1404 upto PSV14026 + check valve and manual are SS340L | 5 X 5 LG | Moderate | Improbable | P4 | |
| | | 3. Syngas reverse to MDEA line when P1474A/B trip then pass through T1404 | 3. Syngas reverse through FV14002 and exchangers upto T1404. Overpressure to equipment and T1404 | 4. XV12001 trip when FALL14002 (SIL1). No additional gas coming in 5. Chenck valve at at P1474A/B discharge (Safety relevant check valve) 6. PIC14015, PV14015 in function 7. SV1402 setting at 3.5 barg 10. SV1406, SV1407 setting 13 barg at suction P1474A,B (Double protection when check valve at discharge leak and suction valve closed) | LE3 | 3-Moderate | 3-Unlikely | Transition | P3 CAR 56. To perform manually close FV14002A/B by operator when both P1474A/B trip or failure to auto start. Update in work instruction |
| | | 4. NG reverse though carbon dioxide compressor when shutdown (While Plant is running) | 4. High pressure T1404 and MDEA equipment leading to rupture and large volume release (<5000kg with 5 mins) | 6. PIC14015, PV14015 in function 7. SV1402 setting at 3.5 barg 8. Check valve XAE009 (Safety function) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | Rec 4. To put interlocking close FV10016B when 'CO2 compressor trip |
| | | | 5. Toxic and flammable gas release through PV14015 to atmosphere | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. NG reverse though carbon dioxide compressor when shutdown (While Plant is shutdown lesser consequence woth above case) | 4. High pressure T1404 and MDEA equipment leading to rupture and large volume release (<5000kg with 5 mins) | 6. PIC14015, PV14015 in function 7. SV1402 setting at 3.5 barg 8. Check valve XAE009 (Safety function) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 5. Toxic and flammable gas | | LE3 | 4-Serious | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|--|----------|---------|------------|----|---|
| | | | release through PV14015 to atmosphere | | | | Unlikely | | |
| 6.4 | Misdirected flow | 1. Syngas pass D1531 bottom due to no liquid seal (see 6.10) | | | | | | | |
| | | 2. 'CO2 pass through D1441 due to no liquid seal (see 6.10) | | | | | | | |
| | | 3. MDEA pass through any manual line at D1432. Passing through valves | 1. MDEA return to D1432 not enough (No safety issue) | 1. Standard operating procedure for turning all specatacle blinds to this drum during nomal operation 2. LAL14003 for T1401 3. LAL14004 for T1404 4. SV1401 setting 4 barg 5. LI14006 level in MDEA drum (D1432) opertor log shiftwise 6. MDEA pressure gauge PI14010 log by operator shiftwise | | | | | |
| | | | 2. Over pressure D1432 due to level increase (see 6.7) | | 5 X 5 LG | Serious | Improbable | P4 | |
| | | 4. Foaming of MDEA in T1401 due to impurity. MDEA entrained with syngas | 3. Lost of MDEA into D1531/ carbon dioxide might breakthrough to TSA (No safety issue) (see 6.9) | 7. PDAH14003 setting 60 mbar 8. AAH15001 = 15 ppm 9. Side stream filter opeate at 10-15% of total flow 10. Foam test on MDEA sample bi-monthly 11. Munaul sampling analysis, Fe cntent, MDEA concentration 17. Water trap KXA005 at D1531 18. Demister of D1531 | | | | | |
| | | 5. Foaming in T1404 due to overheating of MDEA. | 4. More condensate in D1441/ Contain MDEA in | 12. TAH14006 setting 130 c | 5 X 5 | Serious | Remote | P3 | P3 CAR 53. To re-adjust alarm set point low |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|--|----------|-----------|-------------------|------------|--|
| | | MDEA entrained with carbon dioxide | condensate/ Risk to overflow into carbon dioxide compressor (see 6.9) | 13. TAH14008 setting 100 c 14. LAH14010 setting 60 c 15. Demister of D1441 16. LIC14010, LV14010A/B in control | LG | | | | temperature alarm/High temperature alarm (TAH14006 130 c --> 110 c, TAL14006 85 c --> 95 c, TAH14008 120 c --> 100 c) to corespose temperature indication correct temperature before 'CO2 break thorough |
| | | 6. Misdirected flow - Regeneration gas + hydrogen fraction bypass (see 8.4) | | | | | | | |
| 6.5 | High temperature | 1. Loss of cooling - wrong manual valve setting of E1414 | 1. Lower adsorption carbon dioxide in T1401, carbon dioxide breakthrough TSA | 3. TAH14021 setting 60 c 10. AAH15001 = 15 ppm | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. High temp Lean MDEA, carbon dioxide breakthrough TSA, Drop performance of TSA | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Loss of cooling - wrong manual valve setting of E1415 | 4. Steam breakthrough 'CO2 compressor | 2. TAH12007 setting 65 c 3. TAH14021 setting 60 c 4. TAH14022 setting 60 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. High temperature - failure of cooling fin fan E1216A/B (see 2.6) | 1. Lower adsorption carbon dioxide in T1401, carbon dioxide breakthrough TSA | 1. 'TSHH12007 2oo3 (SIL1) to close XV12001 inlet valve T1401. Setting 90 c 2. TAH12007 setting 65 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Over deisgn temeprature of inlet T1401, Toxic and flammable gas release | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. No carbon dioxide in MDEA during start up (see 6.13) | 5. MDEA overheat and carried over to D1441 and breakthrough 'CO2 compressor causing damage to compressor (see 6.9) | 5. Double control valve recycle back to T1401 via TV14010A/B, changed pump P1473A to have bigger capacity to serve effect of high boiling during start up 6. Standard operating procedure for increaisng MDEA recirculation flow to 38000 Nm3/hr to handle high heat capacity during No carbon dioxide load and | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|----------|--------|----|--------------|
| | | | | earlier put syngas to MDEA after NG feed 7. Contaminated sewer system to contain MDEA drain in place for environment protection 8. TAH14008 setting 85 c 9. LAL14004 setting = 24.5% | | | | | |
| | | | 6. Loss MDEA to sewer by manual operation to maintain level in D1441 when LV14010 fully open | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. High flow - FV13002 fail open (Steam to syngas), FT13002 read low (Steam to syngas) (see 6.1) | 5. MDEA overheat and carried over to D1441 and breakthrough 'CO2 compressor causing damage to compressor (see 6.9) | 9. LAL14004 setting = 24.5% | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. Low/ No flow - Blockage of E1415 causing Higher exit temp from E1415 causing condensate carry over to 'CO2 compressor (see 6.2) | 4. Steam breakthrough 'CO2 compressor | 11. TAH14012 setting 60 c at suction carbon dioxide compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. Low/ No flow - Blockage of E1413/1414 causing Higher lean MDEA temp reduce carbon dioxide adsorption performance in T1404 (see 6.2) | 1. Lower adsorption carbon dioxide in T1401, carbon dioxide breakthrough TSA | 3. TAH14021 setting 60 c 10. AAH15001 = 15 ppm | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. High temp Lean MDEA, carbon dioxide breakthrough TSA, Drop performance of TSA | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. Low/ No flow - Higher temperature of lean MDEA exit E1413, Lean MDEA - higher loading in E1414 require more cooling water to maintain same temperature (No safety issue) (see 6.2) | 7. Higher temperature rich MDEA to T1404 (No safety issue) | 3. TAH14021 setting 60 c 8. TAH14008 setting 85 c | | | | | |
| | | | 8. Higher temperature lean | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|--|---|---|--------|-----------|-------------------|------------|---|
| | | | MDEA exit E1414 (No safety issue) | | | | | | |
| | | 9. High pressure (see 6.7) | | | | | | | |
| 6.6 | Low temperature | 1. Low/ No flow - FV13002 fail close (Steam to syngas), FT13002 read high (Steam to syngas) (see 6.2) | | | | | | | |
| | | 2. Low/ No flow -Lower temperature of rich MDEA feeding into T1404 then required more steam feeding for regeneration (No safety issue) (see 6.2) | 1. High concentration of contaminants - Drier (TSA) (see 7.9) | | | | | | |
| 6.7 | High pressure | 1. PV14015 is not opened when 'CO2 compressor NOT running (Valve is required to open if pressure > 0.7 barg) | 1. T1404 over design temperature leading to rupture (160 c) (see 6.5) | 1. SV1402 setting 3.5 barg 2. TAH14006 130 c, TAH14008 85 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. T1404 over deisgn pressure leading to rupture (4 barg) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. High flow - due to Syngas High pressure upstream resulting Overpressure at T1401 (see 6.1) | 3. High pressure - Drier (TSA) (see 7.7) | | | | | | |
| | | | 4. High flow - Drier (TSA) (see 7.1) | | | | | | |
| | | 3. Low/ No flow - PV15001 fail close when required resulting High pressure - T1401 (see 6.2) | 3. High pressure - Drier (TSA) (see 7.7) | | | | | | |
| | | | 4. High flow - Drier (TSA) (see 7.1) | | | | | | |
| | | 4. Low/ No flow - PV14015 fail close resulting High pressure - T1404 (see 6.2) | | | | | | | Rec 2. To perform review design of water trap to be able to change online. Spare part of water trap to be available for replacement |
| | | 5. Misdirected flow - MDEA pass through any manual | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|------------|--------|-----------|-------------------|------------|--|
| | | line at D1432 that passing through valve (see 6.4) | | | | | | | |
| | | 6. High flow - due to LV14003A/B fail open resulting Over pressure at T1404 (see 6.1) | | | | | | | |
| | | 7. High flow - due to LT14003 read high resulting Over pressure at T1404 (see 6.1) | | | | | | | |
| | | 8. High flow - due to PV14026 fail open resulting Over pressure at T1404 (see 6.1) | | | | | | | |
| | | 9. Low level → D1531 low level due to water trap failure (see 6.10) | 2. T1404 over design pressure leading to rupture (4 barg) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | <p>P3 CAR 59. To establish standard operating procedure for mitigation in case of "LSLL15007,LSLL15008 active during compressor NOT running" to CLOSE manual valve of water traps at outlet of D1531, D1541 (Isolate condensate trap) to prevent Syngas breakthrough. Manual valve (Manual drain) will carefully be used for draining condensate with respectively with condensate level present in drum.</p> <p>P3 CAR 60. In case that"LSLL15007,LSLL15008 during compressor NOT running", EMOC for bypass interlock of LSLL15007,LSLL15008 to vent carbon dioxide only (if the manual valve of Water trap of D1531/D1541, this cannot be done).</p> |
| 6.8 | Low pressure | 1. Low/ No flow (PV14026 failed close - Oxygen ingress due to vacuum condition through leaking joint causing MDEA | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------|---|--|---------------------------|----------|---------|--------|----|--------------|
| | | degraded/ combustible mixture in reformer feed) (see 6.2) | | | | | | | |
| | | 2. Low/ No flow (PV14026 failed close - Low pressure - T1404 vacuum condition) (see 6.2) | 1. Deviation during shutdown (see 6.14) | | | | | | |
| | | 3. High flow - P1474A/B cavitation and pump damage (see 6.1) | | | | | | | |
| 6.9 | High level | 1. Water trap (XKA005) in D1531 all time close | 1. High level in D1531, might entrain MDEA into TSA and damage absorbent | 1. LSH15002 warning alarm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High flow - Liquid flooding at T1401 (see 6.1) | | | | | | | |
| | | 3. High flow - Total amount of liquid in system increase. High level in T1401/ T1404/ D1441 (No safety issue) (see 6.1) | | | | | | | |
| | | 4. Low/ No flow - T1404 high level, LT14004 read low (T1404 sump level control) (see 6.2) | | | | | | | |
| | | 5. Low/ No flow - FV14006 (Carbon dioxide knock out drum drain condensate to waste) fail close, FIC14006 read high (see 6.2) | | | | | | | |
| | | 6. Misdirected flow - Lost of MDEA into D1531/ carbon dioxide might breakthrough to TSA (No safety issue) (see 6.4) | | | | | | | |
| | | 7. Misdirected flow - More condensate in D1441/ Contain MDEA in condensate/ Risk to overflow into carbon dioxide compressor (see 6.4) | | | | | | | |
| | | 8. High temperature - MDEA overheat and carried | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|--|--|--|----------|-----------|-------------------|------------|---|
| | | over to D1441 (High level) and breakthrough 'CO2 compressor causing damage to compressor (see 6.5) | | | | | | | |
| 6.10 | Low level | 1. High flow - LV14010A/B (level control knockout drum) fail open or LIC14010 reading high resulting Low level in D1441 resulting Carbon dioxide gas contain in D1441 might be leakout through FV14006 to atmosphere (see 6.1) | 2. Misdirected flow - 'CO2 pass through D1441 due to no liquid seal causing P1473 damage due to cavitation (see 6.4) | 5. LSL14009 to stop pump P1473A/B | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High flow - FV14006 (Drain carbon dioxide knock out drum drain condensate to waste) fail open or FIC14006 reading low resulting T1404 low level (see 6.1) | 3. P1474A/B cavitation causing pump damaged | 6. LSL14005 2oo3 trip pump P1474A/B | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Low/ No flow - LV14003A/B (Level control T1401) fail close or LT14003 reading low resulting Low level - T1404 (see 6.2) | 3. P1474A/B cavitation causing pump damaged | 6. LSL14005 2oo3 trip pump P1474A/B 7. LAH14004 setting 24.5% | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Water trap (XKA005) in D1531 all time open | 1. Misdirected flow - Syngas pass D1531 bottom due to no liquid seal causing overpressure at T1404 (see 6.4) | 1. LSL1507 interlock trip PV14015 2. LG15001 at local monitoring 3. LSL15007 warning alarm 4. SV1402 setting 3.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | Rec 2. To perform review design of water trap to be able to change online. Spare part of water trap to be available for replacement |
| | | | 4. High pressure in T1404 when 'CO2 compressor not running (see 6.7) | | | | | | |
| | | 5. Water trap (XKA) in D1541 all time open | 4. High pressure in T1404 when 'CO2 compressor not running (see 6.7) | | | | | | |
| 6.11 | High concentration of | 1. PV14026 fail open or setting too high or leak passing through | 5. Nitrogen ingress to carbon dioxide line and feed to reformer and | 8. Product purity analyser 'AI16011 AAL = 98% (%CO) ASLL = 97.5% (trip product | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|--|----------|---------|------------|----|---|
| | contaminants | | contaminated with CO product | valve) | | | | | |
| | | 2. Wrong concentration MDEA | 3. 'CO2 breakthrough TSA and degrade adsorbent (see 7.9) | 6. Manual analysis 2 times/ week for concentration, 1 time/ month for Fe Ion 7. PDI14005/ TI14003A/ TI14021 are available for DCS monitor | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Corrosion in column/ more Fe Ion / More possibility blockage in E1413, E1414 | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 3. Feedgas carbon dioxide content too high carbon dioxide feeding | 3. 'CO2 breakthrough TSA and degrade adsorbent (see 7.9) | 5. AAH15001 setting 15 ppm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Internal coil leak or rupture (E1015) - NG supply (see 1.10) | 1. Hydrogen sulfide contain in carbon dioxide recycle and feed in to reformer (see 2.10) | | | | | | |
| | | 5. Side steam filter not in service | 2. Foaming in T1401 | 1. PDAH14009 setting 60mbarg 2. Anti-foam feeding at least once a shift at 100% load 3. PM to change filter every 3 months / Or condition of PDAH14004 more than 2.2 barg 4. Visual inspection of MDEA color to change filter | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 63. Review and Update I-HYCO-098 for reference color to replace new MDEA by reference with supplier recommendation |
| | | 6. Cross passing leak in E1414, E1415 | 6. MDEA contaminated with cooling water, cause foaming and fouling in system, tray damage | 6. Manual analysis 2 times/ week for concentration, 1 time/ month for Fe Ion 9. Abnormal deviation of flowrate between FIC14001 and FIC14006 10. Offline pressure test during Turnaround | 5 X 5 LG | Major | Remote | P3 | |
| | | 7. Ion content in BFW | 2. Foaming in T1401 | 11. BFW analysis 2 times/week | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Corrosion in column/ | | 5 X 5 | Major | Improbable | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------|---|---|--|----------|----------|--------|----|--------------|
| | | | more Fe Ion / More possibility blockage in E1413, E1414 | | LG | | | | |
| 6.12 | Loss of containment | 1. Heat exchanger gasket leak | 1. Loss of MDEA | 1. LLF 2 time/ day 2. Secondary containment 4. PPE requirement/ ERP during leakage and spillage 5. Haft mask with organic filter cartidge available as additional PPE | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High temp exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Toxic chemical exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Environment contamination | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Pump mechanical seal leak | 1. Loss of MDEA | 3. Redundant pump 4. PPE requirement/ ERP during leakage and spillage 5. Haft mask with organic filter cartidge available as additional PPE | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High temp exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Toxic chemical exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Environment contamination | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. MDEA spillage during filling to back up tank (D1432) | 1. Loss of MDEA | 1. LLF 2 time/ day 2. Secondary containment 5. Haft mask with organic filter cartidge available as additional PPE | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High temp exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Toxic chemical exposure | | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------------|--|---|--|----------|-----------|-----------------|-------------|--------------|
| | | | 4. Environment contamination | | 5 X 5 LG | Moderate | Remote | P4 | |
| 6.13 | Deviation during startup | 1. Improper degreasing after column maintenance intervention/ change packing or internal parts | 4. Foaming in column causing 'CO2 breakthrough, loss MDEA | 1. Standard operating procedure for degreasing and deoxygen from metal surface is available and practiced 2. PDAH14003 setting 60mbarg 3. Anti-foam injection 7. Haft mask with organic filter cartridge available as additional PPE 8. Standard PPE | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 7. Toxic chemical exposure | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Oxygen purge incomplete prior to start up | 5. MDEA degraded by oxygen | 1. Standard operating procedure for degreasing and deoxygen from metal surface is available and practiced 4. Residual oxygen measurement by multigas detect before introduce feed must be less than 1% | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 6. Oxygen combustible mixture in system | | LE3 | 4-Serious | 2-Very Unlikely | Transition: | |
| | | 3. No pressure balance before open XV12001 | 3. Too high flow across column cause packing collapse | 5. PDSHH12004 (SIL1) setting 200 mbar as permissive to open XV12001 6. PI12003, PI12005 to be compared during manual intervention to pressurize T1401 via opening bypass valve XV12001 (SOP) | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. PDT12004 error reading too low | 3. Too high flow across column cause packing collapse | 6. PI12003, PI12005 to be compared during manual intervention to pressurize T1401 via opening bypass valve XV12001 (SOP) | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. MDEA vapor exposure | 7. Toxic chemical exposure | 7. Haft mask with organic | 5 X 5 | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|--|--|---|----------|----------|--------|----|--------------|
| | | during MDEA preparation | | filter cartidge available as additional PPE | LG | | | | |
| 6.14 | Deviation during shutdown | 1. No nitrogen feed into T1404 during shutdown (see 6.8) | | | | | | | |
| | | 2. Residual toxic gas in system | 2. Toxic chemical exposure | 1. Half mask with organic filter cartidge available as additional PPE 2. Standard PPE 3. Standard operating procedure for decommissioning | 5 X 5 LG | Moderate | Remote | P4 | |
| 6.15 | Deviation during maintenance | 1. Improper cleaning MDEA unit prior to confined space entry/ Improper decommissioning | 1. Toxic chemical exposure | 1. Half mask with organic filter cartidge available as additional PPE 2. Standard PPE 3. Safety system of work 4. Standard operating procedure for decommissioning | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Isolation method incomplete | 1. Toxic chemical exposure | 1. Half mask with organic filter cartidge available as additional PPE 2. Standard PPE 3. Safety system of work 4. Standard operating procedure for decommissioning | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Nitrogen asphyxiation risk | 1. Toxic chemical exposure | 1. Half mask with organic filter cartidge available as additional PPE 2. Standard PPE 3. Safety system of work 4. Standard operating procedure for decommissioning | 5 X 5 LG | Moderate | Remote | P4 | |
| 6.16 | Deviation during | 1. High temperature exposure during sampling | 1. High temperauture exposure causng hot | 1. Standard PPE 2. Sampling WI for MDEA | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------------|--|--|---|----------|-----------|-------------------|------------|--------------|
| | sampling | lean MDEA | burning injury | sampling I-HYCO-012 | | | | | |
| | | 2. MDEA vapor exposure | 2. Toxic exposure | 1. Standard PPE 2. Sampling WI for MDEA sampling I-HYCO-012 3. Half mask with organic filter cartidge available as additional PPE | 5 X 5 LG | Moderate | Remote | P4 | |
| 6.17 | Internal coil leak or rupture | 1. E1412 coil leak, Crevice corrosion occurred at gap between tube and tube sheet on SS304L material (localized vaporization of MDEA causing high concentration) | 1. Process gas pass through MDEA column and recycle back with CO2/ remaining gas will be vented to atmosphere causing flammable gas ignition (process gas 32 barg, MDEA column 0.5 - 0.7 barg) | 1. E1412 was changed material SS304L to SS316L to resist chemical corrosion in 2012 2. Offline pressure leakage test plan for every 5 years 7. Eddy current test every 5 years | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. Cross passing leak in E1414, E1415 | 2. MDEA contaminated with cooling water, cause faoming and fouling in system, tray damage | 3. Manual analysis 2 times/ week for concentration, 1 time/ month for fe Ion 4. Abnormal diviation of flowrate between FIC14001 and FIC14006 5. Offline pressure test during Turnaround | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Cross passing leak in E1413A/B | 3. 'CO2 in lean MDEA will be higher dur to risch MDEA mixing, reduce performance of carbon dioxide adsoption, 'CO2 breakthrough Syngas | 2. Offline pressure leakage test plan for every 5 years 5. Offline pressure test during Turnaround 6. AAH15001 setting 15 ppm | 5 X 5 LG | Serious | Remote | P3 | |

