

ภาคผนวก ข

เอกสารประกอบมาตรการป้องกันและ
แก้ไขผลกระทบสิ่งแวดล้อมและมาตรการติดตาม
ตรวจสอบคุณภาพสิ่งแวดล้อม

ภาคผนวก ข-1

เอกสารการจัดทำ HAZOP ของโครงการ

PHA Revalidation_TH_HYCO

Analysis Team Members:

Attapong Campbell
Lai Heng Leong
Napakorn Chalee
Santi Chonabot
Somsak Chukraithai
Khanit Jiamtaweewiboon
Jumphot Jindaphol
Pipat Lubiam
Varinda Sakulpacharoen
Somchai Thavonrattananan

Written by:

Khanit J

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1. INTRODUCTION

In November 2025, Linde Thailand (Linde TH) conducted a hazard analysis of HyCO plant at Map Tha Phut site 1 facility. To perform the hazard analysis, Linde TH assembled a team that included personnel familiar with the design, operation, and maintenance of HyCO plants. The hazard analysis team met on 24-28 November and 17-19 December 2025, to perform the analysis.

1.1 Objectives

The hazard analysis team's objectives were to (1) identify hazards that could lead to consequences of interest and (2) recommend ways for reducing the risk of events associated with the identified hazards.

1.2 Analysis Scope

The hazard analysis covered the process equipment and operations associated with the HyCO plant.

2. ANALYSIS APPROACH

Linde Thailand's safety objectives for the HyCO plant include (1) identifying process hazards and (2) reducing the risk that the hazards pose. To help meet these objectives, Linde Thailand assembled a team to identify and evaluate hazards associated with the HyCO plant.

2.1 Composition of the Team

The analysis team members are listed in the table below.

Table 2.1 Analysis Team Members

First Name	Last Name	Company	Job Title	Role
		Linde plc	Maintenance Manager	HAZOP member
		Linde plc	Head of Process Safety & Environment-RSE	HAZOP member
		Linde plc	Senior On-Site Plant Technician HyCO	HAZOP member
		Linde plc	Operations & Engineering Project Manager	HAZOP member
		Linde plc	Head of SHEQ-TH	HAZOP member
		Linde plc	Process Safety & Behavioral Safety	HAZOP Leader
		Linde plc	HYCO & H2 Plant Manager - MTP1	HAZOP member
		Linde plc	Manager Electrical Maintenance	HAZOP member
		Linde plc	Plant Process Engineer - HYCO	HAZOP member
		Linde plc	HyCO Technology Manager, ASEAN	HAZOP member

2.2 Analysis Methods

The team used the analysis methods listed in the table below. The team believes that these analysis methods were appropriate for each application.

Table 2.2 Analysis Methods Used

Method	Number of Sections Where Used	First Section Where Used
HAZOP	31	1
Previous Incidents Review	1	32
What-if	1	33

Table 3.1 Summary of Recommendations (cont'd)

3. ANALYSIS RECOMMENDATIONS

Based on the results and insight gained from performing this hazard analysis, the analysis team identified several recommendations for reducing risk in the HyCO plant at the MTP1 facility. The table below is a list of the analysis team's recommendations. A complete description of each scenario related to the recommendations can be found in Appendix A.

Table 3.1 Summary of Recommendations

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	2.1 High flow – Pre-reformer & Reformer + Gas Cooling + Waste heat boiler	Limit set point of HIC10517 and HIC10535. Low S:C ratio at 2.2	P3 Recommendation		In Progress	
P3 CAR	1.20 Low reaction rate – NG supply	To improve NG feed sampling test by including Methyl mercaptan, Ethyl mercaptan and hydrogen sulfide	P3 Recommendation		In Progress	
P3 CAR	6.1 High flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) (EMOC 9149-19-052). Change action to re-confirm pump curve and confirm transmitter for high flow capacity	P3 Recommendation		In Progress	
P3 CAR	6.2 Low/ No flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Create procedure for bypass FV13002 steam feed mixing valve (WI I-HYCO-022)	P3 Recommendation		In Progress	
P3 CAR	6.2 Low/ No flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To create procedure for mitigation by manual local control with observe level sight glass in case LT14003 read low or read high (Abnormal) (WI-I-HYCO-022 revised procedure to manual adjust setpoint)	P3 Recommendation		In Progress	
P3 CAR	6.11 High concentration of contaminants – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Review and Update I-HYCO-098 for reference color to replace new MDEA by reference with supplier recommendation	P3 Recommendation		Rejected	