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|--|------|------|--------------------------|
| Linde PLC | HYCO | MTP1 | Name: Drier (TSA) |
| Design Intent: - Syngas from MDEA T1401 Pressure 31 barg temperature 35 c passes through A1501A/B to absorb 'CO2 and 'H2O. Flow direction is from bootom to top then passes E1526 for cooldown then goes to XV15002 feed isolation valve before coldbox. - A1501A/B condition: (MAWP 35 barg, Design temp 190 c) - Adsorbent material : Molecular seive, Silica gel - Adsorb temperature at 35 c pressure , desorb temperature 175 c pressure Pressure 30 barg | | | |
| P&ID: 15PFP01, 15PFP02, 15PFP03, 15PFP04 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|---------|--------|----|---|
| 7.1 | High flow | 1. SV1502 or SV1503 passing leak | 1. Fluidization to adsorbent causing adsorbent cracking (High dP present) | 1. PM to calibration PSVs every 2 years 2. PDAH15006.A/B setting alarm 3 barg to hold step | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 64. Add warning alarm PDAH15006.A/B setting at 0.9 barg P3 CAR 65. Revise tag PDAH15006.A/B to PDAH15006.A/B (Replace from existing PDAH15006A/B in both DCS, P&ID) P3 CAR 66. Update sequential document PMC0110-007 follow real actual logic of TSA unit |
| | | | 2. Fluidization to adsorbent causing adsorbent cracking. Powder is carried over and blockage to CB (see 9.2) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High pressure from MDEA at T1401 (see 6.7) | 1. Fluidization to adsorbent causing adsorbent cracking (High dP present) | 3. FAH15001.c setting 8000 Nm3/hr | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 67. To configue alarm PAH15001 at 33 barg (In case PIC12001 cannot detect due to transmitter problem) |
| | | | 2. Fluidization to adsorbent causing adsorbent cracking. Powder is carried over and blockage to CB (see 9.2) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Low pressure at T1601 | 1. Fluidization to adsorbent causing adsorbent cracking (High dP present) | 3. FAH15001.c setting 8000 Nm3/hr 4. PAL16032 set at 28 barg | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 68. To update PID to add PAL16032 in page 16PFP10 (already in DCS) |
| | | | 2. Fluidization to adsorbent causing adsorbent cracking. Powder is carried over and | | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|--|--|--|----------|----------|--------|----|--|
| | | | blockage to CB (see 9.2) | | | | | | |
| 7.2 | Low/no flow | 1. XV15002 fail close | 2. Process upset | 1. Function test yearly 2. FAL15001.C setting 3,000 Nm3/hr 3. PAL16032 setting 28 barg | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 68. To update PID to add PAL16032 in page 16PPF10 (already in DCS) |
| | | 2. Low pressure upstream | 2. Process upset | 2. FAL15001.C setting 3,000 Nm3/hr 3. PAL16032 setting 28 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. KV15001, KV15002 (Inlet) fail close | 2. Process upset | 1. Function test yearly 2. FAL15001.C setting 3,000 Nm3/hr 3. PAL16032 setting 28 barg 4. PDAH15006.A/B setting 3 barg | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 65. Revise tag PDAH15006.A/B to PDAHH15006.A/B (Replace from existing PDAH15006A/B in both DCS, P&ID) |
| | | 4. KV15010, KV15011 (outlet) fail close | 2. Process upset | 1. Function test yearly 2. FAL15001.C setting 3,000 Nm3/hr 3. PAL16032 setting 28 barg 5. PDSH15002.B setting 3 barg 6. PDSH15004.B setting 3 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. Parellel valve KV15009 fail open in wrong step | 3. Syngas entrains hydrogen fraction line causing PSA adsorbent damaged (No safety issue) (see 7.4) | | | | | | |
| | | 6. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | | |
| 7.3 | Reverse flow (NA) | | | 1. Check valve | | | | | |
| 7.4 | Misdirected flow | 1. KV15001, KV15002 passing leak | 3. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regeneration gas and passing to PSA (see 15.9) | 1. Refer safegaurd in PSA | | | | | |
| | | 2. KV15010, KV15011 | 3. High concentration of | 1. Refer safegaurd in PSA | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|-------------------------------------|--|---|--------|----------------|--------------------------|------------|--------------|
| | | passing leak | contaminants - PSA plant (A1,2,3) -> Syngas mix with regeneration gas and passing to PSA (see 15.9) | | | | | | |
| | | 3. KV15009 passing leak | 3. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regeneration gas and passing to PSA (see 15.9) | 1. Refer safegaurd in PSA | | | | | |
| | | 4. KV15001, KV15002 fail fully open | 3. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regeneration gas and passing to PSA (see 15.9) | 1. Refer safegaurd in PSA | | | | | |
| | | 5. KV15010, KV15011 fail fully open | 2. Coldbox upset (No safety issue) | 1. Refer safegaurd in PSA 2. Operating practice to maintain Coldbox condition | | | | | |
| | | | 3. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regeneration gas and passing to PSA (see 15.9) | | | | | | |
| | | 6. Low/no flow (see 7.2) | | | | | | | |
| 7.5 | High temperature | 1. High temperature upstream | 1. Over design temperature of pipeline (Maximum Design Temp + <50C) Minor syngas leaks | 1. 'TAH15001 setting 60 c 4. Design temperature range of equipment can cover max operating condition | LE3 | 3- Moderate | 1- Highly Unlikely | Acceptable | |
| | | 2. Loss cooling water at E1526 | 2. Over design of E1611 causng Syngas release (see Coldbox node) (see 9.5) | 2. TSHH15012A/B/C setting 50 c to close XV15002 (SIL3) 3. TAH15012 setting 45 c 4. Design temperature range of equipment can cover max operating condition 5. Cooling water valves lock open | | | | | |
| | | 3. Fouling in E1526 | 2. Over design of E1611 causng Syngas release (see Coldbox node) (see 9.5) | 2. TSHH15012A/B/C setting 50 c to close XV15002 (SIL3) 3. TAH15012 setting 45 c 4. Design temperature range of equipment can cover max | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|--|---|----------|------------|-------------------|------------|--------------|
| | | | | operating condition | | | | | |
| 7.6 | Low temperature (NA) | | 1. No issue | | | | | | |
| 7.7 | High pressure | 1. External fire | 1. Loss of containment (if the overpressure cause exceeds the equipment pressure rating) | 1. SV1502, SV1503 setting 35 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. High pressure - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.7) | 1. Loss of containment (if the overpressure cause exceeds the equipment pressure rating) | 1. SV1502, SV1503 setting 35 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 7.8 | Low pressure | | 1. No safety consequence | | | | | | |
| 7.9 | High concentration of contaminants | 1. Internal coil leak or rupture (E1015) - NG supply (see 1.10) | 1. Saturate adsorbent at TSA | 1. AAH15001 setting 15 ppm of 'CO2 at inlet of syngas as warning alarm 2. Standard operating procedure to shutdown coldbox | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Carbon dioxide breakthrough coldbox (see 9.11) | | | | | | |
| | | 2. Low/ No flow - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.2) | 1. Saturate adsorbent at TSA | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Carbon dioxide breakthrough coldbox (see 9.11) | | | | | | |
| | | | 4. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | 3. Low temperature - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.6) | 1. Saturate adsorbent at TSA | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Carbon dioxide breakthrough coldbox (see 9.11) | | | | | | |
| | | | 4. Low/no flow - Coldbox (T1601: Methan wash | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------------|--|--|---|----------|------------|-------------------|------------|--------------|
| | | | column) (see 9.2) | | | | | | |
| | | 4. High concentration of contaminants - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.11) | 1. Saturate adsorbent at TSA | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Carbon dioxide breakthrough coldbox (see 9.11) | | | | | | |
| | | | 4. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | 5. D1531 high level | 1. Saturate adsorbent at TSA | 1. AAH15001 setting 15 ppm of 'CO2 at inlet of syngas as warning alarm 2. Standard operating procedure to shutdown coldbox | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Moisture breakthrough coldbox (see 9.11) | | | | | | |
| | | 6. D1531 demister failed | 1. Saturate adsorbent at TSA | 1. AAH15001 setting 15 ppm of 'CO2 at inlet of syngas as warning alarm 2. Standard operating procedure to shutdown coldbox | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Moisture breakthrough coldbox (see 9.11) | | | | | | |
| 7.10 | Loss of containment | 1. Corrosion at TSA vessel | 1. Syngas release causing fire and explosion | 1. See safeguard of D1531 knockout drum | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. Material defect (HTHA) | 2. Material deteriorated and loss strength. | 2. TSA vessel is stress relieved by Post Weld Heat Treatment (Refer design data) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. Sampling | 1. Syngas release causing fire and explosion | 3. System is design by using zero leakage flexible hose | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| 7.11 | Deviation during startup | 1. Regeneration is not done before start up | 1. 'CO2 breakthrough coldbox (No safety issue at TSA) (see 9.13) | 1. Standard operating procedure for Adsorber start up WI 15-0004 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|---|--|--|----------|----------|--------|----|--|
| | | 2. Not balance pressure before start up (Chain valve after D1531) | 2. TSA inlet gate valve damage due to high differential pressure | 1. Standard operating procedure for Adsorber start up WI 15-0004 | 5 X 5 LG | Moderate | Remote | P4 | |
| 7.12 | Deviation during shutdown | 1. Regeneration is not completed after shutdown | 1. Adsorbent is satuated with impurity | 1. Total Shutdown procedure WI 11-0012 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Chain valve is not closed afte shutdown | 1. Adsorbent is satuated with impurity | 1. Total Shutdown procedure WI 11-0012 | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Desorb impurity from TSA and pass through downstream process | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. No Nitrogen blanket | 1. Adsorbent is satuated with impurity | | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 69. To update shutdown procedure WI 11-0012 including nitrogen blanketing during shutdown |
| | | | 2. Desorb impurity from TSA and pass through downstream process | | 5 X 5 LG | Serious | Remote | P3 | |
| 7.13 | Deviation during maintenance | 1. Open system to atmosphere | 1. Injury to people due to high residual pressure | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 4. PPEs 5. Personal gas detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Toxic gas hazard | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Flammable gas hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Nitrogen release during remove valve for maintenance | 4. Asphyxiation hazard | 1. PTW 2. JSA 4. PPEs 5. Personal gas detector | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Confined space work | 4. Asphyxiation hazard | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 | 5 X 5 LG | Major | Remote | P3 | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|--|--|---|----------|-----------|-------------------|------------|--------------|
| | | | | 4. PPEs 5. Personal gas detector | | | | | |
| 7.14 | Deviation during sampling | 1. High pressure Syngas release during sampling | 1. Fire and explosion | 1. WI I-HYCO-013 2. PPEs 3. Sampling is design for closed loop to prevent release of flammable or Toxic 4. Personal gas detector | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Toxic gas exposure to people | | 5 X 5 LG | Major | Remote | P3 | |
| 7.15 | High level (NA) | | | | | | | | |
| 7.16 | Low level (NA) | | | | | | | | |
| 7.17 | Tube leak or rupture | 1. Corrosion/erosion from fouling accumulate (Under deposit) | 1. Syngas leak to Cooling water creates flammable atmosphere at CW basin | 2. Fixed Gas detector at CW basin 3. CW equipment is design as Explosion proof class (top section) 4. Cleaning every TA 5. Pressure test every TA 6. Flow distribution of Cooling water | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. High temperature | 1. Syngas leak to Cooling water creates flammable atmosphere at CW basin | 1. E1526 design temp cover max operating temperature | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| | | | |
|--|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: Regeneration gas + hydrogen fraction bypass |
| Design Intent: - Crude hydrogen gas leave coldbox at temp 35 c. - Warm hydrogen pass through KV15015 and E1521 to get heat then goes to TSA as the regeneration gas for heating step - In cooling step, hydrogen shall pass KV15017 instead of KV15015 - Exhaust gas from TSA shall be tied in with hydrogen fraction bypass line TSA - Hydrogen fraction bypass TSA shall pass through E1522 then knock moisture at D1541 then goes to FV18001 | | | |
| P&ID: 16PFP02, 15PFP02, 15PFP03, 15PFP04, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|----------|--------|----|--|
| 8.1 | High flow | 1. PV15013 malfunctioned open | 1. Adsorbent support collapse/ Seived damage | 1. Wedge wire support is designed for dP 0.9 barg 2. PDAH 15002.B, PDAH15004.B setting 3 barg | 5 X 5 LG | Major | Remote | P3 | P3 CAR 70. Change set point of alarm PDAH15002.B, PDAH15004.B setting 0.9 barg to prevent high differential pressure at regeneration bed |
| | | 2. PT15013 error reading high | 1. Adsorbent support collapse/ Seived damage | 3. PAL18001 setting 27 barg | 5 X 5 LG | Major | Remote | P3 | P3 CAR 70. Change set point of alarm PDAH15002.B, PDAH15004.B setting 0.9 barg to prevent high differential pressure at regeneration bed |
| | | 4. FV15003,4 malfunction more open in warm step | 2. Reformer fluctuation due to purge composition changes | 4. Operator routine check tempature profile evey shift and logging to checklist 5. Cascade mode fuel to reformer | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. KV15007,8 open malfunction open in warm step | 2. Reformer fluctuation due to purge composition changes | 4. Operator routine check tempature profile evey shift and logging to checklist 5. Cascade mode fuel to reformer 6. FAL15003 setting 13 kg/hr | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. FT15003 error reading low in warm step | 2. Reformer fluctuation due to purge composition changes | 4. Operator routine check tempature profile evey shift and logging to checklist 5. Cascade mode fuel to reformer | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 7. Low pressure - PSA plant (A1,2,3) (see 15.8) | 1. Adsorbent support collapse/ Seived damage | 1. Wedge wire support is designed for dP 0.9 barg | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|---|---|--|-------------|---------|--------|----|--|
| | | | | 2. PDAH 15002.B, PDAH15004.B setting 3 barg | | | | | |
| | | 8. High flow - Coldbox (T1601: Methan wash column) (see 9.1) | 1. Adsorbent support collapse/ Seived damage | 1. Wedge wire support is designed for dP 0.9 barg 2. PDAH 15002.B, PDAH15004.B setting 3 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Damage adsorbent due to high CH4 | | | | | | |
| 8.2 | Low/no flow | 2. Low pressure upstream (see 9.8) | | | | | | | |
| | | 3. FV15003,4 malfunction close in warm step | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 1. FAL15003 at 13 kg/hr 2. Regeneration steps will be on hold 3. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 71. Create troubleshooting case FV15003,4 malfunction close in warm step whether operator should manually operate or required to shutdown plant |
| | | 4. FT15003 error reading high in warm step | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 2. Regeneration steps will be on hold 3. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | Rec 5. Study FI15003 to change from vortex type to be changeable type during online |
| | | 5. KV15007,8 malfunction close in heating step | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 1. FAL15003 at 13 kg/hr 2. Regeneration steps will be on hold | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. KV15015,016 regeneration gas heater inlet-outlet malfunction close | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 1. FAL15003 at 13 kg/hr 2. Regeneration steps will be on hold 3. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. Pressure at T1601 increase, over pressurization (see 9.7) | | | | | | |
| | | 7. KV15005,006 malfunction close regeneratrion bed outlet | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 1. FAL15003 at 13 kg/hr 2. Regeneration steps will be on hold 3. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|--|---|----------|-----------|----------|------------|---|
| | | 8. KV15017 regeneration gas heater bypass malfunction close in cooling step | 2. No cooling gas to cooldown bed. Cooling step is not completed (see 8.5) | 2. Regeneration steps will be on hold 4. TSH15002, TSH15004 setting at 50 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. Pressure at T1601 increase, over pressurization (see 9.7) | | | | | | |
| | | | 6. High temperature (see 8.5) | | | | | | |
| | | 9. PDV15009 malfunction close | 5. Pressure at T1601 increase, over pressurization (see 9.7) | | | | | | |
| | | 10. PDT15009 error reading low | 5. Pressure at T1601 increase, over pressurization (see 9.7) | | | | | | P3 CAR 72. Consider to treat PDIT15009 as the critical spare part |
| | | 11. PV15003A Steam supply to 1521 malfunction close | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 9. TAL15007 setting 170 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 12. PT15003 error reading high | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 3. TSL15005, 15003 setting 130 c 9. TAL15007 setting 170 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 13. Steam trap (XKA) malfunction | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 3. TSL15005, 15003 setting 130 c 5. LLF 6. Shift log sheet 7. PM steam trap every TAR 9. TAL15007 setting 170 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 14. No/Low steam source | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully absorb (see 8.6) | 3. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 15. Closed manual valve cooling water to E1522 | 6. High temperature (see 8.5) | 8. Lock open cooling water valve at E1522 | | | | | |
| 8.3 | Reverse flow | 1. Hydrogen back to nitrogen | 1. Hydrogen fraction entrained to nitrogen and | 1. Check valve | LE3 | 4-Serious | 1-Highly | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|---|----------|---------|----------|----|--------------|
| | | header | contaminated. Risk to fire and explosion (see 8.10) | 2. Double block and bleed valves 3. Spectacle blind 4. WI I-HYCO-056 for switch regeneration gas from hydrogen fraction to nitrogen | | | Unlikely | | |
| 8.4 | Misdirected flow | 1. PDV15009 malfunctioned open 100% at heating step | 2. Incompleted regeneration. Online bed is fully absorbed | 1. Regeneration step on hold 2. TSL15003, 005 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. KV15009 Parallel valve malfunction open during regeneration or cooling step | 2. Incompleted regeneration. Online bed is fully absorbed | 1. Regeneration step on hold 2. TSL15003, 005 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 3. KV15005, 006 regen outlet valve A/B malfunction open (at any step) | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 4. FV15003, 004 regen gas flow control valve A/B malfunction open (at any step) | 2. Incompleted regeneration. Online bed is fully absorbed | 1. Regeneration step on hold 2. TSL15003, 005 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 5. KV15007, 008 regen gas inlet valve A/B malfunction open | 2. Incompleted regeneration. Online bed is fully absorbed | 1. Regeneration step on hold 2. TSL15003, 005 setting | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|--|----------|---------|--------|----|--------------|
| | | | | 130 c | | | | | |
| | | | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 6. KV15001, 002 Process gas inlet valve A/B malfunction open | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 7. KV15010, 011 Process gas outlet valve A/B malfunction open | 2. Incompleted regeneration. Online bed is fully absorbed | 1. Regeneration step on hold 2. TSL15003, 005 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 5. High concentration of contaminants - PSA plant (A1,2,3) -> Syngas mix with regen gas (see 15.9) | | | | | | |
| | | 8. Low level (see 8.14) | 4. Misdirected flow - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum (see 6.4) | | | | | | |
| 8.5 | High temperature | 1. High pressure of steam to E1521 (see 8.7) | | | | | | | |
| | | 2. Loss of cooling E1522 (see 8.2) | 1. High concentration of contaminants - PSA plant (A1,2,3) (see 15.9) | 1. TAH15014 setting 70 c | | | | | |
| | | | 2. High temperature - PSA plant (A1,2,3) (see 15.5) | | | | | | |
| | | 3. Low/no flow --> KV15017 regeneration gas heater bypass malfunction close in cooling step (see 8.2) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|---|--|--|----------|---------|--------|----|---|
| 8.6 | Low temperature | 1. Steam flow control valve closing at E1521 | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully adsorb | 1. TSL15005, 15003 setting 130 c 2. TAL15007 setting 170 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Low steam pressure from steam source | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully adsorb | 1. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Steam trap malfunction at E1521 | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully adsorb | 1. TSL15005, 15003 setting 130 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. PT15003 error reading high | | 1. TSL15005, 15003 setting 130 c | | | | | |
| | | 5. Low/no flow (see 8.2) | | | | | | | |
| | | 7. High concentration of contaminants (see 8.9) | 1. Insufficient heating. Adsorbent is not completed regeneration. Online bed is fully adsorb | | 5 X 5 LG | Serious | Remote | P3 | |
| 8.7 | High pressure | 1. High pressure upstream from coldbox | 2. Adsorbent support collapse/ Seived damage | 1. Wedge wire support is designed for dP 0.9 barg 2. PDAH 15002.B, PDAH15004.B setting 3 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. High flow - PSA plant (A1,2,3) (see 15.1) | | | | | | |
| | | 2. Steam supply PV15003.A fail open more | 1. Over Max temperature design of regeneration pipeline (see 8.5) | 4. PIC15003.B | | | | | |
| | | 3. Steam vent PV15003.B fail closed | 1. Over Max temperature design of regeneration pipeline (see 8.5) | 3. PIC15003.A | | | | | |
| | | 4. PT15003 error reading low | 1. Over Max temperature design of regeneration pipeline (see 8.5) | | | | | | P3 CAR 73. Install presure gauage at location of PT15003 for verifying P3 CAR 74. To provide dedicated spare part for ready to replace in case of PT15003 failure P3 CAR 75. To establish standard operating procedure in case of |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|--|---|----------|-----------|-------------------|------------|--|
| | | | | | | | | | PT15003 failure to replace spare part P3 CAR 76. Add TAH15007 setting 185 c |
| 8.8 | Low pressure | 1. Low/no flow (see 8.2) | | | | | | | |
| 8.9 | High concentration of contaminants | 1. Steam contamination due to entrainment from boiler | 3. Fouling at E1521 tube causing low heat transfer and insufficient heating (see 8.6) | | | | | | |
| | | 2. Liquid entrainment from coldbox (see 9.6) | 2. CS pipe embrittlement. Major Flammable/ Toxic gas release | 1. TSLL16012.A/B/C (SIL1) setting 10 c to close KV15015, KV15017, trip P1671A/B 2. TAL16012 setting 20 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. Demister at D1541 is not function properly | 4. High concentration of contaminants - PSA plant (A1,2,3) -> High moisture (see 15.9) | | | | | | |
| | | 4. High concentration of contaminants - Coldbox (T1601: Methan wash column) (see 9.11) | 1. Incompleted regeneration | 3. WI I-HYCO-056 for switch regeneration gas from hydrogen fraction to nitrogen | 5 X 5 LG | Serious | Remote | P3 | |
| 8.10 | Deviation during startup | 1. Oxygen remain in system | 1. Forming explosive atmosphere in system | 1. Start up procedure 15-0004 to purge with Nitrogen and use portable detector to measure oxygen content before start up 2. PSSR | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Reverse flow (see 8.3) | | | | | | | |
| | | 3. Condensate remains in steam system | 2. Water hammer causing damage E1521. Steam leakage through flange/ pipeline | 1. Start up procedure 15-0004 to purge with Nitrogen and use portable detector to measure oxygen content before start up 2. PSSR 3. Steam trap at E1521 | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. Inert is not vent out from system | 3. Heat exchange efficiency drop at E1521. Regeneration incompleted | 1. Start up procedure 15-0004 to purge with Nitrogen and use portable detector to measure oxygen content | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|--|---|---|----------|------------|--------------------|------------|--------------|
| | | | | before start up 2. PSSR 4. Regeneration steps will be on hold 5. TSL15005, 15003 setting 130 c | | | | | |
| 8.11 | Deviation during maintenance | 1. Steam/ Hot condensate not drained | 1. Personal injury | 1. PTW 2. JSA 3. Isolation WI 15-0003 | 5 X 5 LG | Serious | Remote | P3 | |
| 8.12 | Tube leak or rupture | 1. Corrosion/erosion from fouling accumulate (Under deposit) | 1. hydrogen fraction to Cooling water creates flammable atmosphere at CW basin | 1. E1522 design temp cover max operating temperature 2. Fixed Gas detector at CW basin 3. CW equipment is design as Explosion proof class (top section) 4. Cleanning every TA 5. Pressure test every TA | LE3 | 4-Serious | 1- Highly Unlikely | Acceptable | |
| | | 2. High temperature | 2. Hydrogen fraction gas leak to steam side and release through PV15003.B due to high pressure vent | 1. E1522 design temp cover max operating temperature 7. E1521 design temp cover max operating temperature (Steam at 42 barg) | LE3 | 3-Moderate | 1- Highly Unlikely | Acceptable | |
| | | 3. High pressure | 2. Hydrogen fraction gas leak to steam side and release through PV15003.B due to high pressure vent | 8. E1521 tube design at 35 barg/ Tube made of SS material 9. SV1504 setting 32 barg | LE3 | 3-Moderate | 1- Highly Unlikely | Acceptable | |
| 8.13 | High level | 1. Steam trap is not working (D1541) | 1. High concentration of contaminants - PSA plant (A1,2,3) -> High moisture (see 15.9) | 1. LAH15004 2. LAHH1504 to stop PSA, Close FN18001 3. Routine log condensate level at D1541 2 times/shift | | | | | |
| 8.14 | Low level | 1. Steam trap at D1541 passing | 1. Misdirected flow (see 8.4) | 1. Level indication LI15004 2. LAL15004 | | | | | |
| | | 2. Misoperate steam trap at D1541 bypass valve | 1. Misdirected flow (see 8.4) | 1. Level indication LI15004 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---------------|--------------|--|--------|---|----|----|--------------|
| | | remained open | | 2. LAL15004 3. Operator log condensate level in D1541 2 times/shift | | | | | |

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| | | | |
|--|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: Coldbox (T1601: Methan wash column) |
| Design Intent: 1. Syngas pressure 30 barg, temp 35 c, flowrate 3500 kg/hr enter E1611, E1612 to get cold energy to -181.3 c then passto T1601 2. T1601 (MAWP 35 barg, Max T= 50 Min T = -196 c) - Syngas will be pass to top of column then Liquid CO (Temp -183 pressure 1.5 barg) from T1603 (N7) to condense CO and Methane and some hydrogen. - Hydrogen which is not condensed will be scrubbed by Liquid methane - Residual H2 will exist through top of T1601 as the Hydorgen flaction to E1612, E1611 to give cold energy then exit coldbox 3. Liquid methane - Liq methane from P1671A/B will pump at pressure 32 barg temp -180 c and enter T1601 (Node end at pump discharge valves) | | | |
| P&ID: 16PFP02, 16PFP03, 16PFP04, 16PFP05, 16PFP06, 16PFP10 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|----------------------------|--------|-----------|-------------------|------------|--------------|
| 9.1 | High flow | 1. TV16047 Liq methane injection fail open | 1. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release (see 9.6) | 3. TAL16047 setting -150 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. High flow - Regeneration gas + hydrogen fraction bypass (see 8.1) | | | | | | |
| | | | 3. Low level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.10) | | | | | | |
| | | 2. TI16047 Liq methane injection error reading high | 1. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release (see 9.6) | 3. TAL16047 setting -150 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. High flow - Regeneration gas + hydrogen fraction bypass (see 8.1) | | | | | | |
| | | | 3. Low level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.10) | | | | | | |
| | | 3. TI16002 error reading high | 1. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release (see 9.6) | 3. TAL16047 setting -150 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|------------------------------|---|---|----------|---------|--------|----|--------------|
| | | | 2. High flow - Regeneration gas + hydrogen fraction bypass (see 8.1) | | | | | | |
| | | 4. Low pressure (see 9.8) | | | | | | | |
| 9.2 | Low/no flow | 1. LV16001 failed closed | 1. Low/no flow - Drier (TSA) (see 7.2) | 1. LAH16001 setting 60% | | | | | |
| | | | 2. No refrigerant to E1612. CO and Methane are not condensed/ Impurty in TSA regeneration | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | | 4. Liquid flooding in T1601 (see 9.7) | | | | | | |
| | | | 11. High level (bottom) (see 9.9) | | | | | | |
| | | 2. LT16001 error reading low | 1. Low/no flow - Drier (TSA) (see 7.2) | 2. LAH16002 setting 60% 3. 3mm wire slot link between chamber LT16001, LT16002 at EL+2000 > high level alarm | | | | | |
| | | | 2. No refrigerant to E1612. CO and Methane are not condensed/ Impurty in TSA regeneration | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | | 4. Liquid flooding in T1601 (see 9.7) | | | | | | |
| | | | 11. High level (bottom) (see 9.9) | | | | | | |
| | | 3. LV16002 failed closed | 1. Low/no flow - Drier (TSA) (see 7.2) | 2. LAH16002 setting 60% | | | | | |
| | | | 2. No refrigerant to E1612. CO and Methane are not condensed/ Impurty in TSA regeneration | | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|------------------------------|--|---|----------|---------|--------|----|--------------|
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | | 4. Liquid flooding in T1601 (see 9.7) | | | | | | |
| | | | 11. High level (bottom) (see 9.9) | | | | | | |
| | | 4. LT16002 error reading low | 1. Low/no flow - Drier (TSA) (see 7.2) | 1. LAH16001 setting 60% 3. 3mm wire slot link between chamber LT16001, LT16002 at EL+2000 > high level alarm | | | | | |
| | | | 2. No refrigerant to E1612. CO and Methane are not condensed/ Impurity in TSA regeneration | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | | 4. Liquid flooding in T1601 (see 9.7) | | | | | | |
| | | | 11. High level (bottom) (see 9.9) | | | | | | |
| | | 5. E1611, E1612 blockage | 1. Low/no flow - Drier (TSA) (see 7.2) | 4. Operating practice to monitor coldbox temperature profile/ plant flowrate | | | | | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | 6. XV15002 fail closed | 1. Low/no flow - Drier (TSA) (see 7.2) | 5. PDSH15005 to show XV15002 closed setting 200 mbarg | | | | | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | | 5. Partially low syngas to coldbox causing product off spec (CO, hydrogen) | | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|----------|------------|-------------------|------------|--------------|
| | | | 6. Coldbox upset | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 10. Low pressure (see 9.8) | | | | | | |
| | | 7. Liquid methane freezed at E1612 (see 12.6) | 7. E1612 damage when there is repid change of phase causing interleakage in heat exchanger | 6. PAH16026 setting 10mbar 7. FAL16011, FAL16013 coldbox hydrogen purge 8. Relief valve top coldbox 8mbar 9. Gas detector top of coldbox 10. LLF check for coldbox ice patch 11. Monthly sampling coldbox purge gas | | | | | |
| | | | 8. E1612 damage when there is repid change of phase causing leak at internal of coldbox. Coldbox high pressure, Flammable gas release to atmosphere. | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 8. High flow - Drier (TSA) -> adsorbent plugged strainer XYF007 (see 7.1) | 1. Low/no flow - Drier (TSA) (see 7.2) | 4. Operating practice to monitor coldbox temperature profile/ plant flowrate | | | | | |
| | | | 3. Low/no flow - Coldbox (T1602 : hydrogen stripper column) (see 10.2) | | | | | | |
| | | 9. Misdirected flow - Regeneration gas + hydrogen fraction bypass -> TSA valves malfunction (syngas lower than operating condition) (see 8.4) | 6. Coldbox upset | 4. Operating practice to monitor coldbox temperature profile/ plant flowrate | 5 X 5 LG | Minor | Remote | P4 | |
| | | 10. High temperature - Coldbox (Liq Methane pump) -> Methane pump loss suction and cavitate (see 12.5) | | | | | | | |
| | | 11. High flow - Coldbox (Liq Methan pump) -> | 2. No refrigerant to E1612. CO and Methane are not | 1. LAH16001 setting 60% | 5 X 5 | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|---|--|---|----------|-----------|-------------------|------------|--------------|
| | | FV16003 fail open (see 12.1) | condensed/ Impurity in TSA regeneration | 2. LAH16002 setting 60% 4. Operating practice to monitor coldbox temperature profile/ plant flowrate | LG | | | | |
| | | | 6. Coldbox upset | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 11. High level (bottom) (see 9.9) | | | | | | |
| | | 12. High concentration of contaminants - Drier (TSA) → Carbon dioxide slip from TSA (see 7.9) | 9. E1611 block from carbon dioxide freed. Process interruption | 12. AI15006 AAH setting 0.7 ppm warning alarm 13. AI15006 AAHH setting 1 ppm warning alarm 14. Overload TSA calculation trip at 100% load | 5 X 5 LG | Serious | Remote | P3 | |
| | | 13. High flow - Coldbox (T1602 : hydrogen stripper column) → FV16004 fail open, FI16004 read low (see 10.1) | 2. No refrigerant to E1612. CO and Methane are not condensed/ Impurity in TSA regeneration | 4. Operating practice to monitor coldbox temperature profile/ plant flowrate | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 6. Coldbox upset | | 5 X 5 LG | Minor | Remote | P4 | |
| 9.3 | Reverse flow (NA) | | | | | | | | |
| 9.4 | Misdirected flow (NA) | | | | | | | | |
| 9.5 | High temperature | 1. High temperature - Drier (TSA) (see 7.5) | 1. Different between stream over 50 c at heat exchanger causing too high stress and large toxic/ flammable gas leakage | 1. High-high temperature alarm 15012A/B/C (SIL3) setting 50 c 2. TAH15012 setting 45 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. CO turbine trip | 2. High temp syngas due to loss cold source at E1611 causing coldbox upset (No safety issue) | 3. Alarm turbine speed 5. Standard operating procedure for methane pump trip and CO turbine trip | | | | | |
| | | 3. Liquid methane pump trip | 3. Coldbox upset and product off spec | 4. FAL16003 setting 540 kg/hr 5. Standard operating | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|--|---|---|----------|-----------|-------------------|------------|--|
| | | | | procedure for methane pump trip and CO turbine trip | | | | | |
| | | | 4. High concentration of contaminants (see 9.11) | | | | | | |
| | | 4. High temperature - Coldbox (CO turbine) (see 13.7) | 2. High temp syngas due to loss cold source at E1611 causing coldbox upset (No safety issue) | | | | | | |
| 9.6 | Low temperature | 1. High flow (see 9.1) | 1. High concentration of contaminants - Regeneration gas + hydrogen fraction bypass (see 8.9) | | | | | | |
| | | 2. Low temperature - Coldbox (CO turbine) (see 13.8) | 1. High concentration of contaminants - Regeneration gas + hydrogen fraction bypass (see 8.9) | | | | | | |
| 9.7 | High pressure | 1. Blocked flow by downstream unit | 1. Overpressurize to system causing over pressure to column and vessel | 1. SV1602 setting 35 barg 2. PV16032 setting 30.8 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 80. Add PAH16032 T1601 pressure vent valve at setting 33 barg |
| | | | 2. Coldbox upset, blockage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High pressure upstream | 1. Overpressurize to system causing over pressure to column and vessel | 1. SV1602 setting 35 barg 2. PV16032 setting 30.8 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 80. Add PAH16032 T1601 pressure vent valve at setting 33 barg |
| | | 3. Plugged due to frozen 2 phase CH4 in Syngas | 2. Coldbox upset, blockage | 3. TAL16045 setting -181.8 c 4. Standard operating procedure for coldbox start up (WI 16-0007) | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Low/no flow - Regeneration gas + hydrogen fraction bypass – > PDV15009, KV15015,16,17 malfunction close (see 8.2) | | 1. SV1602 setting 35 barg 2. PV16032 setting 30.8 barg | | | | | |
| | | 5. Low/no flow –> Liquid flooding in T1601 (see 9.2) | 1. Overpressurize to system causing over pressure to column and vessel | 1. SV1602 setting 35 barg 2. PV16032 setting 30.8 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------|--|--|---|----------|-----------|-------------------|------------|--------------|
| | | | | barg 5. SV1501,2,3 setting 35 barg 6. PV15001 setting 31.75 barg | | | | | |
| | | 6. High level (bottom) (see 9.9) | | | | | | | |
| 9.8 | Low pressure | 1. PV16032 fail fully open | 2. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | 1. TSLL16012A/B/C (SIL1) setting 10 C to close KN15015, KN15017 2. TAL16012 setting 20 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. CH4 cannot scrubbed causing hydrogen product off spec/ CO, CH4 high content in hydrogen fraction | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 4. High flow (see 9.1) | | | | | | |
| | | 2. PT16032 error reading high | 2. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | 1. TSLL16012A/B/C (SIL1) setting 10 C to close KN15015, KN15017 2. TAL16012 setting 20 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. CH4 cannot scrubbed causing hydrogen product off spec/ CO, CH4 high content in hydrogen fraction | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 4. High flow (see 9.1) | | | | | | |
| | | 3. Low level (bottom) (see 9.10) | | | | | | | |
| | | 4. Low/no flow -> XV15002 fail close (see 9.2) | 1. Low/no flow - Regeneration gas + hydrogen fraction bypass (see 8.2) | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| 9.9 | High level (bottom) | 1. High flow liquid methane reflux (see 12.1) | 1. Liquid flooding in column (see 9.7) | 1. LAH16001 setting 60% 2. LAH16002 setting 60% 3. PDAH16001 setting 280 mbar | 5 X 5 LG | Minor | Remote | P4 | |
| | | 2. Low/no flow (see 9.2) | 1. Liquid flooding in column (see 9.7) | 1. LAH16001 setting 60% 2. LAH16002 setting 60% | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------|--|---|--|--------|---|----|----|---|
| | | | | 3. PDAH16001 setting 280 mbar | | | | | |
| | | 3. Low/no flow - Coldbox (Liq Methane pump) (see 12.2) | | | | | | | |
| 9.10 | Low level (bottom) | 1. LV16001 (column level control) fail open | 2. Low pressure at T1601 (see 9.8) | 1. LAL16001 setting 40% 6. LV16001 mechanical limitation 80%OV matching with downstream relief valve capacity 7. LV16001 mechanical limitation 75%OV matching with downstream relief valve capacity | | | | | |
| | | | 4. Syngas pass through T1602 causing contaminate to T1602 (see 10.11) | | | | | | |
| | | 2. LT16001 (column level control) error reading high | 1. 35 barg Syngas pass through T1602 causing over pressure T1602 (MAWP 11 barg). Rupture to column T1602 (see 10.7) | 3. See safeguard T1602 high level 4. Operating practice monitoring of temperature profile in coldbox and level in cloumns 5. Spare part CO turbine 6. LV16001 mechanical limitation 80%OV matching with downstream relief valve capacity 7. LV16001 mechanical limitation 75%OV matching with downstream relief valve capacity | | | | | P3 CAR 85. Add troubleshooting in I-HYCO-080 to mention case when no level in T1601. operator must manually shutdown coldbox to prevent damage to CO turbine anf CO compressor. Updated information need to be trained to all operators P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | 2. Low pressure at T1601 (see 9.8) | | | | | | |
| | | | 3. High level (bottom) - Coldbox (T1602 : hydrogen stripper column) (see 10.9) | | | | | | |
| | | | 4. Syngas pass through T1602 causing contaminate to T1602 (see 10.11) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---|---|--|----------|---------|--------|----|---|
| | | 3. LV16002 (column level control) fail open | 2. Low pressure at T1601 (see 9.8) | 2. LAL16002 setting 40% 6. LV16001 mechanical limitation 80%OV matching with downstream relief valve capacity 7. LV16001 mechanical limitation 75%OV matching with downstream relief valve capacity | | | | | |
| | | | 4. Syngas pass through T1602 causing contaminate to T1602 (see 10.11) | | | | | | |
| | | 4. LT16002 (column level control) error reading high | 1. 35 barg Syngas pass through T1602 causing over pressure T1602 (MAWP 11 barg). Rupture to column T1602 (see 10.7) | 3. See safeguard T1602 high level 4. Operating practice monitoring of temperature profile in coldbox and level in cloumns 5. Spare part CO turbine 6. LV16001 mechanical limitation 80%OV matching with downstream relief valve capacity 7. LV16001 mechanical limitation 75%OV matching with downstream relief valve capacity | | | | | P3 CAR 85. Add troubleshooting in I-HYCO-080 to mention case when no level in T1601. operator must manually shutdown coldbox to prevent damage to CO turbine anr CO compressor. Updated information need to be trained to all operators P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | | 2. Low pressure at T1601 (see 9.8) | | | | | | |
| | | | 3. High level (bottom) - Coldbox (T1602 : hydrogen stripper column) (see 10.9) | | | | | | |
| | | | 4. Syngas pass through T1602 causing contaminate to T1602 (see 10.11) | | | | | | |
| 9.11 | High concentration of contaminants | 1. High concentration of contaminants - Drier (TSA) → carbon dioxide breakthrough (see 7.9) | 1. Blockage to E1611, E1612 | 1. AAH15006 setting 0.7 ppm 'CO2 2. AAHH15006 setting 1 ppm 'CO2 3. Overload TSA calculation | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------------------|---|--|---|----------|---------|--------|----|--|
| | | | | trip at 100% load | | | | | |
| | | 2. High concentration of contaminants - Drier (TSA) → H2O breakthrough (see 7.9) | 1. Blockage to E1611, E1612 | 4. AAH15002 setting 0.7 ppm moisture 5. AAHH15002 setting 1 ppm moisture | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. High temperature (see 9.5) | 2. Hydrogen fraction contain more CO, Methane. Overload PSA, product off spec (see 8.9) | | 5 X 5 LG | Minor | | | |
| 9.12 | Loss of containment | 1. See consequence of high flow, High temp and Low/No flow | | | | | | | |
| 9.13 | Deviation during startup | 1. Deviation during startup - Drier (TSA) (see 7.11) | | | | | | | |
| | | 2. Oxygen remain in system | 1. Forming explosive condition | 1. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Too early start of opening main valve to CO turbine | 3. Too fast cooling down leading to thermal stress due to rate of change >25 c/ hr. Major release of toxic/ flammable gas (see 9.17) | 1. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown |
| | | 4. Too early injection of syngas to T1601 when liquid nitrogen in column not enough | 4. Coldbox warm and interrupt with start up plan (No safety issue) | 1. WI 16-0007 coldbox start up | | | | | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown P3 CAR 82. Add TAH16002 setting -180 c for start up case |
| | | 5. Too fast cooling down of E1611, E1612, T1601 | 3. Too fast cooling down leading to thermal stress due to rate of change >25 c/ hr. Major release of toxic/ flammable gas (see 9.17) | 1. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown |
| | | 6. Too differentail between Hot/ cold stream in E1611, E1612 | 2. Thermal stress from high differential temperature >50 c in heat exchanger leading plate exchanger crack. | 1. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|---|--|----------|---------|------------|----|--|
| | | | Major release of toxic/flammable gas (see 9.17) | | | | | | for warning) for coldbox start up and shutdown |
| | | 7. Recirculation of Nitrogen at too low temp in CO circuit | 5. Freeze methane in heat exchanger while introduce feed liquid methane, syngas to system (see 9.17) | 1. WI 16-0007 coldbox start up 2. PIC16006 LPCO suction control CO compressor setting 1.8 barg (during start up CO compressor with nitrogen media) 3. TAL16023 setting -183 c (exit top T1603) 4. TAL16002 setting -182.5 c (Syngas to T1601) | 5 X 5 LG | Major | Remote | P3 | |
| | | 8. Liquid is not completely drained out and remained in column. Freezed up liquid in heat exchanger while start up (see 9.14) | 5. Freeze methane in heat exchanger while introduce feed liquid methane, syngas to system (see 9.17) | 1. WI 16-0007 coldbox start up 2. PIC16006 LPCO suction control CO compressor setting 1.8 barg (during start up CO compressor with nitrogen media) 3. TAL16023 setting -183 c (exit top T1603) 4. TAL16002 setting -182.5 c (Syngas to T1601) | 5 X 5 LG | Major | Remote | P3 | |
| | | 9. Remain moisture and carbon dioxide in system | 6. Freeze moisture or 'CO2 in heat exchanger while introduce feed liquid methane, syngas to system. Delay schedule for start up | 5. WI 16-010 coldbox shutdown 6. Moisture analyzer to swtich to 3rd stage of CO compressor during start up AI16012. Switching is interlock permissive start CO compressor | 5 X 5 LG | Serious | Remote | P3 | |
| | | 10. Too fast pressirization > 0.5 bar/min | 7. Long term impact to reduce strength of cold equipment (see 9.17) | 1. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Improbable | P3 | |
| 9.14 | Deviation during shutdown | 1. Drain liquid without pressure | 1. Liquid is not completely drained out and remain in column. Freezed up liquid in heat exchanger while start up (see 9.13) | 1. Level indication in column 2. Temperature transmitter at low point at heat exchanger detect low temp 3. Flap valve top coldbox | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------|---|---|---|----------|----------|--------|----|--|
| | | | 2. Vaporize remain liquid in warm condition. Damage heat exchanger causing explosive condition in coldbox | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Too fast heating rate of change >25 c / hr | 3. Thermal stress causing heat exchanger crack and flammable/ toxic gas release | 4. WI 16-011 Shutdown for thaw coldbox | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown |
| | | 3. Hot and cold temperature more than 50 c | 3. Thermal stress causing heat exchanger crack and flammable/ toxic gas release | 4. WI 16-011 Shutdown for thaw coldbox | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown |
| 9.15 | Deviation during maintenance | 1. Open system with remaining toxic/ flammable gas in system (Unusual case) | 1. Toxic/ flammable gas release. Personnel exposure | 1. Purge system with nitrogen 2. PTW 3. JSA 4. Planned maintenance for doing calibration of safety valve with major turnaround | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Open coldbox while N2 purge is pressurized | 2. Personnel exposure to asphyxiated gas | 2. PTW 3. JSA 5. Portable Gas detector | 5 X 5 LG | Major | Remote | P3 | |
| 9.16 | Deviation during sampling | 1. Leakage during sampling | 1. Personnel expose to toxic/ flammable gas | 1. Sampling station is desing for closed loop system 2. I-HYCO-013 for sampling bomb | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Personnel expose to cold gas | | 5 X 5 LG | Moderate | Remote | P4 | |
| 9.17 | Tube leak or rupture | 1. Deviation during startup -> Temp deviation > 50 c (see 9.13) | 1. Toxic/ flammable leak to atmosphere | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Deviation during startup -> Rate of change temp > 25 c / hr (see 9.13) | 1. Toxic/ flammable leak to atmosphere | | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|-------|--------|----|--------------|
| | | 3. Deviation during startup → Recirculation of Nitrogen at too low temp in CO circuit (see 9.13) | 1. Toxic/ flammable leak to atmosphere | | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Deviation during startup → Too fast pressurization > 0.5 bar/min (see 9.13) | 1. Toxic/ flammable leak to atmosphere | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Perlite fluidization erodes exchanger tube | 1. Toxic/ flammable leak to atmosphere | 1. Flap valve at top of coldbox (8 mbag) 2. Fix gas detector at top of coldbox 3. LLF for monitor ice pad at coldbox 4. Interspace high pressure alarm (bottom of CB 10 mbar) 5. Monthly analyzer nitrogen purge in coldbox for any leakage | 5 X 5 LG | Major | Remote | P3 | |

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| | | | |
|---|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: Coldbox (T1602 : hydrogen stripper column) |
| Design Intent: T1602 (MAWP= 11 barg Min/Max temp = -196/+50 c) - Crude Liquid CO from bottom T1601 (LV16001,2) to enter T1602 (Pressure 30 bar temp -170 c) - CO, CH4 is scrubbed in T1601 by Liquid CH4. Tail gas will exit top of T1602 end at FN11005 as fuel gas to reformer - Liquid CO/ Methane exit T1602 bottom enter to T1603 through LV16003, HV16009 | | | |
| P&ID: 16PFP02, 16PFP03, 16PFP04, 16PFP05, 16PFP06 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|--|----------|-----------|-------------------|------------|--|
| 10.1 | High flow | 1. FV16004 (Methane reflux) fail open | 1. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | 2. Redundant methane pump 3. PDAH16002 setting 50 mbarg 4. See safeguard in High level T1602 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 84. Set PM for overhaul FV16004 |
| | | | 2. High level in T1602 (see 10.9) | | | | | | |
| | | | 3. T1602 low temperature (see 10.6) | | | | | | |
| | | | 4. Low flow CH4 to T1601. hydrogen fraction off spec (see 9.2) | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 5. P1671A/B cavitate. Pump damage (see 12.1) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 6. Column flooding hydrogen contaminated with CO, CH4 and pass through T1603. | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 7. Low level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.10) | | | | | | |
| | | 2. FI16004 (Methane reflux) error reading low | 2. High level in T1602 (see 10.9) | 2. Redundant methane pump 3. PDAH16002 setting 50 mbarg | | | | | P3 CAR 84. Set PM for overhaul FV16004 |
| | | | 3. T1602 low temperature (see 10.6) | | | | | | |
| | | | 4. Low flow CH4 to T1601. hydrogen fraction off spec (see 9.2) | | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|--|--|--|----------|-----------|-------------------|------------|--------------|
| | | | 5. P1671A/B cavitate. Pump damage (see 12.1) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 6. Column flooding hydrogen contaminated with CO, CH4 and pass thorough T1603. | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 7. Low level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.10) | | | | | | |
| | | 3. Low pressure at tail gas to reformer | 1. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | 1. PIC16003 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. Low pressure (see 10.8) | | | | | | | |
| 10.2 | Low/no flow | 1. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | 1. Low level in T1602. Plant upset (see 10.10) | 1. LAL16003 setting 40% | 5 X 5 LG | Minor | | | |
| | | 2. FV16004 fail closed | 2. CO, CH4 passing to tail gas and effect reformer fuel control | 1. LAL16003 setting 40% 2. FV16003 LCH4 recycle valve | 5 X 5 LG | Minor | | | |
| | | | 3. Coldbox upset. Process interruption (No safety issue) | | | | | | |
| | | | 4. High level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.9) | | | | | | |
| | | | 5. High temperature (see 10.5) | | | | | | |
| | | 3. FT16004 reading high | 2. CO, CH4 passing to tail gas and effect reformer fuel control | 1. LAL16003 setting 40% 2. FV16003 LCH4 recycle valve | 5 X 5 LG | Minor | | | |
| | | | 3. Coldbox upset. Process interruption (No safety issue) | | | | | | |
| | | | 4. High level (bottom) - Coldbox (T1603 : CO methane separation column) (see 11.9) | | | | | | |
| | | | 5. High temperature (see | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|---|---|---|----------|-------|--------|----|--------------|
| | | | 10.5) | | | | | | |
| | | 5. High flow - Coldbox (T1603 : CO methane separation column) -> reboil gas from MP CO (see 11.1) | | 3. PDAH16002 setting 50 mbar | | | | | |
| | | 6. High temperature - Coldbox (Liq Methane pump) (see 12.5) | | | | | | | |
| 10.3 | Reverse flow (NA) | | | | | | | | |
| 10.4 | Misdirected flow (NA) | | | | | | | | |
| 10.5 | High temperature | 1. TV16013 fail open | 1. Loss CO/ CH4. Coldbox upset | 1. PAH16003 setting 8.5 barg 2. SV1606 setting 10 barg | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. High pressure (see 10.7) | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. High flow - Coldbox (CO turbine) (see 13.1) | | | | | | |
| | | 2. TI16013 reading low | 1. Loss CO/ CH4. Coldbox upset | 1. PAH16003 setting 8.5 barg 2. SV1606 setting 10 barg | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. High pressure (see 10.7) | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. High temperature from turbine (see 13.7) | 1. Loss CO/ CH4. Coldbox upset | | 5 X 5 LG | Minor | Remote | P4 | |
| | | 4. Low/no flow -> FV16004 fail close, FT16004 error reading high (see 10.2) | 1. Loss CO/ CH4. Coldbox upset | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | | | | | | | |
| 10.6 | Low temperature | 1. High flow -> failure FV16004 open, FT16004 reading low (see 10.1) | | | | | | | |
| | | 2. TV16013 fail closed | 1. Missing stripping flow. High hydrogen content in CO circuit. Product contamination (No safety issue) | 1. PAL16003 setting 6 barg | | | | | |
| | | | 2. Low pressure (see 10.8) | | | | | | |
| | | | 5. Low/no flow - Coldbox (CO turbine) (see 13.2) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|---|---|---|----------|-----------|-------------------|------------|--------------|
| | | 3. TI16013 error reading high | 1. Missing stripping flow. High hydrogen content in CO circuit. Product contamination (No safety issue) | 1. PAL16003 setting 6 barg | | | | | |
| | | 4. Liquid nitrogen HV16003 passing leakage | 3. CO Product off spec | 2. Isolation valve at LIN tank 3. Monitor pressure in LIN pipeline to coldbox by log sheet by operator. 2 times/day | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Low temperature downstream equipment (see 11.6) | | | | | | |
| | | 5. Low temperature - Coldbox (CO turbine) (see 13.8) | | | | | | | |
| 10.7 | High pressure | 1. Low level (bottom) - Coldbox (TI1601: Methane wash column) → LT16002 or LT16003 reading error (see 9.10) | 1. Column high pressure than MAWP. Possible rupture to column | 1. SV1606 setting 10 barg (capacity can support full flow case) 2. PV16003 setting 7.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. High temperature → TV16013 fail open (see 10.5) | 1. Column high pressure than MAWP. Possible rupture to column | 1. SV1606 setting 10 barg (capacity can support full flow case) 3. PAH16003 setting 8.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. PV16003 fail closed | 1. Column high pressure than MAWP. Possible rupture to column | 1. SV1606 setting 10 barg (capacity can support full flow case) 3. PAH16003 setting 8.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 4. PT16003 reading low | 1. Column high pressure than MAWP. Possible rupture to column | 1. SV1606 setting 10 barg (capacity can support full flow case) 2. PV16003 setting 7.5 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 10.8 | Low pressure | 1. PV16003 failed open | 1. Column pressure drop causing CO/ CH4 losses together with tail gas | 2. TSLL16016A/B/C (SIL1) setting 10 c 3. TAL16016 setting 20 c warning alarm 4. PAL16003 warning alarm setting 6 barg 5. PIC16004 pressure control | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------|---|--|---|----------|-----------|-------------------|------------|--|
| | | | | downtstream E1611 to flare | | | | | |
| | | | 2. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High flow (see 10.1) | | | | | | |
| | | 2. PT16003 error reading high | 1. Column pressure drop causing CO/ CH4 losses together with tail gas | 1. PI16003A/B selector switch with pressure deviation alarm at 5 barg 2. TSL16016A/B/C (SIL1) setting 10 c 3. TAL16016 setting 20 c warning alarm 5. PIC16004 pressure control downtstream E1611 to flare 6. PV16004 can support fullflow case from PV16003 | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Liquid entrainment to downstream equipment causing cold embrittlement to CS pipe. Major flammable / toxic gas release | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. High flow (see 10.1) | | | | | | |
| | | 3. Low temperature → TV16013 failed close (see 10.6) | 1. Column pressure drop causing CO/ CH4 losses together with tail gas | | 5 X 5 LG | Minor | Remote | P4 | |
| | | 4. Low level (bottom) (see 10.10) | 1. Column pressure drop causing CO/ CH4 losses together with tail gas | | 5 X 5 LG | Minor | Remote | P4 | |
| 10.9 | High level (bottom) | 1. High flow → Methane reflux FV16004, FI16004 failure (see 10.1) | 1. High dP in T1602/ Process upset | 1. LAH16003 setting 60% 2. LI16003 3. PDAH16002 setting 50 mbar warning alarm | 5 X 5 LG | Minor | Remote | P4 | P3 CAR 84. Set PM for overhaul FV16004 P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | | 2. Overflow T1602, Lower hydrogen stripping causing hydrogen entrainment with CO/CH4. Results is coldbox | | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|--------------------|--|---|---|----------|---------|--------|----|---|
| | | | upset | | | | | | |
| | | 2. Low level (bottom) - Coldbox (T1601: Methan wash column) (see 9.10) | 2. Overflow T1602, Lower hydrogen stripping causng hydrogen entrainment with CO/CH4. Results is coldbox upset | 1. LAH16003 setting 60% 2. LI16003 4. Instrument fault signal alarm (Cannot detect if failed lock value) | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 86. Update existing operating procedure that operator should cut feed to coldbox if there is sign of column's bottom level transmitter failure |
| | | 3. LV16003 failed close | 1. High dP in T1602/ Process upset | 1. LAH16003 setting 60% 2. LI16003 3. PDAH16002 setting 50 mbar warning alarm | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Overflow T1602, Lower hydrogen stripping causng hydrogen entrainment with CO/CH4. Results is coldbox upset | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. LT16003 reading low (lock value) | 1. High dP in T1602/ Process upset | 3. PDAH16002 setting 50 mbar warning alarm 4. Instrument fault signal alarm (Cannot detect if failed lock value) | 5 X 5 LG | Minor | Remote | P4 | P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | | 2. Overflow T1602, Lower hydrogen stripping causng hydrogen entrainment with CO/CH4. Results is coldbox upset | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. HV16009 failed closed | 2. Overflow T1602, Lower hydrogen stripping causng hydrogen entrainment with CO/CH4. Results is coldbox upset | 1. LAH16003 setting 60% 2. LI16003 3. PDAH16002 setting 50 mbar warning alarm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. TI16008 reading low | 2. Overflow T1602, Lower hydrogen stripping causng hydrogen entrainment with CO/CH4. Results is coldbox upset | 1. LAH16003 setting 60% 2. LI16003 3. PDAH16002 setting 50 mbar warning alarm | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Loss cold energy to E1615 (see 12.5) | | | | | | |
| 10.10 | Low level (bottom) | 1. LV16003 failed open | 1. Liquid from T1602 pass to T1603 causing column flooding (see 11.9) | 1. LI16003 2. LAL16003 setting 40% | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------------------------------------|--|---|----------|----------|--------|----|--|
| | | | | 4. LV16003 mechanical limitation 88%OV | | | | | |
| | | | 2. Low pressure in T1602 (see 10.8) | | | | | | |
| | | | 3. Product contamination with hydrogen due to feedgas from T1602 pass thorough T1603 (When no more liquid level in column) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. LT16003 reading high (lock value) | 1. Liquid from T1602 pass to T1603 causing column flooding (see 11.9) | 1. LI16003 2. LAL16003 setting 40% 4. LV16003 mechanical limitation 88%OV | | | | | P3 CAR 87. Add logic for check instrument reading value freezing (Failed lock value) |
| | | | 2. Low pressure in T1602 (see 10.8) | | | | | | |
| | | | 3. Product contamination with hydrogen due to feedgas from T1602 pass thorough T1603 (When no more liquid level in column) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. HV16009 failed open | 1. Liquid from T1602 pass to T1603 causing column flooding (see 11.9) | 1. LI16003 2. LAL16003 setting 40% 3. LIC16003 | | | | | |
| | | | 2. Low pressure in T1602 (see 10.8) | | | | | | |
| | | | 3. Product contamination with hydrogen due to feedgas from T1602 pass thorough T1603 (When no more liquid level in column) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Low temperature at methane suction pump (see 12.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 5. Higher temp in T1603 then leading to liquid flooding at T1603 (see 11.9) | | | | | | |
| | | 4. TI16008 error reading high | 2. Low pressure in T1602 (see 10.8) | 1. LI16003 2. LAL16003 setting 40% | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|---|--|----------|----------|--------|----|--------------|
| | | | | 3. LIC16003 | | | | | |
| | | | 3. Product contamination with hydrogen due to feedgas from T1602 pass thorough T1603 (When no more liquid level in column) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Low temperature at methane suction pump (see 12.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 5. Higher temp in T1603 then leading to liquid flooding at T1603 (see 11.9) | | | | | | |
| | | 5. Low/no flow → Bottom valves T1601 fail closed (see 10.2) | 2. Low pressure in T1602 (see 10.8) | | | | | | |
| 10.11 | High concentration of contaminants | 1. Low level (bottom) - Coldbox (T1601: Methan wash column) (see 9.10) | 1. High hydrogen contaminated with CO/ CH4 to T1603 (see 11.11) | | | | | | |
| | | | 2. Tail gas composition change. Refomer temperature fluctuation | | 5 X 5 LG | Minor | | | |
| | | 2. Methane contaminated with CO from T1603 due to low temp in column (see 11.6) | 2. Tail gas composition change. Refomer temperature fluctuation | | 5 X 5 LG | Minor | | | |
| 10.12 | Loss of containment | 1. See consequence of high flow, High temp and Low/No flow | | | | | | | |
| 10.13 | Deviation during startup | 1. Wrongly adjust control valve of Liquid/gas inlet more than gas outlet (LV16003, HV16009) | 1. High pressure to T1602. Over pressurization causing leakage Flammable/ Toxic gas | 1. PAH16003 setting 8.5 bar 2. SV1606 setting 10 barg 3. Start up procedure WI 16-007 | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Too early injection of liquid nitrogen | 2. Thermal stress from high differential temperature >50 c in heat exchanger leading plate exchanger crack. Major release of toxic/ flammable gas | 3. Start up procedure WI 16-007 4. TAL16002 setting -182.5 c (Syngas to T1601) 5. TAL16031 setting -170 c (Tail gas) | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---------------------------|---------------------------------------|--|--|----------|---------|--------|----|--------------|
| | | | | 6. TAL16032 setting -170 c (Tail gas) | | | | | |
| 10.14 | Deviation during sampling | 1. Leakage during sampling (Tail gas) | 1. Personnel expose to toxic/falmmable gas | 1. Sampling station is desing for closed loop system 2. I-HYCO-018 for sampling bag | 5 X 5 LG | Serious | Remote | P3 | |

BUSINESS CONFIDENTIAL

| | | | |
|---|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: Coldbox (T1603 : CO methane separation column) |
| Design Intent: - T1603 : MAWP 4 barg, Min/Max temp -196/+50 c - E1615 : MAWP 4/30 barg Min/Max temp -195/+50 c - CO/CH4 from T1602 is controlled by LV16003 feed to T1603, HV16009 will control by temperature of CH4 suction pump passing through E1615 then feeding to T1603. - Low pressure CO will exit top of T1603 as product to C1608 - 'HP CO product are fed to T1603 as reflux and reboil. Temp -181.5 c / -140 c Pressure 26.3 barg - MP CO product are fed to T1603 as reboil. Temp -130 C Pressure 13 barg - Liquid nitrogen is used for start up at pressure 15 barg | | | |
| P&ID: 16PFP02, 16PFP03, 16PFP05, 16PFP06, 16PFP10, 16PFP04 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|------------------------|---|--------------------------------|----------|----------|--------|----|--------------|
| 11.1 | High flow | 1. FV16018 fail open | 1. Column flooding coldbox upset. CO product offspec | 1. PDAH16005 setting 210 mbarg | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. CO compressor discharge low pressure (see 14.8) | | | | | | |
| | | | 9. Low temperature (see 11.6) | | | | | | |
| | | 2. FT16018 reading low | 1. Column flooding coldbox upset. CO product offspec | 1. PDAH16005 setting 210 mbarg | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. CO compressor discharge low pressure (see 14.8) | | | | | | |
| | | | 9. Low temperature (see 11.6) | | | | | | |
| | | 3. FV16008 failed open | 5. Low flow MP CO (Reboiler) to T1602 causing hydrogen cannot be stripped (see 10.2) | 1. PDAH16005 setting 210 mbarg | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. More heat at E1615 causing Liquid methane stream higher temp enter T1603 (nozzle N2). (see 11.5) | | | | | | |
| | | | 10. High flow - Coldbox (CO | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|------------------------|---|--------------------------------|----------|----------|--------|----|--------------|
| | | | turbine) (see 13.1) | | | | | | |
| | | 4. FT16008 reading low | 5. Low flow MP CO (Reboiler) to T1602 causing hydrogen cannot be stirpped (see 10.2) | 1. PDAH16005 setting 210 mbarg | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. More heat at E1615 causing Liquid methane stream higher temp enter T1603 (nozzle N2). (see 11.5) | | | | | | |
| | | | 10. High flow - Coldbox (CO turbine) (see 13.1) | | | | | | |
| | | 5. FV16007 fail open | 3. CO compressor discharge low pressure (see 14.8) | 1. PDAH16005 setting 210 mbarg | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. More heat at E1615 causing Liquid methane stream higher temp enter T1603 (nozzle N2). (see 11.5) | | | | | | |
| | | 6. FT16007 reading low | 3. CO compressor discharge low pressure (see 14.8) | 1. PDAH16005 setting 210 mbarg | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. More heat at E1615 causing Liquid methane stream higher temp enter T1603 (nozzle N2). (see 11.5) | | | | | | |
| | | 7. FV16006 failed open | 3. CO compressor discharge | 1. PDAH16005 setting 210 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|------------------------|---|---|----------|-----------|-------------------|------------|--------------|
| | | | low pressure (see 14.8) | mbarg 2. FIC16007 3. TAL16023 Setting -183 c 4. TSLL16024A/B/C 2oo3D (SIL3) -10 c 5. TAL16024 setting 10 c | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 8. Liquid CO carried over to CO compressor. Compressor rupture and Large toxic gas release (see 14.6) | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 9. Low temperature (see 11.6) | | | | | | |
| | | 8. FT16006 reading low | 3. CO compressor discharge low pressure (see 14.8) | 1. PDAH16005 setting 210 mbarg 2. FIC16007 | | | | | |
| | | | 6. High flow through FV16006/7/8 (JT valves) causing Liquid flooding to T1603. Process upset (see 11.9) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. More heat at E1615 causing Liquid methane stream higher temp enter T1603 (nozzle N2). (see 11.5) | | | | | | |
| | | | 9. Low temperature (see 11.6) | | | | | | |
| 11.2 | Low/no flow | 1. FV16018 fail close | 1. CH4 slip from T1603. Product off spec (see 11.5) | 1. AI16009 CH4 in CO AAH = 7,8,9 ppm 2. AI16011 %CO AAL=97.7 AALL=97.62 3. AI16013 CH4 in CO AAH = 9 ppm AAHH =10 ppm | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High discharge CO | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------|---|---|----------|----------|--------|----|--|
| | | | compressor (see 14.7) | | | | | | |
| | | | 7. Low level (bottom) (see 11.10) | | | | | | |
| | | 2. FT16018 reading high | 1. CH4 slip from T1603. Product off spec (see 11.5) | 1. AI16009 CH4 in CO AAH = 7,8,9 ppm 2. AI16011 %CO AAL=97.7 AALL=97.62 3. AI16013 CH4 in CO AAH = 9 ppm AAHH =10 ppm | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High discharge CO compressor (see 14.7) | | | | | | |
| | | | 7. Low level (bottom) (see 11.10) | | | | | | |
| | | 3. FV16008 failed close | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | 4. PDAH16005 setting 210 mbarg | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 88. Add TAH16022 setting -179 c |
| | | | 6. Suction stage#4 CO compressor high pressure (see 14.7) | | | | | | |
| | | | 8. High temperature - Coldbox (CO turbine) (see 13.7) | | | | | | |
| | | 4. FT16008 reading high | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | 4. PDAH16005 setting 210 mbarg | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 88. Add TAH16022 setting -179 c |
| | | | 6. Suction stage#4 CO compressor high pressure (see 14.7) | | | | | | |
| | | | 8. High temperature - Coldbox (CO turbine) (see 13.7) | | | | | | |
| | | 5. FV16007 fail close | 1. CH4 slip from T1603. Product off spec (see 11.5) | 1. AI16009 CH4 in CO AAH = 7,8,9 ppm 2. AI16011 %CO AAL=97.7 AALL=97.62 3. AI16013 CH4 in CO AAH = 9 ppm AAHH =10 ppm 4. PDAH16005 setting 210 mbarg | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------|---|---|----------|----------|--------|----|--|
| | | | 2. High discharge CO compressor (see 14.7) | | | | | | |
| | | | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. Low level (bottom) (see 11.10) | | | | | | |
| | | 6. FT16007 reading high | 1. CH4 slip from T1603. Product off spec (see 11.5) | 1. AI16009 CH4 in CO AAH = 7,8,9 ppm 2. AI16011 %CO AAL=97.7 AALL=97.62 3. AI16013 CH4 in CO AAH = 9 ppm AAHH =10 ppm 4. PDAH16005 setting 210 mbarg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High discharge CO compressor (see 14.7) | | | | | | |
| | | | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. Low level (bottom) (see 11.10) | | | | | | |
| | | 7. FV16006 failed close | 1. CH4 slip from T1603. Product off spec (see 11.5) | 4. PDAH16005 setting 210 mbarg 5. FIC16007 | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 88. Add TAH16022 setting -179 c |
| | | | 2. High discharge CO compressor (see 14.7) | | | | | | |
| | | | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. FT16006 reading high | 1. CH4 slip from T1603. Product off spec (see 11.5) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. High discharge CO compressor (see 14.7) | | | | | | |
| | | | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 7. Low level (bottom) (see 11.10) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|--|---|--|----------|----------|--------|----|--|
| | | | 11.10) | | | | | | |
| | | 9. Low pressure - CO compressor + CO supply line → Loss suction to stage#4 causing 'HP CO to T1603 loss (see 14.8) | 4. No reboil E1615 causing column flooding tray. CO off spec (see 11.6) | | 5 X 5 LG | Moderate | Remote | P4 | |
| 11.3 | Reverse flow (NA) | | | | | | | | |
| 11.4 | Misdirected flow (NA) | | | | | | | | |
| 11.5 | High temperature | 1. High flow → Higher heat input to E1615 (see 11.1) | 1. High pressure T1603 (see 11.7) | | | | | | |
| | | 2. Low/no flow → Loss reflux (see 11.2) | 1. High pressure T1603 (see 11.7) | | | | | | |
| 11.6 | Low temperature | 1. High flow from HV16009 causing low temp at E1615 | 1. Liquid CH4 freezing and block in E1615 (see 12.6) | 3. Mechanical lock opening value at HV16009 at 80% OV. | | | | | P3 CAR 96. Update all information sent from LE for flow limitation in SLE-1003 list of safety relevant control valves and orifices |
| | | | 2. Methane contaminated with CO (see 10.11) | | | | | | |
| | | | 3. CO product off spec | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. nitrogen injection valve HV16021 leakage | 1. Liquid CH4 freezing and block in E1615 (see 12.6) | 1. Monitor pressure in LIN pipeline to coldbox by log sheet by operator. 2 times/day 2. Isolation at LIN tank 4. AI16011 %CO AAL=97.7% AALL=97.62% | | | | | |
| | | | 2. Methane contaminated with CO (see 10.11) | | | | | | |
| | | | 3. CO product off spec | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Low/no flow → Low flow from reboil streams in E1615 (see 11.2) | 2. Methane contaminated with CO (see 10.11) | | | | | | |
| | | 4. High flow → Excess | 2. Methane contaminated | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|--|--|--|----------|-----------|-------------------|------------|---|
| | | reflux to T1603 (see 11.1) | with CO (see 10.11) | | | | | | |
| | | 5. Low temperature - Coldbox (T1602 : hydrogen stripper column) -> Liquid nitrogen valve HV16003 passing leak (see 10.6) | 1. Liquid CH4 freezing and block in E1615 (see 12.6) | 1. Monitor pressure in LIN pipeline to coldbox by log sheet by operator. 2 times/day 2. Isolation at LIN tank | | | | | |
| | | | 2. Methane contaminated with CO (see 10.11) | | | | | | |
| | | 6. Low temperature - Coldbox (CO turbine) (see 13.8) | | | | | | | |
| 11.7 | High pressure | 1. PV16033 failed close when require to open | 1. Over pressure T1603 | 1. SV1603 setting 3 barg 2. PAH16033 setting 2.9 barg 3. PI16033 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | P3 CAR 89. To change PAH16033 set point at 2.5 barg |
| | | 2. PT16033 reading low | 1. Over pressure T1603 | 1. SV1603 setting 3 barg 2. PAH16033 setting 2.9 barg 3. PI16033 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. CO compressor suction high pressure (see 14.7) | | | | | | | |
| | | 4. High temperature (see 11.5) | 1. Over pressure T1603 | 1. SV1603 setting 3 barg 2. PAH16033 setting 2.9 barg 3. PI16033 | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 5. High temperature - Coldbox (CO turbine) (see 13.7) | 1. Over pressure T1603 | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 11.8 | Low pressure | 1. PV16033 failed open | 1. CO compressor loss suction. CO compressor damage (see 14.8) | 1. PIC16006 2. CO Compressor suction pressure PAL16300 0.85 barg 3. CO Compressor suction pressure PSL16300A/B/C 0.8 barg trip CO compressor | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Coldbox upset CO off spec | | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---------------------|---|--|--|----------|----------|--------|----|--------------|
| | | | 3. Low/no flow - Coldbox (Liq Methane pump) (see 12.2) | | | | | | |
| | | 2. PT16033 reading high | 1. CO compressor loss suction. CO compressor damage (see 14.8) | 1. PIC16006 2. CO Compressor suction pressure PAL16300 0.85 barg 3. CO Compressor suction pressure PSL16300A/B/C 0.8 barg trip CO compressor | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Coldbox upset CO off spec | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Low/no flow - Coldbox (Liq Methane pump) (see 12.2) | | | | | | |
| 11.9 | High level (bottom) | 1. CH4 pump trip | 1. Plant upset | 1. Redundant pump with cold standby condition 2. WI I-HYCO-046 start up methane pump/ Cold standby | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Low/no flow - Coldbox (T1602 : hydrogen stripper column) -> T1602 reflux methane valve failed close (see 10.2) | 1. Plant upset | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Low level (bottom) - Coldbox (T1602 : hydrogen stripper column) -> T1602 bottom valves failed open (see 10.10) | 1. Plant upset | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. Low level (bottom) - Coldbox (T1602 : hydrogen stripper column) -> T1602 bottom valves failed open (see 10.10) | 1. Plant upset | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. High flow -> Excessive reflux to T1603 (see 11.1) | 1. Plant upset | | 5 X 5 LG | Moderate | Remote | P4 | |
| 11.10 | Low level (bottom) | 1. High flow - Coldbox (T1601: Methan wash column) -> TV16047 fail open (see 9.1) | 1. Methane pump loss suction and damage | 1. LAL16005A/B/C setting 25% 2. LSL16005A/B/C 2oo3 | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|--|---|---|----------|---------|--------|----|--------------|
| | | | | trip P1671A/B setting 5 % | | | | | |
| | | 2. High flow - Coldbox (T1602 : hydrogen stripper column) -> FV16004 failed open (see 10.1) | 1. Methane pump loss suction and damage | 1. LAL16005A/B/C setting 25% 2. LSL16005A/B/C 2oo3 trip P1671A/B setting 5 % | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Hydrogen mixing with liquid CO/ CH4 (see 11.11) | | | | | | |
| | | 3. Low/no flow -> Reflux valves fail close (see 11.2) | 1. Methane pump loss suction and damage | 1. LAL16005A/B/C setting 25% 2. LSL16005A/B/C 2oo3 trip P1671A/B setting 5 % 3. Methane pump is designed for 50% LCO and 50% LCH4 mixture as a worst case | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Hydrogen mixing with liquid CO/ CH4 (see 11.11) | | | | | | |
| 11.11 | High concentration of contaminants | 1. High concentration of contaminants - Coldbox (T1602 : hydrogen stripper column) -> Bottom valve T1601 failed open (see 10.11) | 1. High hydrogen content in CO circuit causing damage of CO compressor (see 14.9) | 1. See safeguard at T1601, T1602 | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. High hydrogen content in CO circuit causing damage of CO turbine | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Low level (bottom) -> Loss methane reflux CO/ CH4 from T1601, T1602 (see 11.10) | 1. High hydrogen content in CO circuit causing damage of CO compressor (see 14.9) | 1. See safeguard at T1601, T1602 | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. High hydrogen content in CO circuit causing damage of CO turbine | | 5 X 5 LG | Serious | Remote | P3 | |
| 11.12 | Tube leak or rupture (E1615) | 1. Deviation during startup -> Temp deviation > 50 c (see 9.13) | 1. Toxic/ flammable leak to atmosphere (see 12.14) | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Deviation during startup -> Rate of change temp > 25 c / hr (see 9.13) | 1. Toxic/ flammable leak to atmosphere (see 12.14) | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Deviation during startup | 1. Toxic/ flammable leak to | | 5 X 5 | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---|--|---|---|----------|---------|--------|----|--|
| | | → Recirculation of Nitrogen at too low temp in CO circuit (see 9.13) | atmosphere (see 12.14) | | LG | | | | |
| | | 4. Deviation during startup → Too fast pressurization > 0.5 bar/min (see 9.13) | 1. Toxic/ flammable leak to atmosphere (see 12.14) | | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Perlite fluidization erodes exchanger tube | 1. Toxic/ flammable leak to atmosphere (see 12.14) | 1. Flap valve at top of coldbox (8 mbag) 2. Fix gas detector at top of coldbox 3. LLF for monitor ice pad at coldbox 4. Interspace high pressure alarm (bottom of CB 10 mbar) 5. Monthly analysis nitrogen purge in coldbox for any leakage | 5 X 5 LG | Major | Remote | P3 | |
| 11.13 | Deviation during startup (For only E1615) | 1. Oxygen remain in system | 1. Forming explosive condition | 1. WI 16-007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Too fast cooling down of E1615, T1603 | 3. Too fast cooling down leading to thermal stress due to rate of change >25 c/ hr. Major release of toxic/ flammable gas | 1. WI 16-007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Too differential between Hot/ cold stream in E1615 | 2. Thermal stress from high differential temperature >50 c in heat exchanger leading plate exchanger crack. Major release of toxic/ flammable gas | 1. WI 16-007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | P3 CAR 81. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown |
| | | 4. Liquid is not completely drained out and remained in column. Freezed up liquid in heat exchanger while start up | 4. Freeze methane in heat exchanger while introducing feed liquid methane to system to E1615 | 2. WI 16-010 coldbox shutdown | 5 X 5 LG | Major | Remote | P3 | |
| | | | 5. Freeze moisture or 'CO2 in heat exchanger while introduce feed liquid methane or syngas to | | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---|---|---|--|----------|---------|------------|----|---|
| | | | system. Delay schedule for start up | | | | | | |
| | | 5. Remain moisture and Carbon dioxide in system | 5. Freeze moisture or 'CO2 in heat exchanger while introduce feed liquid methane or syngas to system. Delay schedule for start up | 1. WI 16-007 coldbox start up 3. Moisture analyzer to switch to 3rd stage of CO compressor during start up AI16012. Switching is interlock permissive start CO compressor | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. Too fast pressurization > 0.5 bar/min | 6. Long term impact to reduce strength of cold equipment | 1. WI 16-007 coldbox start up | 5 X 5 LG | Major | Improbable | P3 | |
| | | 7. To early inject LIN to E1615 stream liquid CO/CH4 | 4. Freeze methane in heat exchanger while introducing feed liquid methane to system to E1615 | | 5 X 5 LG | Major | Remote | P3 | P3 CAR 90. Add TAL16026, TAL16067 setting -175 c in order to detect freezed liquid methane at E1615 |
| | | | 7. TAL16008 Liquid suction methane pump setting -175 c | | | | | | |
| 11.14 | Deviation during shutdown (Only for E1615) | 1. Drain liquid without pressure | 1. Liquid is not completely drained out and remain in column. Freezed up liquid in heat exchanger while start up | 1. Level indication in column 2. Temperature transmitter at low point at heat exchanger detect low temp | | | | | |
| | | | 2. Vaporize remain liquid in warm condition. Damage heat exchanger causing explosive condition in coldbox | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Too fast heating rate of change >25 c / hr | 3. Thermal stress causing heat exchanger crack and flammable/ toxic gas release | 3. Flap valve top coldbox 4. WI 16-011 Shutdown for thaw coldbox | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Hot and cold temperature stream in E1615 different more than 50 c | 3. Thermal stress causing heat exchanger crack and flammable/ toxic gas release | 3. Flap valve top coldbox 4. WI 16-011 Shutdown for thaw coldbox | 5 X 5 LG | Serious | Remote | P3 | |
| 11.15 | Deviation during maintenance (Only for E1615) | 1. Open system with remaining toxic/ flammable gas in system (Unusual case) | 1. Toxic/ flammable gas release. Personnel exposure | 1. Purge system with nitrogen 2. PTW 3. JSA | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|-------|--------|----|--------------|
| | | | | 4. Planned maintenance for doing calibration of safety valve with major turnaround 5. Portable Gas detector | | | | | |
| | | 2. Open coldbox while N2 purge is pressurized | 2. Personnel exposure to asphyxiated gas | 1. Purge system with nitrogen 2. PTW 3. JSA 4. Planned maintenance for doing calibration of safety valve with major turnaround 5. Portable Gas detector | 5 X 5 LG | Major | Remote | P3 | |