Table 3.1 Summary of Recommendations (cont'd)

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	7.1 High flow – Drier (TSA)	Update sequential document PMC0110-007 follow real actual logic of TSA unit to explain about logic of PDAHH15006 A/B and update PID for PDAHH15006 A/B	P3 Recommendation		In Progress	
P3 CAR	16.1 High flow – PSA plant Node (E1/R1) 16.2 Low/no flow – PSA plant Node (E1/R1) 17.1 High flow – PSA plant Node (E2/R2) 17.2 Low/no flow – PSA plant Node (E2/R2) 17.3 Reverse flow – PSA plant Node (E2/R2) 17.4 Misdirected flow – PSA plant Node (E2/R2) 18.1 High flow – PSA plant (P1/PP1 and P5/PP5) 19.1 High flow – PSA plant (D)	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	P3 Recommendation		In Progress	
P3 CAR	10.1 High flow – Coldbox (T1602 : hydrogen stripper column)	To limit opening of FV16004 to prevent methane pump cavitate. To raise EMOG for reviewing the optimum set point (Cavitation phenomena will not happen in reciprocating pump type)	P3 Recommendation		Rejected	
P3 CAR	13.13 Deviation during shutdown – Coldbox (CO turbine)	Add content for completely purge CO turbine in I-HYCO-0037 CO turbine start up and shutdown (updated only start up, no update for shutdown: purge CO before maintenance)	P3 Recommendation		In Progress	
P3 CAR	14.10 Deviation during startup – CO compressor + CO supply line	Update CO compressor start procedure for open gas line at lowest point to check for any water leak from cooling tube (update WI -I-HYCO-070 to cover for starting CO comp)	P3 Recommendation		In Progress	
P3 CAR	21.15 Deviation during maintenance – Warm, Cold Flare	Add I-HYCO-032 (Start up and shutdown flare system) for purging NG pilot header before maintenance (Revise I-HYCO-032)	P3 Recommendation		In Progress	

Table 3.1 Summary of Recommendations (cont'd)

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	25.11 Deviation during startup – Carbon dioxide compressor	Provide narrative description for 6KV motors (C1408, C1608) interlock logic for starting cycle protection and communicate to maintenance and operation team (relay protection system changed, so current logic are not the same as current procedure)	P3 Recommendation		In Progress	
P3 CAR	22.2 Low/no flow – Package boiler 22.8 Low pressure – Package boiler	To create PM schedule to ensure PSV1202 (Diesel recirculation pressure control) is properly function together with yearly Recertify (removed Diesel unit out in 2020)	P3 Recommendation		Rejected	
P3 CAR	22.3 Reverse flow – Package boiler	To revise WI-I-HYCO-040 to include isolation of steam from process reverse to package boiler (revise I-HYCO-040 to cover steam from process reverse to package boiler)	P3 Recommendation		In Progress	
P3 CAR	22.14 Deviation during startup – Package boiler	To revise WI I-HYCO-048 to include flushing for removing Fe before start up (Revise and add flushing in I-HYCO-048)	P3 Recommendation		In Progress	
P3 CAR	32.4 Synergi#175756 Gas leak flange E1122(Syngas, temp 400 deg C) and fire at insulation – previous incidents	Recalculation from 3rd party vendor results of Reformed gas pipe outlet E1122, Recommendations to be implemented within TAR2020	P3 Recommendation		In Progress	
P3 CAR	27.8 Deviation during start up – CO2 pump (P851A/B)	To revise standard operating procedure 10-0013 for mentioning slowly open vent/drain valve to prevent dry ice blockage due to rapid depressurizing (Need to update in I-HYCO-041)	P3 Recommendation		In Progress	
P3 CAR	3.9 High concentration of contaminants – Steam drum + steam system + Steam back up from package boiler	Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 (EMOC 9149-19-012 set at low alarm, will set high alarm with new MOC)	P3 Recommendation		In Progress	