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|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: Coldbox (Liq Methane pump) |
| Design Intent: - Process description : LCH4 from bottom T1603 pass E1615 and enter P1671A/B. Discharge pressure LCH4 pressure 35 barg, Temp -187 c to E1612 to give cold energy then supply as reflux to T1601, T1602. Residual LCH4 is recycled back to E1615 to give cold energy. Exit from T1603 and recycled stream will enter P1671A/B suction. - Equipment details - E1612 MAWP (N1/N2) = 35 barg, MDT = -196 c - E1615 MAWP (N7/N8/N9) = 4 barg, MDT = -196 c - P1671 Discharge 35 barg Temp = -196, Suction 4 bar Temp = -196 c, flow rate = 1642 kg/hr | | | |
| P&ID: 16PFP02, 16PFP04, 16PFP05, 16PFP06 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|--|--|--------|------------|-------------------|------------|--------------|
| 12.1 | High flow | 1. FV16003 failed close | 1. Low/no flow - Coldbox (T1601: Methan wash column) (see 9.2) | | | | | | |
| | | | 2. High level (bottom) - Coldbox (T1601: Methan wash column) (see 9.9) | | | | | | |
| | | 2. High flow - Coldbox (T1602 : hydrogen stripper column) → Methane reflux T1602 failed open (see 10.1) | 3. No safety issue for this node | | | | | | |
| 12.2 | Low/no flow | 1. FV16003 failed closed | 1. High level (bottom) - Coldbox (T1601: Methan wash column) (see 9.9) | | | | | | |
| | | 2. Low pressure upstream T1603 (see 11.8) | 2. Loss suction P1671A/B (see 12.8) | | | | | | |
| | | 3. Plugged strainer | 2. Loss suction P1671A/B (see 12.8) | 1. FAL16003 setting 450 kg/hr | | | | | |
| | | 4. Misdirected flow (see 12.4) | | | | | | | |
| 12.3 | Reverse flow | 1. Methane Pump stop/ trip | 1. Reverse from downstream | 1. Check valve XAE007A/B 2. Pump is reciprocating type | | | | | |
| 12.4 | Misdirected flow | 1. Check valve XAE007A or B passing | 1. Over pressure suction pump | 1. Startup procedure I-HYCO-046 2. PSV1613A/B at suction setting 4 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 2. Low/no flow (see 12.2) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|---|---|----------|-------------|--------------------|------------|--------------|
| 12.5 | High temperature | 1. High level (bottom) - Coldbox (T1602 : hydrogen stripper column) → HV16009 failed close (see 10.9) | 1. Methane pump loss suction and pump cavitate | 1. See safeguard in T1602 "High level" | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Loss reflux to T1601 (see 9.2) | | | | | | |
| | | | 3. Loss reflux to T1602 (see 10.2) | | | | | | |
| | | 2. External fire case | 4. Overpressure/ Flammable gas release | 2. SV1607, SV1608 setting 35 barg | 5 X 5 LG | Major | Remote | P3 | |
| 12.6 | Low temperature | 1. Low level (bottom) - Coldbox (T1602 : hydrogen stripper column) → HV16009 fail open (see 10.10) | 1. Low/no flow - Coldbox (T1601: Methan wash column) → Liq methane freeze at E1612 (see 9.2) | | | | | | |
| | | | 2. Liquid methane freeze at E1615. Pump loss suction (see 12.7) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Low temperature - Coldbox (T1603 : CO methane separation column) → HV16021 leak (see 11.6) | 1. Low/no flow - Coldbox (T1601: Methan wash column) → Liq methane freeze at E1612 (see 9.2) | 3. Redundant pump | | | | | |
| | | | 2. Liquid methane freeze at E1615. Pump loss suction (see 12.7) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Crystalization with liquid methane | 3. Methane pump worn out. Minor flammable gas release | 1. Suction strainer 2. TAL16063, TAL16064 setting 10 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | | | | | | | |
| 12.7 | High pressure | 1. Low temperature → Freeze methane at E1615 recycle line (see 12.6) | 1. Potential release through the relief valve | 1. SV1607, SV1608 setting 35 barg | | | | | |
| | | | 2. High pressure discharge. Overpressurized pipeline and downstream equipment than MDP causing rupture. Large flammable gas release | | LE3 | 3- Moderate | 1- Highly Unlikely | Acceptable | |
| 12.8 | Low pressure | 1. Low/no flow → Low pressure upstream resulting pump loss suction (see 12.2) | 1. Methane pump piston ring wornout | 1. Overhaul every 8000 hr 2. Redundant pump | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|---|--|----------|----------|-------------------|------------|--------------|
| | | | 2. Packing of piston rod leak | | 5 X 5 LG | Serious | Remote | P3 | |
| 12.9 | High concentration of contaminants | 1. No issue | | | | | | | |
| 12.10 | Loss of containment | 1. Thermal expansion of liquid in isolated pump | 1. Flammable gas release | 5. SV1613, SV1614 setting 4 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Flexible hose rupture | | 1. WI I-HYCO-046 4. Control rate for cooling down pump < 25 c/hr | | | | | |
| | | 3. Check valve leak | 1. Flammable gas release | 2. LLF | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. Rod packing leak | 1. Flammable gas release | 2. LLF 3. TAL16063, TAL16064 setting 10 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. Copper ring hardening | 1. Flammable gas release | 6. Wear part replacement every year | 5 X 5 LG | Moderate | Remote | P4 | |
| 12.11 | Deviation during startup | 1. Improper pump cooling down | 1. Pump wear/ deterioration | 2. WI I-HYCO-046 | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 2. Flexible leakage from Thermal fatigue | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Discharge manual valve is not opened | 3. Flange leak (discharge pressure <150% MDP) | 1. SV1607, SV1608 setting 35 barg | LE3 | 2-Minor | 1-Highly Unlikely | Acceptable | |
| | | 3. Moisture remain in system | 4. Crystalization, pump worn out | 3. Pump Suction filter 4. WI 16-0007 coldbox start up | 5 X 5 LG | Serious | Remote | P3 | |
| 12.12 | Deviation during shutdown | 1. Liquid not drained completely | 1. Liquid methane vaporized causing E1615 rupture | 1. WI 16-0012 Total shutdown 2. WI 16-0011 thawing coldbox | 5 X 5 LG | Major | Remote | P3 | |
| 12.13 | Deviation during maintenance | 1. Remain flammable gas in system | 1. Flammable gas release | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|----------------------|--|---|---|-------------|---------|--------|----|--------------|
| | | | | 4. Portable detector | | | | | |
| | | 2. Improper isolation | 2. People expose to toxic/ Flammable gas | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Pressurized system | 3. Injury | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |
| 12.14 | Tube leak or rupture | 2. Tube leak or rupture (E1615) - Coldbox (T1603 : CO methane separation column) (see 11.12) | | | | | | | |

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| | | | |
|--|------|------|-----------------------------------|
| Linde PLC | HYCO | MTP1 | Name: Coldbox (CO turbine) |
| Design Intent: Process descriptions - 'HP CO from CO compressor pressure 26.5 barg Temp 35 c enter to E1611 to get cold energy until temp -109 c and enter turbine suction to expand. Outlet temp is -130 c pressure 13 bar as MP CO - MP CO exit turbine 13 barg temp -130 c to enter E1611 and enter CO compressor stage 3 until manual valve suction of stage 3rd compressor - 'LP CO 1.5 barg from seal gas back to CO compressor suction - Bypass turbine 'HP CO to MP CO - Start up line - Start up line CO turbine (PFP02) - Start up line 'HP CO to T1601 feed (PFP02) - Start up line hydrogen fraction to MP CO (PFP10) - Seal gas; 'HP CO 26.5 barg from exit 'CO2 absorber - Coolinbg water | | | |
| P&ID: 16PFP08, 16PFP01, 16PFP02 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|--------|---|----|----|--------------|
| 13.1 | High flow | 1. High CO comprssor discharge pressure (see 14.7) | 1. Low temperature outlet turbine (MP CO) (see 13.8) | 1. HV16102B cascade mode by SIC16101 4. PAH16101A 28.46 barg 5. PAHH16101A 29.81 barg | | | | | |
| | | 2. HV16102 open more | 1. Low temperature outlet turbine (MP CO) (see 13.8) | 2. 'TAL16103 setting -148 c 3. TALL16103 settting -153 c trip turbine | | | | | |
| | | | 2. Low pressure - CO compressor + CO supply line (see 14.8) | | | | | | |
| | | 3. High temperature - Coldbox (T1602 : hydrogen stripper column) -> TV16013 failed open (see 10.5) | 1. Low temperature outlet turbine (MP CO) (see 13.8) | 1. HV16102B cascade mode by SIC16101 2. 'TAL16103 setting -148 c 3. TALL16103 settting -153 c trip turbine | | | | | |
| | | | 2. Low pressure - CO compressor + CO supply line (see 14.8) | | | | | | |
| | | 4. High flow - Coldbox (T1603 : CO methane separation column) -> FV16008, FI16008 failure (see 11.1) | 1. Low temperature outlet turbine (MP CO) (see 13.8) | 1. HV16102B cascade mode by SIC16101 2. 'TAL16103 setting -148 c 3. TALL16103 settting -153 c | | | | | |
| | | | | | | | | | |
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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|--|---|----------|----------|--------|----|--------------|
| 13.2 | Low/no flow | | | trip turbine | | | | | |
| | | | 2. Low pressure - CO compressor + CO supply line (see 14.8) | | | | | | |
| | | 1. HV16102 fail close | 1. High temperature turbine outlet (see 13.7) | 1. Valve proximity switch ZAL16012 2. SAL16101 setting 390 Hz | | | | | |
| | | | 2. Low pressure (see 13.6) | | | | | | |
| | | 2. Plugged strainer with carbon dioxide | 1. High temperature turbine outlet (see 13.7) | 3. PDAH16101 setting 1.5 barg 4. PDSHH16101 setting 2.5 barg to trip turbine | | | | | |
| | | | 2. Low pressure (see 13.6) | | | | | | |
| | | 3. CO compressor low discharge pressure (see 14.8) | 1. High temperature turbine outlet (see 13.7) | 2. SAL16101 setting 390 Hz 5. HV16102 cascade mode by SIC16101 | | | | | |
| | | 4. Low temperature - Coldbox (T1602 : hydrogen stripper column) (see 10.6) | 1. High temperature turbine outlet (see 13.7) | 2. SAL16101 setting 390 Hz 5. HV16102 cascade mode by SIC16101 | | | | | |
| | | 5. Low pressure - CO compressor + CO supply line → Loss suction to stage#4 causing loss 'HP CO to Turbine (see 14.8) | 1. High temperature turbine outlet (see 13.7) | | | | | | |
| | | | | | | | | | |
| 13.3 | Reverse flow | 1. CO reverses into nitrogen header | 1. CO contaminate in nitrogen. ersonnel exposed with Toxic gas | 1. Check valve 2. Spectacle blinde NC | 5 X 5 LG | Major | Remote | P3 | |
| 13.4 | Misdirected flow | 1. Bypass line HV16001 fail close on demand | 1. High pressure CO compressor discharge (see 14.7) | 1. PAH16500 setting 27.5 barg 2. PAHH16500A/B/C 2oo3D setting 29 barg | | | | | |
| | | | 3. Process upset due to loss MP CO. Product off spec | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Bypass line HV16001 fail open | 2. High pressure CO compressor suction stage#4 (see 14.7) | 3. SV1610 setting 16 barg | | | | | |
| | | | 4. High discharge temp | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|---|---|----------|-------|--------|----|--|
| | | | turbine (see 13.7) | | | | | | |
| 13.5 | High pressure | 1. Turbine brake gas pressure regulator PCV16102 passing | 1. High temp outlet turbine (see 13.7) | 1. PAH16104 setting 9.05 barg 2. PDSHH16104 setting 10.05 barg to trip turbine | | | | | |
| | | 2. Turbine seal gas pressure regulator PCV16103 passing | 2. Process upset due to warm outlet turbine | 3. Operation practice | 5 X 5 LG | Minor | Remote | P4 | P3 CAR 91. Revise existing plant P&ID at turbine section (16PFP01) with correct details reference with vendor package P&ID |
| 13.6 | Low pressure | 1. Low/no flow (see 13.2) | | | | | | | |
| 13.7 | High temperature | 1. Low/no flow (see 13.2) | 1. Discharge turbine high temp. T1602 high temp (see 10.5) | | | | | | |
| | | | 2. Discharge turbine high temp. T1603 high temp (see 11.7) | | | | | | |
| | | | 3. High temperature - Coldbox (T1601: Methan wash column) (see 9.5) | | | | | | |
| | | 2. High pressure (see 13.5) | 1. Discharge turbine high temp. T1602 high temp (see 10.5) | | | | | | |
| | | | 2. Discharge turbine high temp. T1603 high temp (see 11.7) | | | | | | |
| | | | 3. High temperature - Coldbox (T1601: Methan wash column) (see 9.5) | | | | | | |
| | | 3. Misdirected flow (see 13.4) | 1. Discharge turbine high temp. T1602 high temp (see 10.5) | | | | | | |
| | | | 2. Discharge turbine high temp. T1603 high temp (see 11.7) | | | | | | |
| | | | 3. High temperature - Coldbox (T1601: Methan wash column) (see 9.5) | | | | | | |
| | | 4. Low/no flow - Coldbox (T1603 : CO methane | 1. Discharge turbine high temp. T1602 high temp (see | | | | | | |
| | | | temp. T1602 high temp (see | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|--|--|--|----------|-----------|-------------------|------------|--|
| | | separation column) (see 11.2) | 10.5) | | | | | | |
| | | | 2. Discharge turbine high temp. T1603 high temp (see 11.7) | | | | | | |
| | | | 3. High temperature - Coldbox (T1601: Methan wash column) (see 9.5) | | | | | | |
| 13.8 | Low temperature | 1. High flow (see 13.1) | 1. Cold CO gas pass to suction CO compressor 4th stage. Toxic gas large release | 1. TSLL16059A/B/C (SIL3) 2oo3D setting -10 c trip CO compressor 2. TAL16059 setting 10 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 3. Low temperature - Coldbox (T1601: Methan wash column) (see 9.6) | | | | | | |
| | | | 4. Low temperature - Coldbox (T1602 : hydrogen stripper column) (see 10.6) | | | | | | |
| | | | 5. Low temperature - Coldbox (T1603 : CO methane separation column) (see 11.6) | | | | | | |
| | | 2. Loss warm stream passing through E1611 | 2. Liquid CO gas pass to suction CO compressor 4th stage causing cold embrittlement CS pipe, Large toxic gas release | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | | | | | | | |
| 13.9 | Critical Speed | 1. Turbine create resonance frequency | 1. Turbine severe damage | 1. Complete set turbine spare part 2. SAH16101A setting 2 mins (Critical speed range 470 - 510 Hz) 3. SAHH16101B setting 3 mins (Critical speed range 470 - 510 Hz) trip turbine 4. SAL16101 warning alarm (< 390 Hz) | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 92. Confirm lower critical speed with turbine manufacturer (Air liquid) and change set point SAL1601 if any deviation found |
| 13.10 | High concentration of contaminants | 1. Nitrogen from thawing remains in system | 1. Nitrogen contaminated with CO product | 1. AAH16011 CO purity setting 97.6% 2. I-HYCO-061 WI for turbine | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------|--|---|--|----------|-----------|-------------------|------------|--|
| | | | | thawing | | | | | |
| 13.11 | Loss of containment | 1. Leakage turbine seal | 1. Personnel expose to Toxic gas | 1. Fixed CO detectors 2. CO turbine enclosure vent linbe connected with flare | 5 X 5 LG | Serious | Remote | P3 | |
| 13.12 | Deviation during startup | 1. Start up line hydrogen fraction to MP CO valve is left open when syngas introduced to coldbox | 2. Hydrogen entrain to CO circuit and damage to CO compressor | 2. WI for turbine start up #16-007 3. Swing blind | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Start up line 'HP CO to T1601 feed gas valve is left open when syngas introduced to coldbox | 3. Syngas entrain to CO circuit and damage to CO compressor | 2. WI for turbine start up #16-007 3. Swing blind | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. To early main valve HV16039 open to CO turbine before -138 c | 1. Too fast cooldown causing nitrogen condense at outlet of Turbine. Turbine damage | 2. WI for turbine start up #16-007 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Start up after longer shutdown (No thawing) | 4. Liquid CO entrains to downstream CS pipe section and embrittlement causing large toxic gas release | 4. TSLL16059A/B/C (SIL3) 2oo3D setting -10 c trip CO compressor 5. TAL16059 setting 10 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 13.13 | Deviation during shutdown | 1. Incompleted purge CO remain in system | 1. Personnel exposure to toxic gas | 1. WI for shutdown turbine | 5 X 5 LG | Major | Remote | P3 | P3 CAR 93. Add content for completely purge CO turbine in I-HYCO-0037 CO turbine start up and shutdown |
| 13.14 | Deviation during maintenance | 1. Improper isolation | 1. Toxic/ Flammable gas relaese | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. People expose to toxic/ Flammable gas | | 5 X 5 LG | | | | |
| | | 2. Pressurized system | 3. Injury | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |

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|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: CO compressor + CO supply line |
| Design Intent: - Operating condition - CO suction pressure 1.5 bar, Temp 35 C - Discharge 3rd stage 12.9 bar, Temp 35 c, flow rate 1903 Nm3/hr - Discharge 4th stage 26.5 bar, Temp 35 c, flow 4472 Nm3/hr - Compressor design data - Compressor shut off pressure = xxx Barg - Casing MAWP stage 1,2,3,4 = 9,15,27,60 barg - Carbon dioxide absorber A1651 MAWP = 35 barg MDT = 190 c | | | |
| P&ID: 16PFP10, 16PFP07, 16PFP08, 16PFP13, 16PFP14 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------------|---|--|--|----------|-----------|-------------------|------------|--|
| 14.1 | High flow (NA) | | | | | | | | |
| 14.2 | Low/no flow | 1. Low flow cooling water supply | 1. High temperature compressor (see 14.5) | 1. FAL16575 set point 120 Nm3/hr at header | | | | | |
| | | 2. Soot filter blockage | 2. High pressure discharge (see 14.7) | | | | | | |
| | | 3. Carbon dioxide adsorber blockage | 2. High pressure discharge (see 14.7) | | | | | | |
| 14.3 | Reverse flow | 1. Compressor trip | 1. CO reverse from pipeline to 3rd stage causing internal part damage | 1. Check valve XAR (Check valve with safety function) 2. Compressor's check valve | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. CO reserve to nitrogen header at Soot filter purging valve V24 | 2. Nitrogen contaminated with CO and personnel exposure to toxic gas | 3. Swing blind close 4. Check valve N01 5. I-HYCO-020 isolation method for soot filter cleaning | 5 X 5 LG | Major | Remote | P3 | P3 CAR 94. Create WI for soot filter purging/ carbon dioxide adsorber purging and train to all operators |
| 14.4 | Misdirected flow (NA) | | | | | | | | |
| 14.5 | High temperature | 1. Low flow cooling water supply (see 14.2) | 1. High temperature to coldbox causing over design temp of equipment in coldbox. Coldbox failure | 1. TSHH16040A/B/C 2oo3D (SIL2) setting 50 c (stage 4) 2. TAH16040 setting 45 c (stage 4) 3. CO product pipeline is | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|--|---|--|--------|------------|-------------------|------------|--------------|
| | | | | design for 200 c @ 14 barg (stage 3) | | | | | |
| 14.6 | Low temperature | 1. High flow - Coldbox (T1603 : CO methane separation column) → FV16006 fail open at T1603 (see 11.1) | 1. Liquid CO carried over to suction of CO compressor. Compressor casing rupture causing large toxic gas release | 1. TSL16024A/B/C 2003D (SIL3) -10 c 2. TAL16024 setting 10 c | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 14.7 | High pressure | 1. PV16020 failed close | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 3. PIC16035 4. SV1610 setting 16 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 2. PT16020 error reading low | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 3. PIC16035 4. SV1610 setting 16 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 3. PV16035 failed close on demand | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 4. SV1610 setting 16 barg 5. SV1665 setting 16 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 4. PT16035 error reading low | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 4. SV1610 setting 16 barg 5. SV1665 setting 16 barg 6. PAH16400 setting 13 barg (Suction stage#4) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 5. HV16603 failed close | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 3. PIC16035 4. SV1610 setting 16 barg 5. SV1665 setting 16 barg 6. PAH16400 setting 13 barg (Suction stage#4) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 6. Low/no flow - Coldbox (T1603 : CO methane separation column) → FV16018, FI16018 fail close (see 11.2) | 4. High discharge pressure 3rd stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 7. SV1611 setting 30 barg 8. SV1651 setting 32 barg | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | | 6. High 'HP CO pressure. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|--|--|----------|------------|-------------------|------------|--------------|
| | | 7. Low/no flow - Coldbox (T1603 : CO methane separation column) → FV16008, FI16008 fail close (see 11.2) | 5. High suction pressure at 4th stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 4. SV1610 setting 16 barg 5. SV1665 setting 16 barg 6. PAH16400 setting 13 barg (Suction stage#4) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 8. Misdirected flow - Coldbox (CO turbine) → HV16001 fail closed (see 13.4) | 6. High 'HP CO pressure. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 7. SV1611 setting 30 barg 8. SV1651 setting 32 barg 9. PAH16500 setting 27.5 barg (Discharge stage#4) 10. PSHH16500 setting 29 barg (Discharge stage#4) trip compressor | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 9. Misdirected flow - Coldbox (CO turbine) → HV16001 fail open (see 13.4) | 5. High suction pressure at 4th stage. Overpressure to downstream equipment and pipe rupture. Toxic gas release (<5000 kg in 5 mins) | 3. PIC16035 4. SV1610 setting 16 barg 5. SV1665 setting 16 barg 6. PAH16400 setting 13 barg (Suction stage#4) | LE3 | 3-Moderate | 1-Highly Unlikely | Acceptable | |
| | | 10. Low/no flow → 'CO2 adsorber, Soot filter blockage (see 14.2) | 3. Loss supply 'HP CO to coldbox causing cold upset | 1. PAH16510 setting 15 mbar 2. PAH16520 setting 160 mbar | 5 X 5 LG | Moderate | Remote | P4 | |
| 14.8 | Low pressure | 1. High flow - Coldbox (T1603 : CO methane separation column) → Methane pump discharge low pressure (see 11.1) | 1. Low/no flow - Coldbox (CO turbine) (see 13.2) | | | | | | |
| | | 2. Low pressure - Coldbox (T1603 : CO methane separation column) → Methane pump suction low pressure (see 11.8) | 2. Oxygen ingress due to vacuum condition. Blockage to Coldbox/ Possible forming explosive condition | 1. 'PAL16300A/B/C setting 0.85 barg 2. PSL16300A/B/C 2oo3D setting 0.8 barg trip compressor | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. High flow - Coldbox (CO turbine) → MP CO low pressure (see 13.1) | 3. MP CO Low pressure. Short supply customer | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. PV16020 fail open | 3. MP CO Low pressure. Short supply customer | 3. PAL16400 A/B/C setting 12.4 barg 4. PALL16400A/B/C 2oo3D setting 11 barg trip CO compressor | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------------------------|--|---|----------|----------|--------|----|--------------|
| | | | 4. Loss suction to stage#4 causing 'HP CO to T1603 loss (see 11.2) | | | | | | |
| | | | 5. Loss suction to stage#4 causing 'HP CO to Turbine (see 13.2) | | | | | | |
| | | 5. PT16020 reading high | 3. MP CO Low pressure. Short supply customer | 3. PAL16400 A/B/C setting 12.4 barg 4. PALL16400A/B/C 2oo3D setting 11 barg trip CO compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Loss suction to stage#4 causing 'HP CO to T1603 loss (see 11.2) | | | | | | |
| | | | 5. Loss suction to stage#4 causing 'HP CO to Turbine (see 13.2) | | | | | | |
| | | 6. PV16035 fail open | 3. MP CO Low pressure. Short supply customer | 3. PAL16400 A/B/C setting 12.4 barg 4. PALL16400A/B/C 2oo3D setting 11 barg trip CO compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Loss suction to stage#4 causing 'HP CO to T1603 loss (see 11.2) | | | | | | |
| | | | 5. Loss suction to stage#4 causing 'HP CO to Turbine (see 13.2) | | | | | | |
| | | 7. PT16035 reading high | 3. MP CO Low pressure. Short supply customer | 3. PAL16400 A/B/C setting 12.4 barg 4. PALL16400A/B/C 2oo3D setting 11 barg trip CO compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. Loss suction to stage#4 causing 'HP CO to T1603 loss (see 11.2) | | | | | | |
| | | | 5. Loss suction to stage#4 causing 'HP CO to Turbine (see 13.2) | | | | | | |
| 14.9 | High | 1. High concentration of | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|--------------------------------|---|---|--|----------|---------|--------|----|---|
| | concentration of contaminants | contaminants - Coldbox (T1603 : CO methane separation column) (see 11.11) | | | | | | | |
| 14.10 | Deviation during startup | 1. High moisture in system | 1. Coldbox blockage | 1. AAH16012 setting 0.7 ppm 2. AAHH16012 setting 1 ppm trip CO compressoe within 15 mins after starting | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 95. Update CO compressor start procedure for open gas line at lowest point to check for any water leak from cooling tube |
| | | 2. High oxygen in system | 2. Forming explosive condition in system | 3. Oxygen check % Oxygen < 1% 4. WI 16-0007 coldbox start up | 5 X 5 LG | Major | Remote | P3 | |
| 14.11 | Deviation during shutdown (NA) | | | | | | | | |
| 14.12 | Deviation during maintenance | 1. CO remains in system | 1. Toxic/ Flammable gas relaese | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Improper isolation | 2. People expose to toxic/ Flammable gas | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation 4. Portable detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Injury | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Pressurized system | 3. Injury | 1. PTW 2. JSA 3. Lockout/tagout procedure & Physical isolation | 5 X 5 LG | Serious | Remote | P3 | |
| 14.13 | Deviation during sampling | 1. Leakage during sampling | 1. Personnel exposure to Toxic/ Flammable gas | 1. Sampling point design gfor close loop 2. PPEs 3. I-HYCO-013 sampling | 5 X 5 LG | Serious | Remote | P3 | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---------------------|-------------------------------------|---|--|----------|----------|--------|----|--------------|
| | | | | bomb | | | | | |
| | | | 2. High pressure hazard | | 5 X 5 LG | Moderate | Remote | P4 | |
| 14.14 | Loss of containment | 1. Leakage from compressor sealling | 1. Small/large release of Toxic gas contained in enclosure area | 1. Fixed area monitor alarm at entrance 2. Yearly PM 3. Area ventilation | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Leakage from compressor pipeline | 1. Small/large release of Toxic gas contained in enclosure area | 2. Yearly PM 3. Area ventilation | 5 X 5 LG | Major | Remote | P3 | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|---------------------------------|
| Linde PLC | HYCO | MTP1 | Name: PSA plant (A1,2,3) |
| Design Intent: Adsorption step (A1,2,3) - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|--|---|---|----------|---------|--------|----|--------------|
| 15.1 | High flow | 1. High pressure - Regeneration gas + hydrogen fraction bypass (see 8.7) | 1. Product contaminate due to bed pressure drop (No safety issue) | 1. FAH18001 setting 750 kg/hr 2. PAH18001 setting 30 barg | | | | | |
| | | | 2. Bed fluidization causing adsorbent break and block filter at customer's metering | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Low pressure (see 15.8) | | | | | | | |
| 15.2 | Low/no flow | 1. PV18002.A fail close | 1. Loss hydrogen product supply | 1. PIC18002.B setting 29 barg | 5 X 5 LG | Minor | Remote | P4 | |
| | | 2. FV18001 fail close | 1. Loss hydrogen product supply | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. Low pressure (see 15.8) | | | | | | |
| | | 3. FI18001 error reading high | 1. Loss hydrogen product supply | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---------------------------------|---|----------|-------|--------|----|--------------|
| | | | 3. Low pressure (see 15.8) | | | | | | |
| | | 4. XV18011-51 fail close (Bed feed gas inlet) | 1. Loss hydrogen product supply | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. Low pressure (see 15.8) | | | | | | |
| | | 5. XV18012-52 fail close (Bed feed gas outlet) | 1. Loss hydrogen product supply | 2. Safety valve at bed setting 32 barg 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. Low pressure (see 15.8) | | | | | | |
| | | 6. PV18065A/B fail close (Pressurizing control valve) | | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| | | 7. PIC18065 error reading high | | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| | | 8. High flow - Regeneration gas + hydrogen fraction bypass (see 8.1) | | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|--|---|---|--------|-----------|-------------------|------------|--------------|
| | | | | 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| | | 9. Low/no flow - Regeneration gas + hydrogen fraction bypass (see 8.2) | | 3. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| 15.3 | Reverse flow (NA) | | | | | | | | |
| 15.4 | Misdirected flow | 1. Valve fail open at XV18013-53 in A1 step | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 15.7) | 1. PV18003 setting 2. 'PAH18003 setting 0.8 barg 3. SV1801 setting 3 barg (cap 738 kg/hr) 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Low pressure at adsorption bed causing trip with bed pressure low (No safety issue) (see 15.8) | | | | | | |
| | | 2. Valve fail open at XV18013-53 in A2 step | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 15.7) | 1. PV18003 setting 2. 'PAH18003 setting 0.8 barg 3. SV1801 setting 3 barg (cap 738 kg/hr) 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|--------|-----------|-------------------|------------|--------------|
| | | | 2. Low pressure at adsorption bed causing trip with bed pressure low (No safety issue) (see 15.8) | | | | | | |
| | | | 3. Product off spec (No safety issue) | | | | | | |
| | | 3. Valve fail open at XV18013-53 in A3 step | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 15.7) | 1. PV18003 setting 2. 'PAH18003 setting 0.8 barg 3. SV1801 setting 3 barg (cap 738 kg/hr) 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | | 2. Low pressure at adsorption bed causing trip with bed pressure low (No safety issue) (see 15.8) | | | | | | |
| | | | 3. Product off spec (No safety issue) | | | | | | |
| | | 4. Valve fail open at XV18015-55 in A1 step | 4. Process upset (No safety issue) | 4. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| | | 5. Valve fail open at XV18015-55 in A2 step (No consequence) | | | | | | | |
| | | 6. Valve fail open at XV18015-55 in A3 step (No consequence) | | | | | | | |
| | | 7. Valve fail open at XV18014-54 | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 15.7) | 1. PV18003 setting 2. 'PAH18003 setting 0.8 barg 3. SV1801 setting 3 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|----------------------|---|---|---|----------|-----------|-------------------|------------|--|
| | | | | (cap 738 kg/hr) 4. PALL (2003 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA 7. Valves proximity switch position feedback | | | | | |
| | | | 2. Low pressure at adsorption bed causing trip with bed pressure low (No safety issue) (see 15.8) | | | | | | |
| | | | 3. Product off spec (No safety issue) | | | | | | |
| | | | 5. Bed is fluidized at step P1, P5 causing adsorbent break | | 5 X 5 LG | Moderate | Remote | P4 | |
| 15.5 | High temperature | 1. High temperature - Regeneration gas + hydrogen fraction bypass (see 8.5) | 1. Adsorb efficiency drop causing product off spec (No safety issue) | 1. TAH18001 setting 45 c 2. TAHH18001 setting 50 c trip FN18001 (SIL1) | | | | | P3 CAR 77. To change TAHH18001 to voting 1oo2D from TI18001A,B |
| | | | 2. High moisture in purge gas (see 4.6) | | | | | | |
| | | | 3. Over design temperature PSA vessel (>50 c than MDT) causing rupture vessel | | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 15.6 | Low temperature (NA) | | | | | | | | |
| 15.7 | High pressure | 1. High pressure upstream | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 1. PV18002B open at 29 barg 2. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) 3. PAH18001 setting 30 barg | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. External fire | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 2. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|---|----------|---------|-------------------|------------|--------------|
| | | 3. PV18002.B fail close when required to open | 2. High pressure to pipeline and Vessel | 3. PAH18001 setting 30 barg 4. Safety valve at bed setting 32 barg | LE3 | 2-Minor | 1-Highly Unlikely | Acceptable | |
| | | 4. Misdirected flow (see 15.4) | | | | | | | |
| 15.8 | Low pressure | 1. PV18002.A fail open more | 2. Product contaminate due to bed pressure drop (No safety issue) | 1. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 2. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | | | | | |
| | | | 3. Bed fluidization causing adsorbent break and block filter at customer's metering | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. High flow (see 15.1) | | | | | | |
| | | 2. PV18002.B fail open more | 1. High flow - Regeneration gas + hydrogen fraction bypass (Product off spec) (see 8.1) | 1. 'PAL (2oo3 from PI18001 = 26 barg, PI18060=25 barg PI18002 = 25 barg) warning alarm 2. PALL (2oo3 from PI18001 = 23.5 barg, PI18060=23 barg PI18002 = 23 barg) trip PSA | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Product contaminate due to bed pressure drop (No safety issue) | | | | | | |
| | | | 3. Bed fluidization causing adsorbent break and block filter at customer's metering | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. High flow (see 15.1) | | | | | | |
| | | 3. Misdirected flow (see 15.4) | | | | | | | |
| | | 4. Low/no flow (see 15.2) | | | | | | | |
| | | 6. High flow - PSA plant (P1/PP1 and P5/PP5) (see 18.1) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---|---|--|----------|-------|------------|---------------|--------------|
| | | 7. High flow - PSA plant Node (E2/R2) (see 17.1) | | | | | | | |
| | | 8. Reverse flow - PSA plant Node (E2/R2) (see 17.3) | | | | | | | |
| | | 9. High flow - PSA plant Node (E1/R1) (see 16.1) | | | | | | | |
| | | 10. High flow - PSA plant (D) (see 19.1) | | | | | | | |
| | | 11. Reverse flow - PSA plant (R0/R01) (see 20.3) | | | | | | | |
| 15.9 | High concentration of contaminants | 1. Misdirected flow - Drier (TSA) (see 7.4) | 2. High concentration of contaminants - Fuel gas system → High CO (see 4.5) | 1. AASH18015 setting 1 ppm CO in hydrogen 2. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| | | | 3. Syngas mix with regeneration gas causing product off spec | | 5 X 5 LG | Minor | Improbable | Insignificant | |
| | | 2. Misdirected flow - Regeneration gas + hydrogen fraction bypass (see 8.4) | 2. High concentration of contaminants - Fuel gas system → High CO (see 4.5) | 1. AASH18015 setting 1 ppm CO in hydrogen 2. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| | | | 3. Syngas mix with regeneration gas causing product off spec | | 5 X 5 LG | Minor | Improbable | Insignificant | |
| | | 3. High temperature - Regeneration gas + hydrogen fraction bypass (see 8.5) | 1. High concentration of contaminants - Fuel gas system → High moisture (see 4.6) | 1. AASH18015 setting 1 ppm CO in hydrogen 2. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| | | | 4. High moisture in PSA purge gas causing product off spec (CO/CH4) | | | | | | |
| | | 4. High concentration of contaminants - Regeneration gas + hydrogen fraction bypass (see 8.9) | 1. High concentration of contaminants - Fuel gas system → High moisture (see 4.6) | | | | | | |
| | | | 4. High moisture in PSA purge gas causing product | | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---------------------------|--|--|---|----------|-----------|-------------------|------------|---|
| | | | off spec (CO/CH4) | | | | | | |
| | | 5. High level - Regeneration gas + hydrogen fraction bypass (see 8.13) | 1. High concentration of contaminants - Fuel gas system -> High moisture (see 4.6) | | | | | | |
| | | | 4. High moisture in PSA purge gas causing product off spec (CO/CH4) | | | | | | |
| 15.10 | Loss of containment | 1. Pressure vessel fatigue due to cyclic pressure condition (Design 788400 cycles) | 1. Small/large release causing fire and explosion | 1. Pressure vessel inspection included SAP PM 2. Gas detector (LEL) install at PSA skid 3. LLF 4. Plant patrol | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 2. Valve packing leakage | 1. Small/large release causing fire and explosion | 2. Gas detector (LEL) install at PSA skid 3. LLF 4. Plant patrol 5. Pressure test yearly (Every TAR) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 15.11 | Deviation during startup | 1. Oxygen remain in system | 1. Form explosive condition in system | 1. Start up procedure for PSA unit 5. PSSR | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. PSA feedgas contaminate to nitrogen system | 3. Flammable gas contaminated to nitrogen system. Fire and explosion case | 2. Check valve 3. Spectacle blind 4. Line up check before start up 5. PSSR | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Inert gas remaining in system | 2. Product off spec (High nitrogen) | 1. Start up procedure for PSA unit | | | | | P3 CAR 78. Revise start up procedure to include hydrogen product purity check with GC before supply to customer |
| 15.12 | Deviation during shutdown | 1. No nitrogen purge PSA bed during Shutdown | 1. Saturated adsorbent leading to adsorbent degradation | | 5 X 5 LG | Minor | Possible | P4 | |
| | | 2. No depressurize bed | 1. Saturated adsorbent | | 5 X 5 | Minor | Possible | P4 | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------|---|---|--|----------|----------|--------|----|--------------|
| | | during Shutdown | leading to adsorbent degradation | | LG | | | | |
| 15.13 | Deviation during maintenance | 1. Open system to atmosphere | 1. Injury to people due to high residual pressure | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 4. PPEs | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Toxic gas hazard | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Flammable gas hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 5. Adsorbent damage | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Nitrogen release during remove valve for maintenance | 4. Asphyxiation hazard | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 4. PPEs 5. Personal gas detector | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Confined space work (inspection) | 2. Toxic gas hazard | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 4. PPEs 5. Personal gas detector | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Flammable gas hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Asphyxiation hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Confined space work (Loading/ Unloading adsorbent) | 2. Toxic gas hazard | 1. PTW 2. JSA 3. WI for TSA physical isolation WI 15-0003 4. PPEs | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|---------------------------|--|------------------------------|---|----------|----------|--------|----|--------------|
| | | | | 5. Personal gas detector | | | | | |
| | | | 3. Flammable gas hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Asphyxiation hazard | | 5 X 5 LG | Major | Remote | P3 | |
| 15.14 | Deviation during sampling | 1. Gas leakage from sample valve/ Flexible hose connection | 1. People exposure Toxic gas | 1. Sampling station is design for closed loop (No vent out) 2. Portable gas detector is used 3. Flexible hose is zero leak type 4. Bomb sampling WI I-HYCO-013 | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Flammable gas release | | 5 X 5 LG | Moderate | Remote | P4 | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|-------------------------------------|
| Linde PLC | HYCO | MTP1 | Name: PSA plant Node (E1/R1) |
| Design Intent: Adsorption step (E1,R1) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattananvit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|---|--|----------|-----------|-------------------|------------|---|
| 16.1 | High flow | 1. XV18011-51 failed open (E1,R1) | 1. High contaminate in other bed causing product off spec (see 16.7) | 1. FAH18001 setting 750 kg/hr 2. AASH18015 setting 1 ppm CO in hydrogen 3. AASH18016 setting 10 ppm CH4 in hydrogen 4. PT180X0 - Pressure diviation end step trip bed 8. Able to offline to stroke valve check for 1 bed | 5 X 5 LG | Minor | Remote | P4 | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Bed fluidization causng adsorbent damage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | 2. XV18014-54 failed open | 3. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 16.5) | 5. PAH18003 setting 0.8 barg 6. PIC18003 high pressure vent 7. SV1801 setting 3 bar (Support full flow) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| | | 3. XV18012-52 failed open (No safety consequence) | | 3. AASH18016 setting 10 ppm CH4 in hydrogen 4. PT180X0 - Pressure diviation end step trip bed | | | | | |
| | | 4. XV18013-53 failed open | 1. High contaminate in other bed causing product off spec (see 16.7) | 3. AASH18016 setting 10 ppm CH4 in hydrogen 4. PT180X0 - Pressure | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|--|---|--|--------|------------|--------------------|------------|---|
| | | | | diviation end step trip bed 5. PAH18003 setting 0.8 barg 6. PIC18003 high pressure vent 7. SV1801 setting 3 bar (Support full flow) | | | | | |
| | | | 3. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 16.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 16.2 | Low/no flow | 1. XV18035-XV18055 failed close when require to open | 1. PSA Step interruption (No safety issue) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | 2. XV18035-XV18055 failed close when require to open | 1. PSA Step interruption (No safety issue) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| 16.3 | Reverse flow (NA) | | | | | | | | |
| 16.4 | Misdirected flow | 1. See high flow case XV18041-45 failed open | | | | | | | |
| 16.5 | High pressure | 1. High flow (see 16.1) | | | | | | | |
| | | 2. High pressure upstream | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 1. PV18002B open at 29 barg 2. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) 3. PAH18001 setting 30 barg | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | 3. External fire | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 2. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | 4. Low pressure (see 16.6) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--|--|--|--------|---|----|----|--------------|
| 16.6 | Low pressure | 1. XV18014-54 failed open | 1. High pressure → High pressure at D1832 (see 16.5) | 1. PV18002B open at 29 barg 2. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) 3. PAH18001 setting 30 barg | | | | | |
| 16.7 | High concentration of contaminants | 1. High flow → High contaminate in other bed causing product off spec (see 16.1) | | | | | | | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|-------------------------------------|
| Linde PLC | HYCO | MTP1 | Name: PSA plant Node (E2/R2) |
| Design Intent: Adsorption step (E2,R2) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm³/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH₄ and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amorphous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|---|--|----------|------------|--------------------|------------|---|
| 17.1 | High flow | 1. XV18011-51 failed open when close (E2 step) | 1. Bed fluidized causing adsorbent damage | 1. PT180X0 - Pressure deviation end step and Valve position feedback alarm → trip bed 2. FAH18001 setting 750 kg/hr | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| 17.2 | Low/no flow | 1. XV18013-XV18053 failed close when require to open (E2,R2 step) | 1. Step interruption (No safety issue) | 1. PT180X0 - Pressure deviation end step and Valve position feedback alarm → trip bed | | | | | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| 17.3 | Reverse flow | 1. XV18011-51 failed open when close (R2 step) | 1. Bed fluidized causing adsorbent damage | 1. PT180X0 - Pressure deviation end step and Valve position feedback alarm → trip bed 2. FAH18001 setting 750 kg/hr | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| 17.4 | Misdirected flow | 1. XV18014-54 failed open when requires to close (E2) | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 17.5) | 1. PT180X0 Pressure deviation end step trip bed and valve position feedback command to trip Bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|---|---|---|----------|------------|--------------------|------------|---|
| | | | | vent 4. SV1801 setting 3 bar (Support full flow) | | | | | |
| | | 2. XV18014-54 failed open when requires to close (R2) | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 17.5) | 1. PT180X0 Pressure diviation end step trip bed and valve position feedback command to trip Bed | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Bed fluidized (Lifted) at E2 step causing adsorbent damage | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. XV18015-55 fail open when requires to close (E2) | 3. E2, R2 pressure deviation causing product impurity high, pressure fluctuation | 1. PT180X0 Pressure diviation end step trip bed and valve position feedback command to trip Bed 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |
| | | 4. XV18015-55 fail open when requires to close (R2) | 3. E2, R2 pressure deviation causing product impurity high, pressure fluctuation | 1. PT180X0 Pressure diviation end step trip bed and valve position feedback command to trip Bed 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |
| 17.5 | High pressure | 1. Misdirected flow (see 17.4) | | | | | | | |
| | | 2. Low pressure (see 17.6) | | | | | | | |
| | | 3. External fire | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 1. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 17.6 | Low pressure | 1. XV18014-54 fail open at E2 step. Pressurized gas in E2 release to purge gas drum | 1. Pressurized gas in E2 release to purge gas drum causing too fast regeneration (No impact) | | | | | | |
| | | | 2. High pressure → High pressure to D1832 | | | | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------|-------------------------|------------|--------|---|----|----|--------------|
| | | | (Downstream) (see 17.5) | | | | | | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: PSA plant (P1/PP1 and P5/PP5) |
| Design Intent: Adsorption step (P1/PP1 and P5/PP5) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|--|----------|---------|--------|----|--------------|
| 18.1 | High flow | 1. PV18003 fail open more (P1/PP1) | 1. Low pressure to PP1 step (No impact), D1832 (see 18.6) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | | 2. Low/no flow - Fuel gas system (see 4.2) | | | | | | |
| | | 2. PT18003 error reading high (P1/PP1) | 1. Low pressure to PP1 step (No impact), D1832 (see 18.6) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | | 2. Low/no flow - Fuel gas system (see 4.2) | | | | | | |
| | | 3. XV18011-51 failed open (PP1) | 3. Bed fluidization due to high flowrate from feedgas at 30 barg pass thorough | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Impurity in feedgas contaminate to another bed | | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---------------------------------|---|---|----------|------------|--------------------|------------|--------------|
| | | | 5. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 18.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 7. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | 4. XV18011-51 failed open (PP5) | 3. Bed fluidization due to high flowrate from feedgas at 30 barg pass thorough | 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Impurity in feedgas contaminate to another bed | | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 7. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | 5. XV18011-51 failed open (P1) | 4. Impurity in feedgas contaminate to another bed | 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | 5. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 18.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 6. Reverse flow → Reverse flow to PP1,5 and P1,5 beds (see 18.3) | | | | | | |
| | | | 7. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | 6. XV18011-51 failed open (P5) | 4. Impurity in feedgas contaminate to another bed | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 5. AASH18015 setting 1 ppm | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|--|---|--|----------|-------|--------|----|--------------|
| | | | | CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| | | | 6. Reverse flow → Reverse flow to PP1,5 and P1,5 beds (see 18.3) | | | | | | |
| | | | 7. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| 18.2 | Low/no flow | 1. XV18014-54 failed close (Step P1) | 1. Short supply fuel to reformer (see 4.2) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | | 2. Incompleted regeneration at bed P1 causng product contamination | | 5 X 5 LG | Minor | Remote | P4 | |
| | | 2. XV18013-53 failed close (Step P1, PP1) | 1. Short supply fuel to reformer (see 4.2) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | | 2. Incompleted regeneration at bed P1 causng product contamination | | 5 X 5 LG | Minor | Remote | P4 | |
| | | 3. XV18013-53 failed close (Step P5, PP5) | 1. Short supply fuel to reformer (see 4.2) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | | 3. Incompleted regeneration at bed PP5 causng product contamination | | 5 X 5 LG | Minor | Remote | P4 | |
| 18.3 | Reverse flow | 1. High flow (see 18.1) | | | | | | | |
| | | 2. XV18015-55 failed open (P1,P5). Hydrogen product 28 barg reverse to another bed (PP1,PP5) | 1. Incompleted regneration (PP1,PP5), Product off spec | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. AASH18015 setting 1 ppm CO in hydrogen 3. AASH18016 setting 10 ppm CH4 in hydrogen 4. PAH18003 setting 0.8 barg 5. PIC18003 high pressure | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|---|---|---|--------|---------------|--------------------------|------------|--------------|
| | | | | vent 6. SV1801 setting 3 bar (Support full flow) | | | | | |
| | | | 2. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 18.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 18.4 | Misdirected flow | 1. XV18014-54 failed open (PP1,PP5) | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 18.5) | 1. PAH18003 setting 0.8 barg 2. PIC18003 high pressure vent 3. SV1801 setting 3 bar (Support full flow) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 18.5 | High pressure | 1. Reverse flow (see 18.3) | | | | | | | |
| | | 2. High flow (see 18.1) | | | | | | | |
| | | 3. Misdirected flow (see 18.4) | | | | | | | |
| | | 4. External fire | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 1. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 18.6 | Low pressure | 1. High flow → PV18003 fail open, PT18003 error reading high (see 18.1) | | | | | | | |

BUSINESS CONFIDENTIAL

| | | | |
|---|------|------|----------------------------|
| Linde PLC | HYCO | MTP1 | Name: PSA plant (D) |
| Design Intent: Adsorption step (D) - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|-------|--------|----|---|
| 19.1 | High flow | 1. PV18003 fail open more | 1. Low pressure to D step (No impact) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Low/no flow - Fuel gas system (see 4.2) | | | | | | |
| | | 2. PT18003 error reading high | 1. Low pressure to D step (No impact) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | P3 CAR 79. Add standard operating procedure of PSA operation in case there is any bed valve alarm. operator to 1. Isolate bed, 2. Depressurized 3. Test valve |
| | | | 2. Low/no flow - Fuel gas system (see 4.2) | | | | | | |
| | | 3. XV18051-55 failed open (D) , hydrogen product pass thorough bed D | 3. Incompleted regeneration (D) causing product contamination | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 | 5 X 5 LG | Minor | Remote | P4 | |
| | | | | | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|------------|--------------------|------------|--------------|
| | | | | ppm CH4 in hydrogen | | | | | |
| | | | 4. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 19.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 5. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | | 6. Misdirected flow (see 19.4) | | | | | | |
| | | 4. XV18012-52 failed open (D) , hydrogen product pass thorough bed D | 3. Incompleted regeneration (D) causing product contamination | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 4. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 19.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 5. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | | 6. Misdirected flow (see 19.4) | | | | | | |
| | | 5. XV18013-53 failed open (D) , pressurized gas from Bed E2 pass through bed D | 3. Incompleted regeneration (D) causing product contamination | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|--|---|--|----------|------------|--------------------|------------|--------------|
| | | | | 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| | | | 4. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 19.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 6. Misdirected flow (see 19.4) | | | | | | |
| | | 6. XV18011-51 failed open (D) , Feedgas enter bed D as well as pass to D1832 | 3. Incompleted regeneration (D) causing product contamination | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) 5. AASH18015 setting 1 ppm CO in hydrogen 6. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 4. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 19.5) | | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 5. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| | | | 6. Misdirected flow (see 19.4) | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| 19.2 | Low/no flow | 1. XV18014-54 failed close (D) | 2. Low/no flow - Fuel gas system (see 4.2) | 1. AASH18015 setting 1 ppm CO in hydrogen 2. AASH18016 setting 10 ppm CH4 in hydrogen | | | | | |
| 19.3 | Reverse flow (NA) | | | | | | | | |
| 19.4 | Misdirected flow | 1. High flow → XV18011-51 failed open (D) (see 19.1) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|-------------------------|--|--|--------|------------|--------------------|------------|--------------|
| 19.5 | High pressure | 1. High flow (see 19.1) | | | | | | | |
| | | 2. External fire | 1. Vessel rupture at bed which is under adsorption step causing major Fire and explosion | 1. Safety valves at Bed setting 32 barg (design for external fire case cap 3029 kg/hr) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| 19.6 | Low pressure (NA) | | | | | | | | |

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| | | | |
|---|------|------|---------------------------------|
| Linde PLC | HYCO | MTP1 | Name: PSA plant (R0/R01) |
| Design Intent: Adsorption step (R0/R01) <ul style="list-style-type: none"> - Bed pressure=30 barg, temperature = 32 C Flowrate =4600 Nm3/hr - Hydrogen regeneration from TSA will enter PSA bed for purify to remove CO, CH4 and Moisture in hydrogen - Adsorbents are consisted with <ul style="list-style-type: none"> - Amopheous Alumina oxide - Activated carbon - Aluminosilicate | | | |
| P&ID: 18PFP03, 18PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Tidarat Pattanothai (HAZOP member), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|--|----------|------------|--------------------|------------|--------------|
| 20.1 | High flow | 1. XV18014-54 failed open | 1. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 20.5) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent 4. SV1801 setting 3 bar (Support full flow) | LE3 | 4- Serious | 1- Highly Unlikely | Acceptable | |
| | | | 2. Low pressure → consider at Bed R0/R01 (see 20.6) | | | | | | |
| 20.2 | Low/no flow | 1. XV18065A/B fail close | 1. PSA step interruption (No safety issue) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | 2. XV18015-55 failed close | 1. PSA step interruption (No safety issue) | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed | | | | | |
| 20.3 | Reverse flow | 1. XV18011-51 failed open. Feedgas reverse through bed R1/R01 | 1. Product contamination | 1. PT180X0 - Pressure diviation end step and Valve position feedback alarm → trip bed 2. AASH18015 setting 1 ppm CO in hydrogen 3. AASH18016 setting 10 ppm CH4 in hydrogen | 5 X 5 LG | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|-----------------------------|--|---|--------|---|----|----|--------------|
| | | | 2. Low pressure - PSA plant (A1,2,3) (see 15.8) | | | | | | |
| 20.4 | Misdirected flow | 1. XV18012-52 failed open | 1. Too fast presurization to bed R0/ R01 (No impact) | | | | | | |
| | | 2. XV18013-53 failed open | 1. Too fast presurization to bed R0/ R01 (No impact) | | | | | | |
| 20.5 | High pressure | 1. High flow (see 20.1) | | | | | | | |
| 20.6 | Low pressure | 1. XV18065A/B failed closed | 1. Pressurize step doesn't meet causing bed is ready for adsorption step (No safety issue) | 1. PT180X0 - Pressure deviation end step and Valve position feedback alarm → trip bed | | | | | |
| | | 2. High flow (see 20.1) | | | | | | | |