Table 3.1 Summary of Recommendations (cont'd)

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	27.3 Reverse flow – CO2 pump (P851A/B)	Recheck that PSV851A-1, 851B-1 can cover full flow rate in case of reserve flow from running pump: Irrelevant case by design of reciprocating pump reverse flow of running pump cannot overpressure of stand-by pump	P3 Recommendation		Rejected	
P3 CAR	2.6 High temperature – Pre-reformer & Reformer + Gas Cooling + Waste heat boiler	Revise WI I-HYCO-080 to handle FIC10004NG fuel lower than 5%	P3 Recommendation			
P3 CAR	5.1 High flow – Deareator	To install restriction orifice at demin pump (P90916A/B) at min flow line to maintain minimum flow 2 m3/h according to datasheet	P3 Recommendation			
P3 CAR	6.1 High flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Update and add Work instruction HYCO-I-080 for feedback failure case. If feedback closed, what operators have to do (Troubleshooting case)	P3 Recommendation			
P3 CAR	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To add interlock to close FV14002A and B when MDEA recycle pum (P1474A and B) both stopped/tripped after 20 sec (to protect reverse flow)	P3 Recommendation			
P3 CAR	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To review WI I-HYCO-022 for manual close FV14002A and B (By removing step to close manual valve)	P3 Recommendation			
P3 CAR	9.13 Deviation during startup – Coldbox (T1601: Methan wash column)	Create standard operating procedure for operators to manage temperature rate of change alarm for start up, thawing, and normal operation	P3 Recommendation			
P3 CAR	13.9 Critical Speed – Coldbox (CO turbine)	Update speed critical to be the same DCS both tag# and setting (page D-4040-A-002 rev 01) and keep a mail PHA 2019#276918 and original Air liquid PID together. Add mail to confirm current operation at 470-510 Hz to close this action	P3 Recommendation			

Table 3.1 Summary of Recommendations (cont'd)

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	1.7 High pressure – NG supply	Change setpoint alarm trip of NG discharge compressor:PI10535 and PI10537. Alarm high at 46 barg and alarm HH at 47 barg (existing H at 48 barg and HH at 49 barg). SV NG booster at 51 barg	P3 Recommendation			

Table 3.1 Summary of Recommendations (cont'd)

HAZOP Recommendations for HYCO Plant

Company: Linde Thailand

Location: Map Tha Phut Site 1

Facility: HyCO plant

Total number of unique recommendations in the project: 3

Recommendations Data				
#	Recommendations	Priority	By	Reference Numbers
1	To implement jumper log form (MS-84780/84781) by Jan 2026			1.15.1.1
2	Recommend to install barriers/bollards at CO2 VIE tank and Packaged boiler			1.24.2.1
3	Recommend to install bollards at Switchgear and pipeline. Install bollards at Demin plants			1.24.3.1

APPENDIX A
Analysis Results

The proceedings of the hazard analysis of the HyCO plant at the MTP1 facility were recorded in tables generated by *LEADER*[™] software specifically designed for this purpose. Error! Reference source not found. provides a list of the process sections reviewed during the analysis, and Table A.1 includes the detailed analysis worksheets summarizing the results of the analysis.

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Table A.1 Hazard Analysis Worksheets for the HyCO plant

Linde PLC	HYCO	MTP1	Name: NG supply
Design Intent: - 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			
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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Pipat Lubiam (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 desulpherization 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 alarm at 400 c	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 intruction troubleshooting for detecting hydrogen sulfide is avialable 7. Set up approch temperature at TDI10016 (action from PHA2019) 9. WI I-HYCO-080 has been updated for HyCO troubleshooting (action from PHA2019)	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. Bypss valve of E1015 fail open (TV10003)	1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulphur, sulphure break through Prereformer/ Reformer (see 2.10)	2. Maintenance PM and stroke check (Yearly) 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 6. Work intruction troubleshooting for detecting hydrogen sulfide is avialable 12. Completed	LE3	3- Moderate	1-Highly Unlikely	Acceptable	
		3. Tempeature control error reading low (TIC10003)	1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulphur, sulphure 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 9. WI I-HYCO-080 has been updated for HyCO troubleshooting (action from PHA2019) 12. Completed	LE3	3- Moderate	1-Highly Unlikely	Acceptable	
		4. Tempeature control error reading low (TIC10014A)	1. Reaction temperature too low for Hydrogenation reaction of hydrocarbon sulphur, sulphure 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 8. Set up TAL10014 at 300 degree C (action from PHA 2019) 9. WI I-HYCO-080 has been updated for HyCO troubleshooting (action from PHA2019) 11. Test 12. Completed	LE3	3- Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
1.7	High pressure	1. Feed shut off valve malfunction fully close (HV10025) while booster compressor running	1. Pipe/ vessel rupture create fire and explosion	2. PSV-1301 set at 46 barg 3. SV-1001 setting 47 barg design for external fire case of R-1001. Relief capacity 1673 Nm3/hr 6. PIC10535 and PIC10537 Limit setpoint compressor discharge below 42 barg, which is lower than SV1001 (47 barg) 7. Test 8. PIC901308 set at 45 barg 11. completed 12. completed	5 X 5 LG	Major	Possible	P2	P3 CAR 130. Change setpoint alarm trip of NG discharge compressor:PI10535 and PI10537. Alarm high at 46 barg and alarm HH at 47 barg (existing H at 48 barg and HH at 49 barg). SV NG booster at 51 barg
			2. High flow (see 1.16)						
		2. External fire	1. Pipe/ vessel rupture create fire and explosion	3. 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	
		3. PVC75B-3 fail fully open (H2 feed)	1. Pipe/ vessel rupture create fire and explosion	4. SV1006 setting 43 barg and its capacity (605.3 kg/hr) can support PCV75B-3 fail fully open (571.78 kg/hr) 5. PT10019, PT10019B vote 1oo2D value of high pressure alarm at 40 barg (action from PHA 2019) 9. Test 10. tes	5 X 5 LG	Major	Possible	P2	Conf 1. To add troubleshooting for high pressure alarm PAH10019
		4. Low/no flow (Normal+Steam operation) - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.2)							
		5. High pressure - NG compressor + NG supply line (see 23.7)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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) 11. WI I-HYCO-098 Response checklist for high olefin has been prepared for high temperature of Olefin (action from PHA 2019)	LE3	4-Serious	0-Extremely Unlikely	Acceptable	
			5. High temperature expose to downstream of R1001		LE3	4-Serious	1-Highly Unlikely	Acceptable	
		2. High concentration of Oxygen in feedgas (see 1.13)	3. Fire at CoMo catalyst in R1001 and damage to downstream equipment	2. Purging procedure during start up process 3. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 4. Operating practice is recommended to start up plant with Nitrogen before introduce NG 9. PV1009 to close due to high temperature of R1001 11. WI I-HYCO-098 Response checklist for high olefin has been prepared for high temperature of Olefin (action from PHA 2019) 13. Test	LE3	4-Serious	1-Highly Unlikely	Acceptable	
					LE3	4-Serious	1-Highly Unlikely	Acceptable	
		3. High concentration of CO in feedgas	1. High temperature at R1001 (see 1.5)	3. 'TAHH 10014 A/B/C/D (2004) set at 420 c to shutdown plant (SIL1) 6. 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		4. High concentration of Sulphur in feedgas (see 1.19)	1. High temperature at R1001 (see 1.5)	3. '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	