BUSINESS CONFIDENTIAL

| | | | |
|---|------|------|-------------------------------|
| Linde PLC | HYCO | MTP1 | Name: Warm, Cold Flare |
| Design Intent: Cold flare <ul style="list-style-type: none"> - All liquid drain valves from coldbox, Heat exchanger - Safety valves from coldbox section - Pressure control valves from coldbox section All pipelines connects with header and D9131 for liquid knockout. MDT -196 C , MAWP 4 barg. Warm flare <ul style="list-style-type: none"> - All vent valves from process connect to header and pass thorough stand pipe from trapping condensate. Design temp 250 c MAWP 4 barg NG fuel for pilot <ul style="list-style-type: none"> - Receiving 5 barg NG from NG metering PCV1311 and regulates pressure to 1.5 barg by PV90004 Note : Flare design for flow condition that PV16004, PV 16035, PV18002, PV18003 can relief simultaneously at heat release 1.26e8 KJ/hr flow 9,508.8 Nm3/hr which is less than SV16006 capacity. so, flare design can refer to SV1606 capacity at 10,821 Nm3/hr heat release 1.32e8 KJ/ hr. | | | |
| P&ID: 90PFP01, 90PFP02, 91PFP01, OSBL P&ID: H0202-T-D-115-01, 16002312-T-D-101-03 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|--|--|----------|---------|--------|----|--------------|
| 21.1 | High flow | 1. Incoming gas over design of flare system | 1. Emission to environment | 1. Flame detector at flare vent with alarm warning 2. Fix gas detectors at process area with alarm warning 4. Vent/ drain valve which required frequently operated is design as self close (Dead man valve) 5. Flare design for flow control valves open at same time or maximum flow of safety valve lift which cover all possible cause in this HAZOP | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Incoming liquid over design of flare system | 1. Emission to environment | 2. Fix gas detectors at process area with alarm warning 3. LAH91001 warning alarm 4. Vent/ drain valve which required frequently operated is design as self close (Dead man valve) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Cold embrittlement to warm flare section causing major Toxic and flammable gas release (see 21.6) | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. High level (see 21.9) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|--|--|----------|---------|--------|----|---|
| | | 3. High pressure from upstream (see 21.7) | 1. Emission to environment | 1. Flame detector at flare vent with alarm warning 2. Fix gas detectors at process area with alarm warning 3. LAH91001 warning alarm 4. Vent/ drain valve which required frequently operated is design as self close (Dead man valve) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Cold embrittlement to warm flare section causing major Toxic and flammable gas release (see 21.6) | | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Nitrogen purge more open | 3. High nitrogen consumption (no safety issue) | | | | | | |
| 21.2 | Low/no flow | 1. No/low NG flow to pilot | 1. No pilot and toxic gases release to atmosphere | 1. 'FAL90002 setting 2 Nm3/hr 2. TAL90001A/B/C setting 250 c 4. PIC90004 | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Low pressure (see 21.8) | | | | | | |
| | | 2. No nitrogen purge | 2. Oxygen ingress and ignition in header causing pipe rupture and explosion | 3. FAL90001 setting 25 NM3/hr FIS90001 located at NG flare header (warm flare) 5. FAL91002 setting 3 Nm3/hr (cold flare) | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Reverse flow (see 21.3) | | | | | | |
| 21.3 | Reverse flow | 1. Low/no flow → No nitrogen purge (see 21.2) | | | | | | | |
| 21.4 | Misdirected flow | 1. Flare stack bottom drain XAH001 passing leak | 1. Oxygen ingress to flare header (system is vacuum) | 1. Valve is self close (Dead man valve) | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 97. To create PM inspection for check leak of 2 XAH001 (Dead man valve) at every 5 years |
| 21.5 | High temperature | 1. Deviation during startup → Oxygen remain in system (see 21.13) | 1. Over design temperature of CS material of warm flare line causing major gas leakage | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. High temperature upstream manual vent valve of prereformer at 540 c | 1. Over design temperature of CS material of warm flare line causing major gas leakage | 1. Upgrade material specification at upstream of warm flare line connection without insulation from pre- | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------------|--|---|--|----------|---------|--------|----|--------------|
| | | | | repfrmer to let gas cooldown to proper temperature | | | | | |
| | | 3. High temperature at SV1103 from outlet prereformer at 540 c | 1. Over design tempeature of CS material of warm flare line causing major gas leakage | 1. Upgrade material specification at upstream of warm flare line connection without insulation from pre-repfrmer to let gas cooldown to proper temperature | 5 X 5 LG | Major | Remote | P3 | |
| 21.6 | Low temperature | 1. High flow (see 21.1) | | | | | | | |
| 21.7 | High pressure | 1. NG supply to pilot PCV1311 fail open | 1. High flow (see 21.1) | 1. SV1311 setting 17 barg | | | | | |
| | | | 2. Over pressure NG pipe causing rupture laiding fire & explosion | | 5 X 5 LG | Major | Remote | P3 | |
| 21.8 | Low pressure | 1. Low/no flow (see 21.2) | | | | | | | |
| 21.9 | High level | 1. High level condensate at stand pipe | 1. Condensate carry over causing higher pressure in flare header create back pressure to process's PSVs | 1. LAH9001 warning alarm setting 50 cm 2. Plant patrol by operator to dain out condasate if high level is observed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. High level condasate in flare stack | 1. Condensate carry over causing higher pressure in flare header create back pressure to process's PSVs | 2. Plant patrol by operator to dain out condasate if high level is observed 3. LAH9001 warning alarm setting 50 cm 4. LAH9003 with warning alarm setting 80 cm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. High level liquid knock out drum D9131 | 1. Condensate carry over causing higher pressure in flare header create back pressure to process's PSVs | 2. Plant patrol by operator to dain out condasate if high level is observed 3. LAH9001 warning alarm setting 50 cm 4. LAH9003 with warning alarm setting 80 cm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. High flow (see 21.1) | 1. Condensate carry over causing higher pressure in flare header create back pressure to process's PSVs | 2. Plant patrol by operator to dain out condasate if high level is observed 3. LAH9001 warning alarm | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|---|---|----------|---------|--------|----|--------------|
| | | | | setting 50 cm 4. LAH9003 with warning alarm setting 80 cm | | | | | |
| 21.10 | Low/No level | 1. No safety issue | | | | | | | |
| 21.11 | High concentration of contaminants | 1. High contamination in NG feed to pilot | 1. Pilot flame extinguished. Toxic/ flammable gas release at atmosphere | 1. TAL90001A/B/C setting 250 c | 5 X 5 LG | Serious | Remote | P3 | |
| 21.12 | Loss of containment (NA) | | | | | | | | |
| 21.13 | Deviation during startup | 1. Oxygen remain in system | 1. Ignition in flare header causing over temperature to header. Pipe rupture and flammable/ toxic as release (see 21.5) | 1. Start up procedure mentions purging <1% Oxygen must be done before start up | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Pilot is not on | 2. Toxic/ flammable gas release | 2. Flame detection TAL90001A/B/C setting 250 c 3. NG pilot flare PAL90002 setting 1 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. No nitrogen purge | 1. Ignition in flare header causing over temperature to header. Pipe rupture and flammable/ toxic as release (see 21.5) | 4. FAL90001 setting 25 NM3/hr FIS90001 located at NG flare header (warm flare) 5. FAL91002 setting 3 Nm3/hr (cold flare) 6. WI I-HYCO-032 start and shutdown flare system | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Remaining condensate in stand pipe | 3. Back pressure to process relief valve causing set point higher | 6. WI I-HYCO-032 start and shutdown flare system 7. LAH90001 setting 50 cm | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Remaining water in flare stack | 3. Back pressure to process relief valve causing set point higher | 6. WI I-HYCO-032 start and shutdown flare system 8. LAH9003 setting 80 cm | 5 X 5 LG | Serious | Remote | P3 | |
| 21.14 | Deviation during shutdown | 1. See deviation during maintenance | | | | | | | |
| 21.15 | Deviation during maintenance | 1. Toxic / flammable gas remaining in fire stack due to nitrogen not properly purge | 1. Personnel expose to toxic and flammable gas | 1. Shutdown procedure WI 11-0012 2. PTW | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-----------------------------------|--|---|----------|-------|--------|----|--------------|
| | | | 2. Fire and explosion during hot work | | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Oxygen depletion create asphyxiace hazard | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Nitrogen purge is not isolated | 3. Oxygen depletion create asphyxiace hazard | 1. Shutdown procedure WI 11-0012 2. PTW 3. Lockout/tagout procedure | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. NG remain in pilot line | 2. Fire and explosion during hot work | 1. Shutdown procedure WI 11-0012 | 5 X 5 LG | Major | Remote | P3 | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|-----------------------------|
| Linde PLC | HYCO | MTP1 | Name: Package boiler |
| Design Intent: NG fuel - NG metering supply 21 barg pass through valve PCV1301A/B to reduce pressure to 3 barg and let down pressure to 90 mbar by PCVxxx Diesel fuel - T1203 cap 15000 L. Diesel pump supply 3 barg diesel to burner. - PSV202 recirculate fuel back to tank at pressure xxx barg Dearator - Demineral from demineral unit. Max flow rate 4.5 M3/hr pressure 5 barg - Checmical treatment unit contains ;NH3OH and Eliminox Boiler - Operating pressure 41.5 bar, temp 250 c - Design presure 45 barg, flowrate 4 ton/hr temp 258 c - Water tube type | | | |
| OSBL P&ID: H0202-T-D-115-01, 030109-087 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---|--|---|----------|----------|--------|----|--------------|
| 22.1 | High flow | 1. Upstream high pressure (Demin water) | 1. Packing in dearator flooding. Oxygen residual in BFW (see 22.9) | 1. LCSH900106 to close ECV900104 4. Yearly PM inspection and recertify | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Water hammer in dearator | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 6. Overflowed hot water could expose to personnel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Dearator level control valve ECV900104 fail open | 1. Packing in dearator flooding. Oxygen residual in BFW (see 22.9) | 2. LCSH900106 warning alarm 4. Yearly PM inspection and recertify | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Water hammer in dearator | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 6. Overflowed hot water could expose to personnel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Dearator LT900106 error reading low | 1. Packing in dearator flooding. Oxygen residual in BFW (see 22.9) | 3. LI0106 dearator level monitor by operator every shift 4. Yearly PM inspection and recertify | 5 X 5 LG | Serious | Remote | P3 | |
| | | | | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|---|--|--|----------|----------|--------|----|--------------|
| | | | 2. Water hammer in dearator | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 6. Overflowed hot water could expose to personnel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Steam drum level control valve 'LCV900105 fail open | 3. High level in steam drum causing water entrains into steam lead to water hammer damage to pipeline. Steam leakage causing injury to people (see 22.9) | 5. LAH900104 local warning alarm 6. LASH900101 trip boiler package and warning alarm to CCR | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Steam drum level transmitter 'LT900104 error reading low | 3. High level in steam drum causing water entrains into steam lead to water hammer damage to pipeline. Steam leakage causing injury to people (see 22.9) | 6. LASH900101 trip boiler package and warning alarm to CCR | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. High pressure from upstream (NG fuel) (see 22.7) | 4. Incompleted combustion creates pollution | 7. PSH0116 trip burner 8. Flame detector in burner 9. PSV1302 setting 4 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 5. NG fuel Pipeline rupture | | 5 X 5 LG | Major | Remote | P3 | |
| 22.2 | Low/no flow | 1. Dearator level control ECV900104 fail closed | 1. Loss supply water to steam drum. Steam drum low level and overheat could lead to explosion (see 22.10) | 1. LSLL900102 trip burner 2. LSLL900103 trip burner 3. LC900106 low level alarm at local panel 4. LI0106 dearator level monitor by operator every shift | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Dearator level indicator LT900106 error reading high | 1. Loss supply water to steam drum. Steam drum low level and overheat could lead to explosion (see 22.10) | 1. LSLL900102 trip burner 2. LSLL900103 trip burner 3. LC900106 low level alarm at local panel 4. LI0106 dearator level monitor by operator every shift | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Steam drum level control valve 'LCV900105 fail close | 1. Loss supply water to steam drum. Steam drum low level and overheat could lead to explosion (see 22.10) | 1. LSLL900102 trip burner 2. LSLL900103 trip burner 3. LC900106 low level alarm | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|--|----------|----------|--------|----|---|
| | | | | at local panel 5. LI0105,7 dearator level monitor by operator every shift | | | | | |
| | | 4. Steam drum level transmitter 'LT900104 error reading high | 1. Loss supply water to steam drum. Steam drum low level and overheat could lead to explosion (see 22.10) | 1. LSLL900102 trip burner 2. LSLL900103 trip burner 3. LC900106 low level alarm at local panel 5. LI0105,7 dearator level monitor by operator every shift | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Loss of demin water supply | 1. Loss supply water to steam drum. Steam drum low level and overheat could lead to explosion (see 22.10) | 1. LSLL900102 trip burner 2. LSLL900103 trip burner 3. LC900106 low level alarm at local panel 4. LI0106 dearator level monitor by operator every shift 6. LALL900106 trip P901201A/B 7. Standby pump | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. P901201A/B loss suction causing damage | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. Low pressure → No NG supply (see 22.8) | 3. No fuel to burner. No steam supply (No safety issue) | | | | | | |
| | | 7. Diesel fuel pump P901202A/B trip | 3. No fuel to burner. No steam supply (No safety issue) | 7. Standby pump 8. Flame detector in burner | | | | | |
| | | 8. Diesel recirculation valve PSV1202 fail open | 3. No fuel to burner. No steam supply (No safety issue) | 8. Flame detector in burner | | | | | P3 CAR 100. To create PM schedule to ensure PSV1202 (Diesel recirculation pressure control) is properly function together with yearly Recertify |
| | | 9. Diesel pump suction strainer N1255, 57 plugged | 3. No fuel to burner. No steam supply (No safety issue) | 7. Standby pump 8. Flame detector in burner | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|--|---|----------|---------|--------|----|--|
| | | 10. Low pressure → No 'LP steam supply to dearator (see 22.8) | 4. Oxygen remains in dearator create corrosion (see 22.11) | 9. Temperature indication at dearator logged by operator every shift 10. PI0116 at dearator logged by operator every shift | 5 X 5 LG | Serious | Remote | P3 | |
| | | 11. V1273 is left close | 4. Oxygen remains in dearator create corrosion (see 22.11) | 9. Temperature indication at dearator logged by operator every shift 10. PI0116 at dearator logged by operator every shift | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 5. High pressure (see 22.7) | | | | | | |
| 22.3 | Reverse flow | 1. Reverse from process steam during package boiler not in operation | 1. Main steam pressure drop (No safety issue) | 1. Check valve N1221 | | | | | |
| | | 2. Misoperation during using steam to E852 carbon dioxide vaporizer | 1. Main steam pressure drop (No safety issue) | 2. WI I-HYCO-040 service E852 'CO2 vaporizer | | | | | P3 CAR 101. To revise WI-I-HYCO-040 to include isolation of steam from process reverse to package boiler |
| | | | 2. Steam reverse to package boiler (No safety issue) | | | | | | |
| 22.4 | Misdirected flow | 1. V1208 is left open during normal operation | 1. Reverse flow - Stream drum + steam system + Steam back up from package boiler (No safety issue) (see 3.5) | 1. Checklist that specifies valve alignment 2. Startup testing | | | | | |
| 22.5 | High temperature | 1. High pressure → High 'LP steam supply to dearator (see 22.7) | | | | | | | |
| 22.6 | Low temperature | 1. No safety issue | | | | | | | |
| 22.7 | High pressure | 1. AI0112 error reading low causing NG over feed | 5. Over steam production leading to over pressure and explosion to steam drum | 6. PSV1203, 04 setting 45 barg 7. PSHH900114 trip burner 8. PSHH900115 trip burner | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. NG fuel PCV1301A/B fail open | 2. High flow (see 22.1) | | | | | | |
| | | 3. NG supply PCVxxx at burner fail open | 2. High flow (see 22.1) | | | | | | P3 CAR 119. To correct tag number of NG supply |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|--|---|----------|---------|------------|----|--|
| | | | | | | | | | pressure regulator at burner. Currently P&ID is mentioned "FI901202" which is not correct and duplicated tag number |
| | | 4. Low pressure steam to dearator PCV1205 fail open | 3. High temperature → High 'LP steam supply to dearator (see 22.5) | 2. V1273 vent to atmosphere 3. PSV1206 setting 1.5 barg 4. Dearator pressure safety loop 5. PSV1205 setting 10.5 barg | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 4. Over design pressure to dearator vessel | | 5 X 5 LG | Serious | Improbable | P4 | |
| | | 5. Low pressure steam to dearator PCV1206 fail open | 3. High temperature → High 'LP steam supply to dearator (see 22.5) | 2. V1273 vent to atmosphere 3. PSV1206 setting 1.5 barg 4. Dearator pressure safety loop 5. PSV1205 setting 10.5 barg | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 4. Over design pressure to dearator vessel | | 5 X 5 LG | Serious | Improbable | P4 | |
| | | 6. Low/no flow → V1273 is left closed (see 22.2) | 4. Over design pressure to dearator vessel | 1. Pressure indication 3. PSV1206 setting 1.5 barg 4. Dearator pressure safety loop | 5 X 5 LG | Serious | Improbable | P4 | |
| 22.8 | Low pressure | 1. High steam consumption | 1. BFW carries over with steam causing water hammer in pipeline. Leakage steam causingf injury | 1. PI0113 at package boiler is logged by operator every shift 2. PAL901201 warning alarm 3. PC0112 at at package boiler local panel is logged by operator every shift | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. PCV1301A/B failed closed | 2. No NG fuel supply (see 22.2) | | | | | | |
| | | 3. NG supply PCVxxx at burner fail closed | 2. No NG fuel supply (see 22.2) | | | | | | P3 CAR 119. To correct tag number of NG supply pressure regulator at burner. Currently P&ID is mentioned "FI901202" which is not correct and duplicated tag number |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|--|---|---|----------|---------|--------|----|---|
| | | 4. Low pressure steam to dearator PCV1205 fail close | 3. No 'LP steam to dearator (see 22.2) | | | | | | |
| | | 5. Low pressure steam to dearator PCV1206 fail close | 3. No 'LP steam to dearator (see 22.2) | | | | | | |
| 22.9 | High level | 1. High flow → Dearator level control failure (see 22.1) 2. High flow → Steam drum level control failure (see 22.1) | | | | | | | |
| 22.10 | No/Low level | 1. Low/no flow → Dearator level control failure (see 22.2) | | | | | | | |
| 22.11 | High concentration of contaminants | 1. High contamination of demin water | 1. Scaling in boiler tube causing hot tube lead to tube crack | 1. Demineral quality control by service provider (NALCO) 2. pH, conductivity check every day by HYCO operator | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. High dozing of chemical due to pump is not automatically stop | 2. Stress corrosion crack in boiler when pH > 11 | 2. pH, conductivity check every day by HYCO operator 3. Dearator BFW regular checked by NALCO 2 times/week | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Low/no flow → High oxygen in dearator (see 22.2) | | | | | | | |
| 22.12 | Deviation combustion | 1. Incompleted combustion due to wrong setting ratio of air to fuel | 1. NOx, SOx emission to atmosphere | 1. Flame detector in burner 2. PM yearly for tuning ratio 3. 3rd party measurring flue stack every 6 months to comply with regulatory requirement | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Lower efficiency of boiler (No safety issue) | | | | | | |
| | | | 3. Afterburn in boiler chamber creates fire and explosion | | 5 X 5 LG | | | | |
| | | 2. Servomotor controller malfunction | 1. NOx, SOx emission to atmosphere | 1. Flame detector in burner 4. PM servomotor every TA | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 102. To add TAL900105 setting 100 c below normal operating temperature and active with burner running signal |
| | | | 2. Lower efficiency of boiler (No safety issue) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|--------------------------|---|---|--|----------|----------|--------|----|--|
| | | | 3. Afterburn in boiler chamber creates fire and explosion | | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Sequence controller malfunction | 1. NOx, SOx emission to atmosphere | 1. Flame detector in burner 4. PM servomotor every TA | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Afterburn in boiler chamber creates fire and explosion | | 5 X 5 LG | Major | Remote | P3 | |
| 22.13 | Loss of containment | 1. Sight glass failure at NH3OH | 1. Chemical spillage | 2. Secondary bund in place | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 37. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM |
| | | 2. Ammonia hydroxide/ Eleminox release during refill activity | 1. Chemical spillage | 1. NALCO's procedure 3. PPE requirement 4. Emergency chemical spillage kit | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Concentrated Chemical expose to personel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Ammonia hydroxide/ Eleminox Tank leakage | 2. Diluted Chemical expose to personel | 2. Secondary bund in place 3. PPE requirement 4. Emergency chemical spillage kit | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 37. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM |
| | | 4. Pump leak (P901203) | 1. Chemical spillage | 2. Secondary bund in place 3. PPE requirement 4. Emergency chemical spillage kit 5. LLF daily | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Concentrated Chemical expose to personel | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. UPVC pipe at chemical dosing unit damage due to aging | 2. Diluted Chemical expose to personel | | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 38. Set schedule to replace new UPVC pipline of dosing every 15 years |
| | | | | | | | | | |
| 22.14 | Deviation during startup | 1. Fe is not flush out properly | 1. Create corrosion at steam drum/ Dearator | 1. Boiler start up procedure I-HYCO-048 | 5 X 5 LG | Moderate | Remote | P4 | P3 CAR 103. To revise WI I-HYCO-048 to include flushing for removing Fe before start up |
| | | 2. pH control is properly (Normal 9-11) | 1. Create corrosion at steam drum/ Dearator | 1. Boiler start up procedure I-HYCO-048 2. Test by NALCO before start up | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------|---|--|--|----------|----------|--------|----|--------------|
| | | 3. Raise up pressure too fast | 3. Stress at burner tube leads to cracking. Explosion could be expected | 1. Boiler start up procedure I-HYCO-048 | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. No boil out process in first time commissioning | 2. Remain oil in system prevent good heat exchange/ low efficiency (No safety issue) | 1. Boiler start up procedure I-HYCO-048 | | | | | |
| 22.15 | Deviation during shutdown | 1. See deviation during maintenance | | | | | | | |
| 22.16 | Deviation during maintenance | 1. NG is not completely purge out | 1. Fire during hot work | 1. Boiler shutdown procedure WI 11-0012 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Access to steam drum/ Dearator vessel | 2. Asphyxiation hazard | 2. PTW 3. JSA | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Hot work nearby diesel tank | 1. Fire during hot work | 2. PTW 3. JSA | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Wrong isolation of steam interconnection with process steam line | 3. Hot condensate steam expose to workers | 2. PTW 3. JSA | 5 X 5 LG | Serious | Remote | P3 | |
| 22.17 | Deviation during sampling | 1. Sampling valve/ pipe leakage | 1. People expose to hot condensate | 1. PPE requirement 2. Warning sign at sampling points 3. Heat surface protection guard | 5 X 5 LG | Moderate | Remote | P4 | |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: NG compressor + NG supply line |
| Design Intent: NG supply - NG from PTT metering 39 barg then pass thorough M10594 for removing oil then letdown pressure to 27 bar by PCV10594-1 before enter compressor suction. Discharge pressure 45 barg pass through PCV901308 to letdown pressure to 42 barg then enter HYCO as a feed - C10501, C10502 Design pressure 47 barg, designtemp 78 c, capacity 2119 kg/hr | | | |
| OSBL P&ID: 16001330-T-D-101-01, 637400-01-02, B050.001, H0202-T-D-115-01, H0202-T-D-101-01, H0202-T-D-105-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|--|--|---|----------|----------|--------|----|--|
| 23.1 | High flow | 1. High pressure from upstream PTT metering | 1. Overpressure downstream | 1. Safety vave at PTT metering/ Releif valve of C10501 (SV10530). C10502 (SV10532) 2. SSV-slam shut off valve at PTT metering 4. V-51 of impulse line to PVC10954-1 is lock open to ensure functioning of PVC10954-1,2 5. NG booster suction line PAH10594-3 setting 33 barg | 5 X 5 LG | Major | Remote | P3 | P3 CAR 109. Reconfirm V-51 of impulse line to PVC10954-1 is locked open to ensure functioning of PVC10954-1,2 P3 CAR 110. Add alarm set point PAH901301 setting 45 barg, PAL901301 setting 36 barg at NG booster discharge pressure to warning operator |
| | | | 4. High pressure (see 23.7) | | | | | | |
| | | 2. High demand from Hyco plant | 2. Low pressure at upstream | 3. DPI1905-2 setting PDAHH 500 mbarg | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 3. Damage filter element | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 4. High pressure (see 23.7) | | | | | | |
| 23.2 | Low/no flow | 1. (Upstream compressor) closed valve/ Control valve closing | 1. Vacuum at suction side. Oxygen ingress and feed into reformer | 1. PALL10534, 36 trip compressor setting 25 barg 2. PAL10534, 36 warning alarm setting 26 bar | 5 X 5 LG | Major | Remote | P3 | P3 CAR 111. Some discrepancy found in alarm list e.g PALL value is written tag as 'PAHH while set point value is PALL correctly. To review and update alarm list |
| | | | 2. Short NG supply to Hyco plant (No safety issue) | | | | | | |
| | | | 3. Low pressure downstream (No safety issue) | | | | | | |
| | | | 4. Low pressure (see 23.8) | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|--|--|--|----------|-------|--------|----|--------------|
| | | 2. High pressure downstream | 2. Short NG supply to Hyco plant (No safety issue) | | | | | | |
| | | 3. Low pressure upstream | 1. Vacuum at suction side. Oxygen ingress and feed into reformer | 1. PALL10534, 36 trip compressor setting 25 barg 2. PAL10534, 36 warning alarm setting 26 bar | 5 X 5 LG | Major | Remote | P3 | |
| | | | 4. Low pressure (see 23.8) | | | | | | |
| | | 4. Plugged filter | 1. Vacuum at suction side. Oxygen ingress and feed into reformer | 1. PALL10534, 36 trip compressor setting 25 barg 3. Suction oil coaleser DPI-10594 4. DPI10530,32 at suction compressor strainer 5. DPI at filter inlet in PTT metering | 5 X 5 LG | Major | Remote | P3 | |
| | | | 3. Low pressure downstream (No safety issue) | | | | | | |
| | | | 4. Low pressure (see 23.8) | | | | | | |
| | | 5. (Downstream compreesor) closed valve/ Control valve closing | 1. Vacuum at suction side. Oxygen ingress and feed into reformer | 1. PALL10534, 36 trip compressor setting 25 barg 2. PAL10534, 36 warning alarm setting 26 bar | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Short NG supply to Hyco plant (No safety issue) | | | | | | |
| | | | 3. Low pressure downstream (No safety issue) | | | | | | |
| | | | | | | | | | |
| 23.3 | Reverse flow | 1. Low pressure NG | 1. Contaminate hydrogen to NG line (No safety issue) | 1. Check valve N-02 2. Check valve CV-7001 in PTT meter 3. Operating procedure to close hydrogen gas supply when Hyco plant shutdown (I-HYCO-087) | | | | | |
| | | 2. Reverse flow - Hydrogen mix feed to NG booster (see 24.3) | | | | | | | |
| 23.4 | Misdirected | 1. Operator error - | 1. Short supply to Hyco plant | 1. Checklist that specifies | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|----------------------|---|--|--|----------|-------|------------|----|---|
| | flow | misoperating | (No safety issue) | valve alignment (I-HYCO-081,87) 3. checklist specifies valve operating (I-HYCO-081,87) | | | | | |
| | | 2. Check valve seat leakage on manual valve bypass open at line No.NG-005-3C1-4" while compressor running | 2. High pressure (see 23.7) | 3. checklist specifies valve operating (I-HYCO-081,87) | | | | | |
| | | 3. Mis operate to connect Nitrogen hose to NG process line | 3. NG reserve to nitrogen line. | 2. Check valve N-91 4. SOP to connect nitrogen gas hose when system depressurize only (I-HYCO-081,087) | 5 X 5 LG | Major | Remote | P3 | |
| 23.5 | High temperature | 1. Fire case around NG line | 1. High temperature - NG supply (see 1.5) | 1. Relief valve on NG line 2. Review spacing between NG & hydrogen gas line for installation 3. Recommend to install hydrogen gas supply station in MIG hydrogen gas meter area. (need to get permit from MIG to install this station) | | | | | |
| | | | 2. Over pressure in NG line causing pipeline rupture | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 2. Loss cooling water supply | 1. High temperature - NG supply (see 1.5) | 4. TAH10543, 544 setting 50 c 5. TAHH10543, 544 trip compressor setting 55 c 6. Pipeline is design for higher temperature rating than compressor | | | | | |
| | | | 2. Over pressure in NG line causing pipeline rupture | | 5 X 5 LG | Major | Improbable | P3 | |
| 23.6 | Low temperature (NA) | | | | | | | | |
| 23.7 | High pressure | 1. High pressure upstream | 1. Over pressure discharge | 1. PSV10530, 32 at suction compressor 2. Recirculation valve of | 5 X 5 LG | Major | Improbable | P3 | P3 CAR 110. Add alarm set point PAH901301 setting 45 barg, PAL901301 setting 36 |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|---|---|----------|-------|------------|----|---|
| | | | | compressor 3. PSV10531,34 at discharge compressor | | | | | barg at NG booster discharge pressure to warning operator |
| | | | 2. Over pressure down stream (see 1.7) | | | | | | |
| | | 2. No demand of HyCO plant / Downstream pressure control valve closing /Blocked flow down stream compressor | 1. Over pressure discharge | 2. Recirculation valve of compressor 3. PSV10531,34 at discharge compressor | 5 X 5 LG | Major | Improbable | P3 | P3 CAR 110. Add alarm set point PAH901301 setting 45 barg, PAL901301 setting 36 barg at NG booster discharge pressure to warning operator |
| | | | 4. Short supply to HyCO plant (No safety issue) | | | | | | |
| | | 3. By-pass line compressor open while compressor running (see 23.4) | 3. Over pressure at suction | 1. PSV10530, 32 at suction compressor 4. Check valve, N-03 5. Pipeline is design cover discharge pressure | 5 X 5 LG | Major | Improbable | P3 | |
| | | 4. High flow (see 23.1) | | | | | | | |
| 23.8 | Low pressure | 1. PTT supply low pressure | 1. Compressor trip | 1. Low pressure alarm 2. Pressure indication | | | | | P3 CAR 110. Add alarm set point PAH901301 setting 45 barg, PAL901301 setting 36 barg at NG booster discharge pressure to warning operator |
| | | 2. Low/no flow (see 23.2) | 1. Compressor trip | 1. Low pressure alarm 2. Pressure indication | | | | | |
| 23.9 | High concentration of contaminants | 1. High concentration of oil contaminants upstream | 1. Wearing internal compressor part | 1. Oil coleaser | | | | | |
| 23.10 | Loss of containment | 1. External fire (see high temp) | | | | | | | |
| | | 2. Gasket failure | 1. Small/large release of combustible gas | 1. Operation/maintenance response as required, including isolation if needed | | | | | |
| | | 3. Improper maintenance | 1. Small/large release of combustible gas | 1. Operation/maintenance response as required, including isolation if needed | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|--------------------------|--|--|--|----------|----------|--------|----|--------------|
| | | | | 2. Plugs in vent and drain valves | | | | | |
| | | 4. Instrument or instrument line failure | 1. Small/large release of combustible gas | 1. Operation/maintenance response as required, including isolation if needed | | | | | |
| | | 5. Material defect | 1. Small/large release of combustible gas | 1. Operation/maintenance response as required, including isolation if needed | | | | | |
| | | 6. Vent or drain valve leaking | 1. Small/large release of combustible gas | 2. Plugs in vent and drain valves | | | | | |
| | | 7. High pressure (if the overpressure cause exceeds the equipment pressure rating) | 1. Small/large release of combustible gas | 3. Relief valve | | | | | |
| 23.11 | Deviation during startup | 1. In proper purging NG before start-up | 1. Oxygen remain in system causing fire and explosion | 1. Standard operating procedure WI-I-HYCO-081, 087 | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Improper proper nitrogen vent out | 2. Nitrogen contamination with NG feed (see 1.9) | 2. AI16011 CO product purity setting > 97.62% | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. Cooler tube leak | 3. Cooling water contaminated with NG. High moisture could damage Desulphur unit catalyst (see 1.13) | 1. Standard operating procedure WI-I-HYCO-081, 087 | | | | | |