		5. Different source of supply from NG supplier	2. Plant condition upset	6. Online GC analyzer for CO, carbon dioxide, nitrogen 7. Routine sampling by Draggar tube by weekly (Sulphur, Chloride, Mercaptan) 8. Routine sampling by laboratory every 3 monthly (H2, nitrogen, CO,CO2, Methane, Olefin, Total Sulpher)	5 X 5 LG	Moderate	Remote	P4	
		6. High concentration of Chloride in feedgas	2. Plant condition upset	7. Routine sampling by Draggar tube by weekly (Sulphur, Chloride, Mercaptan)	5 X 5 LG	Moderate	Remote	P4	
		7. High concentration of Mercaptan in feedgas	2. Plant condition upset	7. Routine sampling by Draggar tube by weekly (Sulphur, Chloride, Mercaptan) 14. completed	5 X 5 LG	Moderate	Remote	P4	
			4. CoMo Catalyst degradation		5 X 5 LG	Major	Remote	P3	
		8. 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. WI I-HYCO-027 Detector tube in hydrogen checking (H2S, hydrochloric acid, Tube Mercaptans) has been prepared 6. Test	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 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 7. completed	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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 the equipment pressure rating)	1. Large NG leakage and fire happen	1. SV1001 set 47 barg (PSV1301 set 46 barg has been removed) 2. PI10535 and PI10537 setpoint high pressure alarm at 48 Barg and high-high pressure alarm 49 barg 8. PI901301 alarm high at 45 barg 9. PAH-901308 set at 45 barg	5 X 5 LG	Major	Remote	P3	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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. WI I-HYCO-103 loading and unloading catalyst R1001 has been prepared 6. Vendor disposes used catalyst by getting factory permit from Ministry of Industry 7. completed 8. completed	5 X 5 LG	Major	Remote	P3	
1.15	Deviation during sampling	1. Leakage during sapling prereform gas	1. Operator expose to Flammable/ Toxic gases	1. Personal gas detector 2. Sampling procedure (WI I-HYCO 027)	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. Sampling point is specifically 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					
		2. Bomb leak during transportation from plant to laboratory		6. WI I-HYCO-102 bomb transportation to Laboratory has been prepared 7. completed					
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)						
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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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)	1. EMOC 9149-19-041 has been closed for removing hydrogen recycle C1008A 2. Test					
		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 19. To improve NG feed sampling test by including Methyl mercaptan, Ethyl mercaptan and hydrogen sulfide
			2. High concentration of contaminants - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.10)						
		2. Zinc oxide bed fully absorb 'H2S after life time design	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	LE3	3-Moderate	2-Very Unlikely	Transition	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (**cont'd**)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. Troubleshooting procedure for 'H ₂ S and Sulphur breakthrough					
			2. High concentration of contaminants - Pre-reformer & Reformer + Gas Cooling + Waste heat boiler (see 2.10)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Pipat Lubiam (HAZOP member), Varinda Sakulpacharoen (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		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		Minor			
			3. Low S:C ratio caused incomplected 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 expensation from pressure drop		5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	
		4. wrong input value of HIC10517 and HIC10535	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	P3 CAR 18. Limit set point of HIC10517 and HIC10535. Low S:C ratio at 2.2
		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 8. EMOC 9149-19-059 Make high alarm set point of DP11028 vaired by % plant load (action from PHA 2019) 9. EMOC 9149-21-06 interlock permissive open-close FV10002 11. completed	5 X 5 LG	Major	Remote	P3	
			4. Catalyst chattering due to suddenly expendation 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)						
		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 10. Completed 11. completed	5 X 5 LG	Major	Remote	P3	P3 CAR 18. Limit set point of HIC10517 and HIC10535. Low S:C ratio at 2.2