BUSINESS CONFIDENTIAL

| | | | |
|---|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: Hydrogen mix feed to NG booster |
| Design Intent: hydrogen from pipeline system at 29 barg pass through PCV301 letdown pressure to 28.6 barg. FCV10595-1 controls flow rate to mixing with NG at such of NG booster. | | | |
| OSBL P&ID: 16001330-T-D-101-01, H0202-T-D-105-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattananvit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|----------------------|--|--|------------------------------------|----------|---------|--------|----|---|
| 24.1 | High flow | 1. Control valve,FCV10595-1 malfunction open | 1. Loss of hydrogen supply in pipe grid (No safety issue) | 1. FAH-10595-1 setting 18 kg/hr | | | | | |
| 24.2 | Low/no flow | 1. Closed valve / Control valve closing | 1. Short supply Hydrogen mix feed could lead to sulphur and chloride slip and damage prereformer. reformer catalyst (see 2.10) | 1. FAL10595-1 | | | | | |
| | | 2. High pressure downstream | 1. Short supply Hydrogen mix feed could lead to sulphur and chloride slip and damage prereformer. reformer catalyst (see 2.10) | 1. FAL10595-1 | | | | | |
| | | 3. Low pressure upstream | 1. Short supply Hydrogen mix feed could lead to sulphur and chloride slip and damage prereformer. reformer catalyst (see 2.10) | 1. FAL10595-1 | | | | | |
| 24.3 | Reverse flow | 1. Low pressure upstream | 1. Reverse flow - NG compressor + NG supply line (see 23.3) | 1. Check valve | | | | | |
| 24.4 | Misdirected flow | 1. Operator error - valve misalignment bypass V-07 | 1. Small & large leakage | | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 112. To revise standard operating procedure I-HYCO-081, 087 to provide valve status checklist for start-up hydrogen mix feed |
| | | 2. Valve seat leakage | 1. Small & large leakage | 1. Add plug or blind on vent valve | 5 X 5 LG | Serious | Remote | P3 | |
| 24.5 | High temperature | 1. Fire case around hydrogen gas line | 1. High pressure (see 24.7) | 1. Relief valve at upstream PSV301 | | | | | |
| 24.6 | Low temperature (NA) | | | | | | | | |
| 24.7 | High pressure | 1. High temperature (see 24.5) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|--------------------------------|--|----------|---------|--------|----|--------------|
| 24.8 | Low pressure | 1. Low/no flow (see 24.2) | | | | | | | |
| 24.9 | High concentration of contaminants | 1. No issue | | | | | | | |
| 24.10 | Loss of containment | 1. Corrosion/erosion | 1. Small/large release | 1. Operation/maintenance response as required, including isolation if needed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. External impact | | 1. Operation/maintenance response as required, including isolation if needed | | | | | |
| | | 3. Gasket, packing, or seal failure | 1. Small/large release | 1. Operation/maintenance response as required, including isolation if needed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Improper maintenance | 1. Small/large release | 1. Operation/maintenance response as required, including isolation if needed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Instrument or instrument line failure | 1. Small/large release | 1. Operation/maintenance response as required, including isolation if needed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 6. Material defect | 1. Small/large release | 1. Operation/maintenance response as required, including isolation if needed | 5 X 5 LG | Serious | Remote | P3 | |
| | | 7. Vent or drain valve leaking | 1. Small/large release | 2. Plugs in vent and drain valves | 5 X 5 LG | Serious | Remote | P3 | |
| 24.11 | Deviation during startup | 1. Improper purging before start-up | 1. Risk for fire and explosion | 1. Standard operating procedure I-HYCO-081, 087 | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Deviation during maintenance (see 24.13) | | | | | | | |
| 24.12 | Deviation during shutdown | 1. Improper isolation | 1. Leakage of flammable gas | 1. PTW 2. Lockout/tagout procedure 3. JSA | 5 X 5 LG | Serious | Remote | P3 | |
| 24.13 | Deviation during maintenance | 1. Deviation during startup (see 24.11) 2. Deviation during shutdown (see 24.12) | | | | | | | |

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| | | | |
|---|------|------|--|
| Linde PLC | HYCO | MTP1 | Name: Carbon dioxide compressor |
| Design Intent: C1408 ; Max flow rate = 3032 kg/h, Design pressure 47 barg/ Temp 170 c, operating discharge pressure 39 barg, suction pressure 0.4 barg - Boost up carbon dioxide pressure from 0.5 barg to 36 barg for injecting to feedgas outlet prereformer at FV10016.B | | | |
| P&ID: 14PFP04, 14PFP05, 14PFP06, 10PFP06, 12PFP02, 94PFP01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|--|---|--|----------|----------|------------|----|--------------|
| 25.1 | High flow | 1. No cause | | | | | | | |
| 25.2 | Low/no flow | 1. Low pressure upstream from T1404 | 1. Compressor lost suction and damage | 1. 'PAL14020 warning alarm setting 0.3 barg 2. PALL14310 trip compressor 0.001 barg 3. PAL14310 warning alarm setting 0.3 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Plant upset due to loss 'CO2 feed | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Oxygen ingress at suction of compressor. Oxygen feed to reformer | | 5 X 5 LG | Major | Improbable | P3 | |
| | | 2. XKA004 passing leak | 1. Compressor lost suction and damage | 1. 'PAL14020 warning alarm setting 0.3 barg 2. PALL14310 trip compressor 0.001 barg 3. PAL14310 warning alarm setting 0.3 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Plant upset due to loss 'CO2 feed | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. High flow - MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum → PV14015 fail open (see 6.1) | 1. Compressor lost suction and damage | 1. 'PAL14020 warning alarm setting 0.3 barg 2. PALL14310 trip compressor 0.001 barg 3. PAL14310 warning alarm setting 0.3 barg | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Plant upset due to loss 'CO2 feed | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Oxygen ingress at suction | | 5 X 5 | Major | Improbable | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|----------------------|---|--|--|----------|-----------|-------------------|------------|--------------|
| | | | of compressor. Oxygen feed to reformer | | LG | | | | |
| | | 4. Low pressure (see 25.8) | | | | | | | |
| 25.3 | Reverse flow | 1. FV10016.B fail open during 'CO2 compressur not running | 1. Reformed gas reserve to compressor and pass thorough recycle line and vent out to atmosphere at PV14015 | 1. Check valve XAE009 (Safety check valve) at discharge compressor 2. Check valve XAE006 (Safety check valve) at suction compressor 3. Built-in check valve at compressor discharge (NV134) | LE3 | 4-Serious | 1-Highly Unlikely | Acceptable | |
| 25.4 | Misdirected flow(NA) | | | | | | | | |
| 25.5 | High temperature | 1. Loss cooling water to E1415 | 1. High temp suction and compressure internal parts damage | 1. TAH14012 setting 60 c 2. TAH14022 setting 60 c 3. 'TAH14315,14317, 14319 warning alarm inter cooler all stages setting 155 c 4. 'TSHH14315,14317,14319 inter cooler all stages setting 165 c trip compressor | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Suction line heat tracing is left on | 1. High temp suction and compressure internal parts damage | 1. TAH14012 setting 60 c 2. TAH14022 setting 60 c 3. 'TAH14315,14317, 14319 warning alarm inter cooler all stages setting 155 c 4. 'TSHH14315,14317,14319 inter cooler all stages setting 165 c trip compressor | 5 X 5 LG | Major | Remote | P3 | |
| 25.6 | Low temperature | 1. Heat tracing is not on | 1. High condensate at suction compressor causing damage | 1. XKA004 condensate trap 2. Regualr monitoring at suction state 1 by shift operator 3. LSHH14300 at knockout drum to trip compressor, setting 402 mm 4. LAH14300 warning alarm at knockout suction stage 1, | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|---|---|---|----------|----------|--------|----|--------------|
| | | | | setting 260 mm | | | | | |
| | | 2. Low temperature upstream | 1. High condensate at suction compressor causing damage | 5. See safe guard in MDEA node | 5 X 5 LG | Major | Remote | P3 | |
| 25.7 | High pressure | 1. Nitrogen passing through start up line | 1. High concentration of contaminants (see 25.9) | 1. SV1405 setting 47 barg 2. PAH14312 warning alarm 3. PAHH14312 trip compressor 4. PAH14020 setting 0.7 barg 5. PIC/PV14015 PAH14015 setting 0.7 barg 6. SV1403 setting 6 barg (at suction stage 1) | | | | | |
| | | | 2. High pressure discharge | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. High pressure suction. Large carbon dioxide vent to atmosphere | | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. Nitrogen passing through PV14016 | 1. High concentration of contaminants (see 25.9) | | | | | | |
| | | 3. FV10016.B fail closed | 2. High pressure discharge | 1. SV1405 setting 47 barg 2. PAH14312 warning alarm 3. PAHH14312 trip compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. PV14020 fail close when discharge pressure in control mode | 2. High pressure discharge | 4. PAH14020 setting 0.7 barg 5. PIC/PV14015 PAH14015 setting 0.7 barg 6. SV1403 setting 6 barg (at suction stage 1) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 5. PV14020 fail open when suction pressure in control mode | 3. High pressure suction. Large carbon dioxide vent to atmosphere | 5. PIC/PV14015 PAH14015 setting 0.7 barg 6. SV1403 setting 6 barg (at suction stage 1) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 6. PT14028 reading low when discharge pressure | 2. High pressure discharge | 1. SV1405 setting 47 barg | 5 X 5 LG | Moderate | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|---|---|---|----------|----------|--------|----|--------------|
| | | in control mode | | 2. PAH14312 warning alarm 3. PAHH14312 trip compressor | | | | | |
| | | 7. PT14028 reading high when discharge pressure in control mode | 3. High pressure suction. Large carbon dioxide vent to atmosphere | 4. PAH14020 setting 0.7 barg 5. PIC/PV14015 PAH14015 setting 0.7 barg 6. SV1403 setting 6 barg (at suction stage 1) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 8. PT14020 error reading low when suction pressure in control mode | 3. High pressure suction. Large carbon dioxide vent to atmosphere | 4. PAH14020 setting 0.7 barg 5. PIC/PV14015 PAH14015 setting 0.7 barg 6. SV1403 setting 6 barg (at suction stage 1) | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 9. PT14020 error reading high when suction pressure in control mode | 2. High pressure discharge | 1. SV1405 setting 47 barg 2. PAH14312 warning alarm 3. PAHH14312 trip compressor | 5 X 5 LG | Moderate | Remote | P4 | |
| 25.8 | Low pressure | 1. PV14020 recycle valve fail close when discharge pressure in control mode | 1. Low/no flow (see 25.2) | 1. PAL14020 2. PAL14310 warning alarm 3. PALL14310 trip compressor | | | | | |
| | | | 2. Low pressure suction. Damage to compressor | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. PV14020 fail open when discharge pressure in control mode | 3. Low pressure discharge. process upset | 4. 'CO2 import FV10016.A to compensate | 5 X 5 LG | Minor | Remote | P4 | |
| | | 3. PV14020 fail closed when suction pressure in control mode | 2. Low pressure suction. Damage to compressor | 1. PAL14020 2. PAL14310 warning alarm 3. PALL14310 trip compressor | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. PT14028 reading high when discharge pressure in control mode | 3. Low pressure discharge. process upset | 4. 'CO2 import FV10016.A to compensate | 5 X 5 LG | Minor | Remote | P4 | |
| | | 5. PT14028 reading low | 2. Low pressure suction. | 1. PAL14020 | 5 X 5 | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|---|---|----------|---------|------------|----|--------------|
| | | when discharge pressure in control mode | Damage to compressor | 2. PAL14310 warning alarm 3. PALL14310 trip compressor | LG | | | | |
| | | 6. PT14020 error reading low when suction pressure in control mode | 3. Low pressure discharge. process upset | 4. 'CO2 import FV10016.A to compensate | 5 X 5 LG | Minor | Remote | P4 | |
| | | 7. PT14020 error reading high when suction pressure in control mode | 2. Low pressure suction. Damage to compressor | 1. PAL14020 2. PAL14310 warning alarm 3. PALL14310 trip compressor | 5 X 5 LG | Serious | Remote | P3 | |
| 25.9 | High concentration of contaminants | 1. High pressure → nitrogen passing leak into CO2 system (see 25.7) | 2. Nitrogen contaminate and product off spec (No safety issue) | | | | | | |
| | | 2. Demister of D1441 failure | 1. Condensate pass through carbon dioxide compressor. Lower efficiency and damage compressor components | 1. XKA004 condensate trap at suction line 2. High level warning alarm at suction knock out drum/ Trip if high high 3. D1441 LAHH14008 trip compressor 4. D1441 LAH14010 warning alarm at 60% | 5 X 5 LG | Major | Improbable | P3 | |
| 25.10 | Loss of containment | 1. External impact | 1. Small/large release | 1. Capability to isolate the line remotely or manually 2. Operation/maintenance response as required, including isolation if needed 7. Fix gas detector with warning alarm at carbon dioxide compressor house | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Improper maintenance | | 4. Vibration monitoring 6. Yearly PM overhaul during TAR 7. Fix gas detector with warning alarm at carbon dioxide compressor house | | | | | |
| | | 3. Deadheading (maximum | | 3. Relief valve | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------|---|--|--|----------|---------|----------|----|---|
| | | suction pressure plus shutoff pressure exceeding compressor casing design pressure) | | 4. Vibration monitoring 5. Design pressure is cover max operating pressure 7. Fix gas detector with warning alarm at carbon dioxide compressor house | | | | | |
| | | 4. Mechanical failure in compressor components | 1. Small/large release | 4. Vibration monitoring 6. Yearly PM overhaul during TAR 7. Fix gas detector with warning alarm at carbon dioxide compressor house | 5 X 5 LG | Major | Remote | P3 | |
| 25.11 | Deviation during startup | 1. Oxygen remain in system | 1. Oxygen ingress to reformer causing fire internal of reformer tube | 2. Plant total start up WI 11-0013 | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Condensate inagress to compressor | 2. Compressor damage | 1. WI for start up 'CO2 compressor WI 14-0010 | 5 X 5 LG | Major | Remote | P3 | |
| | | 3. Restart 'CO2 compressor to often | 3. 6KV Motor damage | 3. Electrcl interlock with timer 15 min to restart again 4. Interlock logics for start up 6KV motors by residual current in coils | 5 X 5 LG | Serious | Possible | P3 | P3 CAR 99. Provide narative description for 6KV motors (C1408, C1608) interlock logic for starting cycle protection and communicate to maintenance and operation team |
| | | 4. Not start up with nitrogen mode after shutdown | 4. No safety issue | | | | | | |
| 25.12 | Deviation during shutdown | 1. See deviation during maintenance | | | | | | | |
| 25.13 | Deviation during maintenance | 1. Toxic / flammable gas remaining in flre stack due to nitrogen not properly purge | 1. Personnel expose to toxic and flammable gas | 1. Shutdown procedure WI 11-0012 2. PTW 3. Lockout/tagout procedure | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Fire and explosion during hot work | | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Nitrogen purge is not isolated | 3. Oxygen depletion create asphyxiace hazard | 1. Shutdown procedure WI 11-0012 2. PTW | 5 X 5 LG | Major | Remote | P3 | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--------|--------------|-----------------------------|--------|---|----|----|--------------|
| | | | | 3. Lockout/tagout procedure | | | | | |

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|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: CO2 tank low pressure tank |
| Design Intent: Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | | | |
| OSBL P&ID: H0202-T-D-104-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---|--|---|--------|---|----|----|--------------|
| 26.1 | High level | 1. Tanker overfilled | | | | | | | |
| | | 2. Back flow from T85B | 1. Hydraulic tank | 2. V-22 (Check valve at Liquid filling connection of T85B) | | | | | |
| 26.2 | Low level | 1. Any Liquid export valve are openned (V13,14) | 1. Getting dry ice clock at pressure below 12 barg | 2. LAL30% | | | | | |
| | | 2. Liquid filling connection tow away | 2. Major release | 1. V-22 (Check valve at Liquid filling connection of T85A) 3. Rec: Add V-22 on P&ID of T-85A | | | | | |
| 26.3 | High pressure | 1. PBR 5 fail open | | 1. PSV34 and tank PSVs | | | | | |
| | | 2. PCV852-1 fail opn | | 2. PSV33 | | | | | |
| | | 3. PCV851-1 fail or wrong open | | 3. PSV85A-3 | | | | | |
| | | 4. Back flow from T85B and vap | | 4. V22 and N85B-2 | | | | | |
| 26.4 | Low pressure | 1. PBR 5 fail | 1. Dry ice | 1. Second feed from PVC852-1 at 25 barg 2. Low pressure alarm | | | | | |
| | | 2. Excess draw off | 1. Dry ice | | | | | | |
| 26.5 | High temperature | 1. Excessive pump recycle | 1. High pressure | 1. PAH85A-1 | | | | | |
| | | 2. Low/no flow - CO2 vaporizer E852 (see 29.2) | | | | | | | |
| 26.6 | Low temperature | 1. Low pressure | | 1. PAL85A-1 | | | | | |
| 26.7 | High concentration of contaminants | 1. Impurity from taker | | 1. Rec: Ensure standard operating procedure cover procedureto check thje purity of feed carbon dioxide from tanker before filling | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|-------------------------------|--------------|--|--------|---|----|----|--------------|
| | | 2. Impurity from recicle flow | | 2. Rec: QC procedure for sampling check impurity | | | | | |
| | | 3. Impurity from PB coil E852 | | | | | | | |

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|---|------|------|---------------------------------|
| Linde PLC | HYCO | MTP1 | Name: CO2 pump (P851A/B) |
| Design Intent: Pump data - Flow rate 4000 kg/hr, Design Pressure 42 barg, Temperature -20 c - Operating; Liquid from T85A pumped to 42 barg for filling T85B. Recycle valve PCV90851-1 used for recycle back to T85A to prevent over pressure downstream before relief valve pop up. | | | |
| OSBL P&ID: H0202-T-D-104-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|---|---|--|----------|---------|------------|----|--------------|
| 27.1 | High flow | 1. Both pump running at the sametime through bypass line (V851-5) | 1. Potential low temp at down vaporizer for direct supply from pumps (see 29.7) | 1. Vent discharge to safe area 2. Interlock for running both pumps at the sametime 3. Access control strategy | | | | | |
| | | | 2. High pressure (see 27.4) | | | | | | |
| 27.2 | Low/no flow | 1. Strainer F851A-1 and F851B-1 blocked | 1. Pump damaged due to loss suction | 1. TAHH851A-1, TAHH851B-1 to prevent pump dry run setting 0 c 2. TAH851A-1, B-1 setting -5 c warning alarm 3. Rec: PM plkan for F85A-1 and F85B-1 6. Standby pump | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 6. Low pressure (see 27.5) | | | | | | |
| | | 2. Tank low level | 2. Low NPSHA to P851A/B. Pump cavitation | 4. Low level alarm 85A-1 > NPSHR 7. LSL9085A-1 setting 20% trip pump 8. PAL9085A-1 setting 15 barg | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 6. Low pressure (see 27.5) | | | | | | |
| | | 3. recycle valve PCV90851-1 fail open | 3. Low flow to T85B (No safety issue) | 9. High pressure alarm T85A | | | | | |
| | | | 6. Low pressure (see 27.5) | | | | | | |
| | | 4. Gas blocking in suction line | 4. Low flow to pump 851A/B | 5. Install pump suction line as vendor recommend | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 6. Low pressure (see 27.5) | | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|---|--|--|----------|---------|------------|----|---|
| 27.3 | Reverse flow | 5. D851A-7, D851A-9, D851B-7, D851B-9 are opened 1. N851A-2, N851B-2 failure | 5. Low flow to T85B (No safety issue) | 1. Pump suction valve ECV85A-1, ECV85B-1 2. The cold liquid in tank will condense incomming has 3. Tank PSVs 5. PSV851A-2,B-2 setting 22.5 barg 6. Suction pipe ratiing > discharge pressure of pump | | | | | |
| | | | 6. Low pressure (see 27.5) | | | | | | |
| | | | 1. High pressure warm gas leaks back through pump | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Revserve flow T85B to T85A | 2. Overpressure of suction side of pump and suction pipe | 4. V22(check valve at liquid transfer connection of T-85B) N851A-2, N851B-2 | 5 X 5 LG | Serious | Improbable | P4 | P3 CAR 123. Recheck that PSV851A-1, 851B-1 can cover full flow rate in case of reserve flow from running pump |
| | | | 3. Potential overpressure of T85A | | 5 X 5 LG | Serious | Remote | P3 | |
| 27.4 | High pressure | 2. Revserve flow T85B to T85A | 4. T85A high pressure | 4. V22(check valve at liquid transfer connection of T-85B) N851A-2, N851B-2 | 5 X 5 LG | Serious | Remote | P3 | |
| | | 1. Thermal expansion between valve block | 1. Pipe rupture | 1. Thermal relieve valve between block valve | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. V85B-1 (common discharge pump),V851A-3, V851B-3 (discharge pump), V851-1, V85A-1 (Recycle line) is wrongly closed during pump operate | 3. High pressure in discharge line | 3. PSV851A-3, PSV851B-3, PSV851A-4,PSV851B-4 (pumps discharge line) PSV85A-3 (recycle line) | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Common discharge pump ECV9085B-1 fail close and Recycle pump PCV90851-1 malfunction or recycle line V85A-1 (downstream PCV90851-1) close | 2. Pump discharge high pressure | 2. PSV85B-4 for full discharge case 4. PAHH90851-1 setting 45 barg, trip pump 5. PSV851A-3, PSV851B-3, PSV851B-4, PSV851A-4 | 5 X 5 LG | Serious | Remote | P3 | |
| 27.5 | Low pressure | 1. T85A low pressure | 1. Pump lost of prime or cavitation | 1. Tank 85A PAL9085A-1 setting 15 barg 2. TAHH90851A-1, TAHH90851B-1 setting 0 c | 5 X 5 LG | Serious | Remote | P3 | |
| | | | | | | | | | |
| 27.4 | High pressure | 4. High flow (see 27.1) | | | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------------------|---|--|--|----------|---------|--------|----|--|
| | | | | (discharge pump) to trip pump | | | | | |
| | | | 2. Low discharge pressure (No safety issue) | | | | | | |
| | | 2. Strainer suction pump block (see 27.2) | 1. Pump lost of prime or cavitation | 2. TAHH90851A-1, TAHH90851B-1 setting 0 c (discharge pump) to trip pump | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Low discharge pressure (No safety issue) | | | | | | |
| | | | 3. Low pump discharge pressure to T85B (No safety issue) | | | | | | |
| | | 3. Seal pump leak | 3. Low pump discharge pressure to T85B (No safety issue) | 3. TAL at P90851A-2/B-2 setting 0 | | | | | |
| | | 4. D851A-7, D851B-7 (pump discharge), D851A-9, D851B-9 (Discharge pump) openned | 2. Low discharge pressure (No safety issue) | 4. standard operating procedure | | | | | |
| 27.6 | High temperature | 1. Pipeline insulation damage | 1. Gas in suction line, Cavitation at suction or loss of prime | 1. Thermal relief valve at all isolated 2. operating instruction cover pump prime before stat up (I-HYCO-041) 3. TAH90851A-1, TAH9085B-1 set point -5 c 4. TAHH90851A-1, TAHH90851B-1 setting 0 c (discharge pump) to trip pump | 5 X 5 LG | Serious | Remote | P3 | |
| 27.7 | Low temperature | 1. NA | | | | | | | |
| 27.8 | Deviation during start up | 1. Open vent, drain valve too fast for depressuring system | 1. Dryice blockage in pipeline | | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 114. To revise standard operating procedure 10-0013 for mentioning slowly open vent/drain valve to prevent dry ice blockage due to rapid depressurizing |
| | | 2. V851A-1, V851B-1 and V7 is not fully openned | 3. Low flow suction P851A,B. Pump cavitate | 1. TAH90851A-1, TAH9085B-1 set point -5 c | 5 X 5 LG | Serious | Remote | P3 | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|----------|---------|--------|----|---|
| | | | | 2. TAAH90851A-1, TAAH90851B-1 setting 0 c (discharge pump) to trip pump | | | | | |
| | | 3. V851A-1, V851B-1 and V7 is fully closed | 2. Pump damaged due to loss suction | 1. TAAH90851A-1, TAAH90851B-1 set point -5 c 2. TAAH90851A-1, TAAH90851B-1 setting 0 c (discharge pump) to trip pump | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Loading hose whip during filling | 4. People hit by hose whipping causing injury | 2. TAAH90851A-1, TAAH90851B-1 setting 0 c (discharge pump) to trip pump 3. Hose anti whipping is inplace | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 115. Add hose anti whip regular inspection check in monthly basis P3 CAR 116. To rearrange anchor point for hose restraint against standard |

BUSINESS CONFIDENTIAL

| | | | |
|--|------|------|-------------------------------------|
| Linde PLC | HYCO | MTP1 | Name: CO2 tank High pressure |
| Design Intent: Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | | | |
| OSBL P&ID: H0202-T-D-104-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattananit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---------------|-----------------------------------|--|---|--------|---|----|----|--------------|
| 28.1 | High level | 1. LT85B-1 fail | 1. High pressure | 1. PSV17A/B, 'PSV8A/B 2. Rec: standard operating procedure for liquid carbon dioxide filling 3. Rec: Log sheet for monitor tank level 4. Rec: Check pressure profile of T85B durring filling | | | | | |
| 28.2 | Low/No level | 1. LT85A-1 failed | 1. Dry ice in T85B | 1. LI85B-1 2. Rec: PM plan for instrument 3. Rec: Log sheet to monitor tank level | | | | | |
| | | | 2. Short supply to Hyco plant | | | | | | |
| | | 2. ECV85B-3 fail locked (open) | 1. Dry ice in T85B | 2. Rec: PM plan for instrument 4. LAL85B-1, LALL85B-1, LI85B-1 | | | | | |
| | | 3. Drain/ Vent valve left openned | 1. Dry ice in T85B | 5. Rec: standard operating procedure cover drain/vent valve open | | | | | |
| | | 4. Low pressure (see 28.4) | | | | | | | |
| 28.3 | High pressure | 1. PT851-1 malfunction | 1. T85B overflow/ High pressure during filling | 1. PSV17A/B, PSV18A/B, high level alarm, LAHH85B-1, PAHH851-1, PAH85B, PI85B-1 3. PM plan for instrument | | | | | |
| | | 2. PBR-5 (T85B) failed open | 2. High pressure supply to HYCO plant | 1. PSV17A/B, PSV18A/B, high level alarm, LAHH85B-1, PAHH851-1, PAH85B, PI85B-1 3. PM plan for instrument | | | | | |
| | | 3. PCV1 (T85B) failed open | 3. T85B overfilled | 1. PSV17A/B, PSV18A/B, high level alarm, LAHH85B-1, | | | | | |

BUSINESS CONFIDENTIAL

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|--------------------------------------|--|--------|---|----|----|--------------|
| | | during filling | | PAHH851-1, PAH85B, PI85B-1 2. Rec: recheck pressure profile during filling 3. PM plan for instrument | | | | | |
| | | 4. Line from V-7 to ECV85B-3 all closed | 4. Pipe rupture | 4. Rec: Locked open V-7 5. Rec: D85-9 opened during isolation valve is closed | | | | | |
| 28.4 | Low pressure | 1. PBR-5 failed closed | 1. No building up pressure to T85B | 1. PAL85B-1 2. Rec: PM plan for instrument 3. Rec: Log sheet for monitor tank pressure | | | | | |
| | | 2. Steam system short supply to E852 | 2. No build up pressure to T85B | 1. PAL85B-1 4. TI852-1 | | | | | |
| | | 3. PSV17A/B, PSV18A/B left open | 3. Carbon dioxide loss to atmosphere | 2. Rec: PM plan for instrument 5. PI85B-1, PAL85B-1 | | | | | |
| | | | 4. Low pressure supply to Hyco plant | | | | | | |
| | | 4. Pipe rupture | 5. Liquid loss | 5. PI85B-1, PAL85B-1 6. TALL852-1 | | | | | |
| | | 5. T85B vent drain valve left open | 3. Carbon dioxide loss to atmosphere | 5. PI85B-1, PAL85B-1 7. Rec: standard operating procedure | | | | | |
| | | 6. LT85B-1/ PT85B-1 fail | 6. Low/No level (see 28.2) | | | | | | |
| | | 7. Low/no flow - CO2 vaporizer E852 (see 29.2) | | | | | | | |
| 28.5 | High temperature | 1. Insulation poor condition// loss vacuum | 1. T85B high pressure | 1. PSV17A/B, PSV18A/B, PAH85B, PI85B-1 2. Rec: PM plan for check vacuum condition | | | | | |
| | | 2. Heat radiation from HYCO flare | 1. T85B high pressure | 1. PSV17A/B, PSV18A/B, PAH85B, PI85B-1 | | | | | |
| | | 3. External fire | 1. T85B high pressure | 1. PSV17A/B, PSV18A/B, PAH85B, PI85B-1 3. Rec: Fire fighting system | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|--------------------------------------|---|------------|--------|---|----|----|--------------|
| 28.6 | Low temperature | 1. Low/No level (see 28.2) | | | | | | | |
| 28.7 | High concentration of contaminants | 1. Contaminated from T85A (see 26.7) | 1. High concentration of contaminants - CO2 vaporizer E852 (see 29.8) | | | | | | |

BUSINESS CONFIDENTIAL

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|---|------|------|---------------------------------|
| Linde PLC | HYCO | MTP1 | Name: CO2 vaporizer E852 |
| Design Intent: Carbon dioxide from high pressure tank - Pressure 40 barg pass through vaporizer coil. Vaporizer coils - MAWP 3000 psi, capacity 4500 kg/hr Demin water - Demin water used for fill up to vaporizer bath Steam heating - Steam from boiler package feed to vaporizer bath at pressure through PCV90102 for letting down pressure from 41 barg to 17.24 barg at flowrate of 500 kg/hr | | | |
| OSBL P&ID: H0202-T-D-104-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------|---|---|--|----------|----------|--------|----|--------------|
| 29.1 | High flow | 1. Pipe rupture at downstream vaporizer | 1. Liquid carried over, cold embrittlement downstream CS pipe | 1. Low temperature alarm/TAL90852-1 setting 14 c 3. TALL90852-1 setting 10 c close valve inlet and outlet of vapozer | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Vent drain valve left open | 2. 'CO2 loss | 1. Low temperature alarm/TAL90852-1 setting 14 c 2. standard operating procedure 3. TALL90852-1 setting 10 c close valve inlet and outlet of vapozer | 5 X 5 LG | Moderate | Remote | P4 | |
| | | | 3. Dry ice formation | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Low temperature (see 29.7) | | | | | | | |
| 29.2 | Low/no flow | 1. Dry ice forming during start up | 1. Low pressure supply to Hyco (No safety issue) | 1. Pressurizing system 2. standard operating procedure | | | | | |
| | | 2. ECV90852-1 closed | 2. Short supply to Hyco (No safety issue) | 3. See high pressure 4. ZAL852-1 | | | | | |
| | | | 3. Upstream high pressure (see 29.4) | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------|--|--|--|----------|----------|--------|----|--------------|
| | | 3. ECV90858-4 fail closed | 1. Low pressure supply to Hyco (No safety issue) | | | | | | |
| | | | 4. Low pressure - CO2 tank High pressure (see 28.4) | | | | | | |
| | | 4. PCV90852-1 failed close | 5. High temperature - CO2 tank low pressure tank (see 26.5) | | | | | | |
| 29.3 | Reverse flow | 1. High flow - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.1) | 1. Carbon dioxide contamination with feed gas. People exposure to flammable gas during vent/ drain | 1. Check valve852-2 2. XAE010 (CO2 import) 3. PDSLL10013 to close import valve FN10016A setting 0.1 barg 4. PDAL10013 warning alarm setting 0.15 barg | 5 X 5 LG | Serious | Remote | P3 | |
| 29.4 | High pressure | 1. High pressure from T85B | 1. High pressure supply to HYCO plant | 1. PSV852-2 setting 45 barg 2. PAH90852-1 setting 42 barg 5. PSV852-1 setting 45 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 2. High temp in water bath | 1. High pressure supply to HYCO plant | 1. PSV852-2 setting 45 barg 2. PAH90852-1 setting 42 barg 3. Water bath temp alarm high TAH901202 setting 90 c | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 3. V852A-1/2 closed during Liquid carbon dioxide in line | 2. Pipe rupture (Thermal expansion) | 4. PSV852-4 for T85B pressure build up line setitng 45 barg | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Low/no flow (see 29.2) | | | | | | | |
| | | 5. PCV901202 fail open/ PIC901202 error reading low | 3. Overflow supply to water bath | | 5 X 5 LG | Minor | Remote | P4 | |
| 29.5 | Low pressure | 1. Low pressure supply from T85B | 1. Low pressure supply to Hyco plant (No safety issue) | | | | | | |
| 29.6 | High temperature | 1. Steam supply valve TCV901203 fail opened/ Temp control valve malfunction | 1. High pressure supply to HYCO | 1. PAH90852-1 setting 42 barg 2. Water high temp alarm TAH901202 setting 90 c 3. PSV852-2 setting 45 barg | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|-------|------------------------------------|---|--|---|----------|----------|----------|----|---|
| | | | | 4. PSV852-1 setting 45 barg 5. TAH901202 setting 90 c | | | | | |
| | | 2. Water in bath low level | 1. High pressure supply to HYCO | 1. PAH90852-1 setting 42 barg 2. Water high temp alarm TAH901202 setting 90 c | | | | | P3 CAR 113. To change hot water sampling valve at E852 (CO2 vaporizer) to needle valve 1/4" |
| | | 3. Deviation during sampling (see 29.10) | | | | | | | |
| 29.7 | Low temperature | 1. TCV901203 fail closed/ Temp control valve malfunction | 1. Liquid carried over causing cold embrittlement CS pipe at downstream pipe | 1. TAL90852-1 setting 14 c 2. TALL90852-1 setting 10 c to close inlet and outlet of vaporizer 3. TAL901202 setting 60 c | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Pipe rupture | 2. High flow (see 29.1) | | | | | | |
| | | 3. High flow - CO2 pump (P851A/B) -> in case bypass line V851-5 in use (see 27.1) | 1. Liquid carried over causing cold embrittlement CS pipe at downstream pipe | 1. TAL90852-1 setting 14 c 2. TALL90852-1 setting 10 c to close inlet and outlet of vaporizer 3. TAL901202 setting 60 c | 5 X 5 LG | Major | Remote | P3 | |
| 29.8 | High concentration of contaminants | 1. High concentration of contaminants - CO2 tank High pressure (see 28.7) | | | | | | | |
| 29.9 | Coil leakage or rupture | 1. Vaporizer coil failure | 1. 'CO2 leakage and hot water splash out causing injury to people nearby | 1. PH monitor for water in hot waterbath in weekly basis (pH>9) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Corrosion in waterbath vessel due to acid water | | 5 X 5 LG | Moderate | Remote | P4 | |
| 29.10 | Deviation during sampling | 1. Sampling valve leakage | 1. Injury to operator | 1. PPE requirement | 5 X 5 LG | Moderate | Possible | P3 | P3 CAR 113. To change hot water sampling valve at E852 (CO2 vaporizer) to needle valve 1/4" P3 CAR 117. To update sampling procedure to cover sampling water from hot waterbath E852 |
| | | | 2. Low level water in hot waterbath (see 29.6) | | | | | | |

BUSINESS CONFIDENTIAL

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|--|------|------|---|
| Linde PLC | HYCO | MTP1 | Name: Liquid Nitrogen tank for Coldbox |
| Design Intent: Original HAZOP report, Not reviewed in this HAZOP section due to this is subject to CMES operation | | | |
| OSBL P&ID: H0202-T-D-101-01 | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--------------|--|---|--|----------|----------|--------|----|--------------|
| 30.1 | High flow | 1. Pipe rupture downstream | 1. Liquid loss supply to Linde (No safety issue) | 1. Minimum distance between tank and battery limit | | | | | |
| | | | 2. Oxygen depletion hazard | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Pipe rupture upstream tank | 1. Liquid loss supply to Linde (No safety issue) | 2. HYCO plant access control 3. Portable gas detector (Multigas) is mandatory | | | | | |
| | | | 2. Oxygen depletion hazard | | 5 X 5 LG | Serious | Remote | P3 | |
| 30.2 | Low/no flow | 1. Tank low level | 1. Low flow supply to Hyco plant (No safety issue) | 1. LAL81-1 | | | | | |
| | | 2. Strainer block | 1. Low flow supply to Hyco plant (No safety issue) | | | | | | |
| | | 3. V81-2 is not fully opened | 1. Low flow supply to Hyco plant (No safety issue) | | | | | | |
| | | 4. Tank low pressure (PCV-2 malfunction) | 1. Low flow supply to Hyco plant (No safety issue) | 2. PAL81-1 | | | | | |
| | | 5. V81-2, V14 closed | 2. No supply to linde (No safety issue) | | | | | | |
| | | 6. No liquid in tank | 2. No supply to linde (No safety issue) | | | | | | |
| 30.3 | Reverse flow | 1. Reverse flow from Hyco plant | 1. Tail gas contaminated to LN tank (No safety issue) | 1. Check valve N81-1 | | | | | |
| 30.4 | High level | 1. Liquid overfilled | 1. Liquid spillage | 1. LAH9081 2. Filling procedure | 5 X 5 LG | Moderate | Remote | P4 | |
| 30.5 | Low level | 1. LT9081 malfunction | 1. No liquid supply to Linde (No safety issue) | 2. LI9081 | | | | | |
| | | 2. Tanker short supply | 1. No liquid supply to Linde (No safety issue) | 1. LAL9081 | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------------------|---------------------------|---|---|----------|---------|--------|----|--------------|
| 30.6 | High pressure | 1. PCV-2 malfunction | 1. High supply pressure to LN tank | 1. PSV81-1, PSV1A/1B | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Tank loss vacuum | 2. High supply pressure to Linde | 2. PAH81-1 3. PSV1A/1B 4. relief valve calibration plan | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. SIVL loss vacuum | 3. 2 phase flow to Linde / Cannot meet supply condition | 5. PSV81-1 | 5 X 5 LG | Serious | Remote | P3 | |
| 30.7 | Low pressure | 1. Low/no flow (see 30.2) | | | | | | | |
| | | 2. High consumption rate | 1. Low pressure supply to Linde (No safety issue) | 1. Maximum flow rate of HV16003, HV16021 matching with HE-1 | | | | | |
| 30.8 | High concentration of contaminants | 1. Impurity from tanker | 1. Impurity in tank (No safety issue) | 1. Filling procedure/ Product certificate (COA) | | | | | |

BUSINESS CONFIDENTIAL

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|---|------|------|-------------------------------------|
| Linde PLC | HYCO | MTP1 | Name: utilities and services |
| Design Intent: | | | |
| Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Sunchai Chaleerin (HAZOP member), Pipat Lubiam (HAZOP member), Taweewat Mingkaew (HAZOP Leader), Preecha Sangpim (HAZOP member), Somchai Thavonrattanavanit (HAZOP member) | | | |

| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|--|-------------------------------|---|---|----------|---------|--------|----|--------------|
| 31.1 | Loss of electric power (momentary or longer) | 1. Cable/bus severed | 1. Nighttime lighting is lost | 1. Breakers and protective logic 2. All system will shutdown safely when power lost 5. Emergency lighting provided for safe evacuation and critical operation 12. Double insulation cable 13. DCS back up by UPS (Control system, Safety system PLC) supply 45 mins 16. Turbo generator automatic start up | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 2. Lightning strike | 1. Nighttime lighting is lost | 14. Lightning arrestor cover all process area 16. Turbo generator automatic start up | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 3. Offsite utility power loss | 1. Nighttime lighting is lost | 2. All system will shutdown safely when power lost | 5 X 5 LG | Minor | Remote | P4 | |
| | | | | | | | | | |
| | | | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|---------------------|---|--|----------|---------|--------|----|--------------|
| | | | | 13. DCS back up by UPS (Control system, Safety system PLC) supply 45 mins 15. Second power supply source from EGAT 16. Turbo generator automatic start up | | | | | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 4. Overload | 1. Nighttime lighting is lost | 1. Breakers and protective logic 4. All control valves are designed to go to fail safe position on loss of power or instrument gas 9. All motors and breakers are fitted with overload protection 10. PM for transformer condition monitoring (oil sampling, etc) 11. Thermoscan inspection of switchgear 13. DCS back up by UPS (Control system, Safety system PLC) supply 45 mins | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 5. Transformer fire | 1. Nighttime lighting is lost | 1. Breakers and protective | 5 X 5 | Minor | Remote | P4 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-----------|--|---|---|----------|---------|--------|----|--|
| | | | | logic 10. PM for transformer condition monitoring (oil sampling, etc) 11. Thermoscan inspection of switchgear 16. Turbo generator automatic start up | LG | | | | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 6. Turbogenerator trip | 1. Nighttime lighting is lost | 13. DCS back up by UPS (Control system, Safety system PLC) supply 45 mins | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 7. UPS failure | 2. Control system (DCS, PLC, etc.) is lost | 17. Yearly PM UPS system 18. Monthly visual inspection in SAP | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 8. Substation and power feeder short circuit by tree branch laying/ Sneak attack | 1. Nighttime lighting is lost | 19. Electrical SAP PM every 60 months | 5 X 5 LG | Minor | Remote | P4 | P3 CAR 104. To install sneak guard around substation fence |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|---|--|---|---|----------|---------|--------|----|--------------|
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| | | 9. Misoperation by unauthorized person | 1. Nighttime lighting is lost | 20. Switch gear access control by only authorized person 21. Access control signage at access door | 5 X 5 LG | Minor | Remote | P4 | |
| | | | 2. Control system (DCS, PLC, etc.) is lost | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Plant shutdown and failure to supply the customer | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 4. Loss of control system (DCS, HIMA Safety PLC) (see 31.2) | | | | | | |
| 31.2 | Loss of control system (DCS, HIMA Safety PLC) | 1. HMI Thin client failure | 1. Operator inconvenience to operate | 1. Time based replacement every 5 years 2. total 6 Thin client | 5 X 5 LG | Minor | Remote | P4 | |
| | | 2. Server failure | 2. Plant interruption | 3. Redundant server 4. Service maintenance contract with high pressure supplier 5. Operation procedure to push ES when loss communication | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. CPU failure | 2. Plant interruption | 6. Redundant CPU with auto switching 7. PM every TAR 9. Stock spare part for critical part | 5 X 5 LG | Serious | Remote | P3 | |
| | | 4. Remote I/O failure | 2. Plant interruption | 7. PM every TAR 8. Redundate remote I/O 9. Stock spare part for critical part | 5 X 5 LG | Serious | Remote | P3 | |
| | | 5. Loss of electric power (momentary or longer) (see 31.1) | | | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|------------------------|--------------------------------------|---|---|----------|----------|--------|----|--------------|
| | | 6. Loss of HVAC (see 31.6) | | | | | | | |
| 31.3 | Loss of instrument gas | 1. High demand for instrument gas | 2. Loss instrument gas causing plant shutdown | 5. PAL90101 setting 10 barg | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. External circuit pipeline failure | 2. Loss instrument gas causing plant shutdown | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Filter blockage from PSA skid | 1. PSA shutdown. hydrogen short supply and process fluctuate due to loss of purge gas | 4. F110 nitrogen supply filter 5. PAL90101 setting 10 barg | 5 X 5 LG | Moderate | Remote | P4 | |
| | | 4. PCV201A/B fail close | 2. Loss instrument gas causing plant shutdown | 1. Control valves failing to their safe position 2. Redundant pressure regulator 3. PAL90201 setting 4 barg | 5 X 5 LG | Serious | Remote | P3 | |
| 31.4 | Loss of fuel gas | 1. Refer to NG supply node | | | | | | | |
| 31.5 | Loss of purge gas | 1. High demand for purge gas | 1. Flammable gas leak out to plant area could create explosive condition | 1. Low pressure alarm 2. Backup purge gas source from pipeline 3. Methan pump seal leak TALL installed 4. PAL90101 setting 10 barg 5. High point vent to atmosphere | 5 X 5 LG | Major | Remote | P3 | |
| | | | 2. Reverse flow at machinery seals (oxygen into purge gas supply, cryogenic temperatures at purge gas supply systems) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Air/moisture ingress into coldbox or tank annular space | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. External circuit pipeline failure | | 2. Backup purge gas source from pipeline 3. Methan pump seal leak TALL installed 4. PAL90101 setting 10 barg 5. High point vent to | | | | | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------|--|---|--|----------|---------|------------|----|--|
| | | | | atmosphere | | | | | |
| | | 3. Filter blockage | | 4. PAL90101 setting 10 barg | | | | | |
| 31.6 | Loss of HVAC | 1. Air condition failure in electrical room | 1. Over temperature of electrical equipment and equipment malfunction | 1. Routine inspection 5. Room temperature indicator with local high temp alarm 6. Room temperature indicator with high temp alarm link to DCS 9. Standby air condition 1 unit running 3 units | 5 X 5 LG | Serious | Improbable | P4 | |
| | | | 2. DCS failure/ Safety instrument system failure (see 31.2) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | 2. Air condition failure in DCS room | 2. DCS failure/ Safety instrument system failure (see 31.2) | 6. Room temperature indicator with high temp alarm link to DCS | 5 X 5 LG | Serious | Remote | P3 | |
| | | 3. Air condition failure in analyzer room | 3. Online analyzer malfunction. Loss supply to customer | 7. LLF Every shift 8. Plant patrol log sheet | 5 X 5 LG | Serious | Remote | P3 | P3 CAR 105. Set up air condition spare part for analyzer room as critical spare part |
| | | 4. Fan doesn't stop when gas leak detected | | 10. Fixed gas detector with warning alarm 11. Gas detector stop ventilation fans 12. PPE requirement for portable gas detector | | | | | |
| | | 5. Loss of electric power (momentary or longer) (see 31.1) | | | | | | | |
| 31.7 | Loss of firewater | 1. Header leak from corrosion | 1. No fire water and out control fire situation | 7. Above ground pipe regular inspection 8. Weekly function test fire pump 9. Weekly diesel level 10. 6 monthly pressure test fire hose | 5 X 5 LG | Major | Remote | P3 | |
| | | 2. Inadequate diesel fuel | 1. No fire water and out control fire situation | | 5 X 5 LG | Major | Remote | P3 | |

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| Item | Deviation | Causes | Consequences | Safeguards | Matrix | S | ML | MR | Action Items |
|------|-------------------------------|--------------------------------|---|--|----------|---------|--------|----|--------------|
| | | 3. Low level in reservoir | 1. No fire water and out control fire situation | 12. Weekly inspection of water level | 5 X 5 LG | Major | Remote | P3 | |
| | | 4. Pump trip | 1. No fire water and out control fire situation | 8. Weekly function test fire pump | 5 X 5 LG | Major | Remote | P3 | |
| | | 5. Inadequate pump performance | | 11. Yearly performance test per regulatory requirement | | | | | |
| 31.8 | Loss of waste water treatment | 1. Overflow waste water pond | 1. Environment impact | 1. Authorized 3rd party waste water treatment 2. Level alarm high LT90916 85% 3. Level alarm high-high LT90916 90% | 5 X 5 LG | Serious | Remote | P3 | |

BUSINESS CONFIDENTIAL

| | | | | |
|---------------------------|--------------------|-------------------|--------------|----------------|
| Company: Linde PLC | Plant: HYCO | Site: MTP1 | Unit: | System: |
|---------------------------|--------------------|-------------------|--------------|----------------|

| Review of previous incident reports | | | | |
|---|-----------------------------------|--|---|--|
| Incident | Initiating Events/Factors | Consequences | Investigation Results | Action Items |
| SIF-18-15 (Thailand): Gas leaks at the HYCO Pre-reformer (Synergi#223345) | Pipe corrosion at low point drain | <ol style="list-style-type: none"> 1. Process gas emission to atmosphere ; Stream 23.6 kg, Methane 10 kg, H2 0.1 Kg 2. Potential consequence: Fire and explosion/ Injury to people | <p>Shut down & start up procedure to ensure all remain condensate are drained out and not remain in the low point of carbon steel material</p> <p>Survey remaining similar issue for thinning material of high temperature carbon steel</p> <p>Survey gas leak and keep record daily monitoring</p> <p>Change new leak reducer in next shutdown</p> <p>Fabricate new spool if found less thinning</p> <p>Behaviour & Communication</p> | <p>P3 CAR 25. Need to list low point drain location and update to shutdown procedure</p> <p>P3 CAR 107. Request permanent EMOC for change low point drain at outlet prereformer from double block valve to flange (Currently temporary EMOC was applied for flange installation)</p> |
| PMIR-13-07 (Thailand) : HYCO steam reformer wall burnout (Synergy#51702) | Hot reformer tube due to overheat | <ol style="list-style-type: none"> 1. Syngas leak and impingeto reformer walls 2. Inner insulation damage 3. Reformer wall damage | <p>Review trouble shooting for 1) Reformer 2) Pre-reformer 3) HDS 4) Overheating tube</p> <p>Increase frequency of reformer tube visual inspection (1 x shift)</p> <p>Review position of Min. stop estimate position with valves (FV10011/FV10012)</p> <p>Removal of process steam solenoids, adding mech. stop disk (FV10012)</p> <p>Modify interlock on Flare valve PV10009 during Cold start up</p> <p>Use of PV10009 (Emphasize risks around operation of PV10009)</p> <ul style="list-style-type: none"> - Ignition procedure - Hot start procedure - Mitigation in case of lack of H2 recycle at HDS - High CH4 slip <p>S/C ratio (refer new material balance)</p> <ul style="list-style-type: none"> - CO2 ratio - Composition changing | |

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| Review of previous incident reports | | | | |
|---|---|---|---|---|
| Incident | Initiating Events/Factors | Consequences | Investigation Results | Action Items |
| | | | <ul style="list-style-type: none"> - Burner operation - Cold box operation - 110% for CO product <p>Re-design burner (Detail&Quotation): Already issued LOI to Selas Linde for new burner design</p> <p>Review SD procedure if no H2 recycle available</p> <p>1) High H2 pressure source (Tube trailer, Pack) 2) Redundant H2 compressor</p> <p>Detail of HDS purging procedure and training</p> <p>Review sampling/analysis procedure (HDS)</p> <p>Add variable PDAH HDS reaction (vs. load)</p> <p>Pre-reformer activation level alarm</p> | |
| Synergi#43687 Methan pump disc flexible hose damage | Thermal stress to CH4 flexible hose | 1. CH4 leakage during start up pump | <p>Hydro test every 1 years (8000 hrs)</p> <p>Replace discharge flexible hose every 5 years</p> <p>Apply thermoscan compare between pump A,B</p> <p>Adjust speed motor to finding suitable for hose and LLF sound of liquid flow and pump. Trained to operator and include in standard operating procedure</p> <p>Retighten both pump&motor</p> <p>Compare discharge temperature</p> <p>Review WO to change from liq to gas coldddown and cooldown rating temp</p> | P3 CAR 106. Reconfirm existing schedulle for replacing methane pump discharge flexible hose every 5 years |
| Synergi#175756 Gas leak flange E1122(Syngas, temp 400 deg C) and fire at insulation | Pipe stress and misalignment from thermal expansion | <p>1. Reformed gas release and conctect with hot surface at 400 c. Fire in insulation</p> <p>2. HYCO plant emergency shutdown due to Syngas leaked and fired at WHB outlet flange</p> | <p>Modify pipe support (no.1) to allow correct movement</p> <p>Recheck pipe movement to ensure no stress after action 1 complete</p> <p>Replace gasket at E1122 every TAR</p> | <p>Rec 6. Reformed gas pipe outlet E1122 needed to recalculate stress 3rd party vendor since there was repeated leakage in 2019. Synergi#270526</p> <p>P3 CAR 108. Recalculation from 3rd</p> |

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| Review of previous incident reports | | | | |
|-------------------------------------|---------------------------|--------------|-----------------------|---|
| Incident | Initiating Events/Factors | Consequences | Investigation Results | Action Items |
| | | | | party ventdor results of Reformed gas pipe outlet E1122, Recommendations to be implemented within TAR2020 |

BUSINESS CONFIDENTIAL

| No.: 33 | | Cooling water treatment chemicals | | | | | | | |
|---|--|---|--|---|----------|---------|--------|----|--------------|
| P&ID: 92PFP01, OSBL P&ID: H0202-T-D-110-01, 4507-T-D-102-01 | | | | | | | | | |
| Item | What if...? | Root Causes/Related Questions | Responses | Safeguards | SOE | S | L | R | Action Items |
| 33.1 | What if the plant has an inadequate water treatment program including poorly installed or maintained equipment | Poor vendor support | 1. Increased corrosion rate leading to a loss of containment | National vendor provides water treatment services (routine testing, inspection and condition monitoring) Water treatment vendor reports reviewed by plant in monthly and review ASEAN Ops support 6 monthly | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Excessive fouling (biological or other debris) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Injury to personnel (chemicals burns, eye damage, etc) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | Failed chemical dosing system including chemical runout | 1. Increased corrosion rate leading to a loss of containment | National vendor provides water treatment services (routine testing, inspection and condition monitoring) Water treatment vendor reports reviewed by plant in monthly and review ASEAN Ops support 6 monthly Monitor corrosion rate in monthly by water treatment vendor (NALCO) | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 2. Excessive fouling (biological or other debris) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Injury to personnel (chemicals burns, eye damage, etc) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | Failure in blowdown controls | 1. Increased corrosion rate leading to a loss of containment | National vendor provides water treatment services (routine testing, inspection and condition monitoring) Operator training by water treatment chemical vendor | 5 X 5 LG | Serious | Remote | P3 | |
| | | | | | | | | | |

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| No.: 33 | | Cooling water treatment chemicals | | | | | | | |
|---|-------------|--|---|---|----------|---------|--------|----|--------------|
| P&ID: 92PFP01, OSBL P&ID: H0202-T-D-110-01, 4507-T-D-102-01 | | | | | | | | | |
| Item | What if...? | Root Causes/Related Questions | Responses | Safeguards | SOE | S | L | R | Action Items |
| | | | | Monitor corrosion rate in monthly by water treatment vendor (NALCO) | | | | | |
| | | | 2. Excessive fouling (biological or other debris) | | 5 X 5 LG | Serious | Remote | P3 | |
| | | Loading incompatible chemicals into fixed chemical storage vessels | 3. Injury to personnel (chemicals burns, eye damage, etc) | Safety shower and eyewash located near chemical storge and handling equipment PPE available in water treatment area including full face shield, chemical apron and gloves, etc Secondary containment for all water treatment chemicals (storage, dosing lines and pumps). Sealed the drain in 1 pit Proper labelling and segregation of chemicals SDS available for all personnel for all chemicals on site Operator training by water treatment chemical vendor | 5 X 5 LG | Serious | Remote | P3 | |
| | | Personnel exposed to chemical spill (skin contact or eyes) | 3. Injury to personnel (chemicals burns, eye damage, etc) | Safety shower and eyewash located near chemical storge and handling equipment PPE available in water treatment area including full face shield, chemical apron and gloves, etc Proper labelling and segregation of chemicals SDS available for all personnel for all chemicals on site Operator training by water | 5 X 5 LG | Serious | Remote | P3 | |















BUSINESS CONFIDENTIAL

| No.: 33 | | Cooling water treatment chemicals | | | | | | | |
|---|---|---|---|---|----------|----------|----------|----|--------------|
| P&ID: 92PFP01, OSBL P&ID: H0202-T-D-110-01, 4507-T-D-102-01 | | | | | | | | | |
| Item | What if...? | Root Causes/Related Questions | Responses | Safeguards | SOE | S | L | R | Action Items |
| | | | | treatment chemical vendor | | | | | |
| 33.2 | What if there is no secondary containment for water treatment chemicals | Improper installation or changes made | 1. Soil contamination | Safety shower and eyewash located near chemical storage and handling equipment PPE available in water treatment area including full face shield, chemical apron and gloves, etc Secondary containment for all water treatment chemicals Proper labelling and segregation of chemicals Separate bund of chemical which can have reaction | 5 X 5 LG | Moderate | Possible | P3 | |
| | | | 2. Personnel exposed to chemical spills | | 5 X 5 LG | Serious | Remote | P3 | |
| | | | 3. Reaction with other equipment or nearby stored chemicals | | 5 X 5 LG | Serious | Remote | P3 | |
| 33.3 | What if cooling water supply lost? | leak cooling tower basin or vent/ drain valve are left open | | High temperature alarm at end equipment 'LIC9091C control at 85-90% LAL9091 setting 85% warning alarm DCS LALL9091 setting 60% warning alarm DCS | | | | | |
| | | Failure level control system | 1. Cooling water lost causing equipment downstream high temperature | High temperature alarm at end equipment | 5 X 5 LG | Serious | Remote | P3 | |
| | | Overflow cooling water basin | 1. Cooling water lost causing equipment downstream high temperature | High temperature alarm at end equipment 'LIC9091C control at 85-90% LAH9091 setting 90% warning alarm DCS LAHH9091 setting 95% | 5 X 5 LG | Serious | Remote | P3 | |



| No.: 33 | | Cooling water treatment chemicals | | | | | | | |
|---|-------------|-----------------------------------|-----------|-------------------|-----|---|---|---|--------------|
| P&ID: 92PFP01, OSBL P&ID: H0202-T-D-110-01, 4507-T-D-102-01 | | | | | | | | | |
| Item | What if...? | Root Causes/Related Questions | Responses | Safeguards | SOE | S | L | R | Action Items |
| | | | | warning alarm DCS | | | | | |

Mark up P&ID

| Node# | Node name | Node's P&ID |
|-------|--|---|
| 1 | NG supply |  Node 1 NG supply.pdf |
| 2 | Pre-reformer & Reformer + Gas Cooling + Waste heat boiler |  Node 2 Pre-reformer & Refo |
| 3 | Stream drum + steam system + Steam back up from package boiler |  Node 3 Stream drum + steam syster |
| 4 | Fuel gas system |  Node 4 Fuel gas system.pdf |
| 5 | Deareator |  Node 5 Deaerator.pdf |
| 6 | MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum |  Node 6 MDEA-Wash unit, M |
| 7 | Drier (TSA) |  Node 7 Drier (TSA).pdf |
| 8 | Regeneration gas + hydrogen fraction bypass |  Node 8 Regeneration gas + |
| 9 | Coldbox (T1601: Methan wash column) |  Node 9 Coldbox (T1601 Methan wash |
| 10 | Coldbox (T1602 : hydrogen stripper column) |  Node 10 Coldbox (T1602 hydrogen str |
| 11 | Coldbox (T1603 : CO methane separation column) |  Node 11 Coldbox (T1603 CO methane |
| 12 | Coldbox (Liq Methane pump) |  Node 12 Coldbox (Liq Methane pump) |

| | | |
|----|---------------------------------|--|
| 13 | Coldbox (CO turbine) |  Node 13 Coldbox (CO turbine).pdf |
| 14 | CO compressor + CO supply line |  Node 14 CO compressor + CO su |
| 15 | PSA plant (A1,2,3) |  Node 15 PSA plant (A1,2,3).pdf |
| 16 | PSA plant Node (E1/R1) |  Node 16 PSA plant Node (E1-R1).pdf |
| 17 | PSA plant Node (E2/R2) |  Node 17 PSA plant Node (E2-R2).pdf |
| 18 | PSA plant (P1/PP1 and P5/PP5) |  Node 18 PSA plant (P1-PP1 and P5-PP5). |
| 19 | PSA plant (D) |  Node 19 PSA plant (D).pdf |
| 20 | PSA plant (R0/R01) |  Node 20 PSA plant (R0-R01).pdf |
| 21 | Warm, Cold Flare |  Node 21 Warm&Cold flare.pc |
| 22 | Package boiler |  Node 22 BOILER PACKAGE DETAIL.pd |
| 23 | NG compressor + NG supply line |  Node 23 NG Booster.pdf |
| 24 | Hydrogen mix feed to NG booster |  Node 24 Hydrogen mix feed.pdf |
| 25 | Carbon dioxide compressor |  Node 25 CO2 Compressor.pdf |
| 26 | CO2 tank low pressure tank |  Node 26-29 CO2 TPV SYSTEM.pdf |
| 27 | CO2 pump (P851A/B) | |

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| | | |
|----|-----------------------------------|--|
| 28 | CO2 tank High pressure | |
| 29 | CO2 vaporizer E852 | |
| 30 | Liquid Nitrogen tank for Coldbox |  Node 30 LIN PHA.pdf |
| 31 | utilities and services | NA |
| 32 | previous incidents | NA |
| 33 | Cooling water treatment chemicals |  Node 33 COOLING WATER SYSTEM.pdf |