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
			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 partial 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 combustible 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 SIL1) set 900 c with delay 5 sec 4. Interlock PV10009 lock close with burner on (HA11035) 6. Yealy PM stroke test	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				11. Burner tripped if proximity ZSL10009 of control vent valve PV10009 show open (EMOC 9149-19-020 Install proximity switch at PV10009 to detect close position, EMOC9149-13-314 add interlock for HV10025 and PV10009) action from PHA 2019					
			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 flammable gas emission		LE3	3-Moderate	1-Highly Unlikely	Acceptable	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
2.3	Low/no flow (Nitrogen mode)	1. XV12001 fail closed	1. No safety issue	6. E1216, E1115 design temperature design 675 c Mat'l 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'l 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 to downstream equipment (see 4.4)		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 Mat'l SS/SA213TP304H, outlet pipeline design at 660 c	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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'l 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'l 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 to downstream equipment (see 4.4)		LE3		4-Serious	1-Highly Unlikely	Acceptable		

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 8. Completed	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	
		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	
					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 to downstream equipment (see 4.4)		LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
2.4	Reverse flow (NA)								
2.5	Misdirected flow	1. HV11001A fail open	3. No safety issue	6. HV11001B					
			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	
		9. HV11001B fail open		7. HV11001A					
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	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. Selector for average control by either TI11010 or TI11011B or TI11011C range 700 - 1000 c					
		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 22. WI I-HYCO-097 reformer tube catalyst change out procedure has been prepared for operations (action from PHA 2019) 25. Completed	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. Carbon deposition in reformer tube	3. Higer skin temperature and Lower coverion at same exit reformer temepreature. Hot tube	6. Visual inspection of tube condition 3 times/week 10. Trouble shooting in case tube get hot spot includeds in operating procedure 11. Steaming procedure carbon elimination 23. WI I-HYCO-109 steaming separation procedure has been prepared for operations (action from PHA 2019) 26. Completed	LE3	3-Moderate	1-Highly Unlikely	Acceptable	P3 CAR 123. Revise WI I-HYCO-080 to handle FIC10004NG fuel lower than 5%
			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 tune that fuel concentrated on lead to skin temperature over deisgn. 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 insluation is 1200- 1400 c can resist flame impingement within short time 15. Offline inpsection during turnaround by Mech team 16. Offline cleaning by production team 24. In case TI11010 is higher than 800degree C and FIC10004NG fuel lower than 5%, will have low alarm	LE3	3-Moderate	1-Highly Unlikely	Acceptable	P3 CAR 123. Revise WI I-HYCO-080 to handle FIC10004NG fuel lower than 5%	
				LE3	3-Moderate	1-Highly Unlikely	Acceptable		
				LE3	3-Moderate	1-Highly Unlikely	Acceptable		
		4. Create hot spot at reformer tube							
		5. Reformer insulation damage causing hot spot at reformer furnance side wall. Fire could expose to personnel							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 24. In case TI11010 is higher than 800degree C and FIC10004NG fuel lower than 5%, will have low alarm 27. Completed	LE3	3-Moderate	1-Highly Unlikely	Acceptable	P3 CAR 123. Revise WI I-HYCO-080 to handle FIC10004NG fuel lower than 5%
		8. Cooling fin (E1216 A/B) fan dirtiness	6. High temperature outlet gas. No water condense or condensate high temperature to dearetor, high temperature to MDEA unit (see 6.5)	18. TI12007 to close valve XV12001 'TAH = 65 'TSHH = 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 condensate 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 to mechanical failure (spring broken), mis-operation or pressure transmitter read high (see 2.1)	1. No production. No safety issue						
		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	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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					
		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 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. Prereformer catalyst deactivation lead to lower production. (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. 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	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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					
			2. Prereformer catalyst deactivation lead to lower prodction. (No safety issue) (see 2.18)						
		5. Preformer expose to HTHA (High temperature Hydrogen Attact) (High hydrogen parital pressure + high temperature)	3. R1105 Weakening carbon steel material (Decarburization and Fissuring). Vessel damage leakage of flammable gas and toxic gas	7. Currently outlet of 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 (6.4 kg/hr, design 5.8 kg/hr running at 110%) FI10595 high flow alarm 18 kg/hr	LE3	4-Serious	0-Extremely Unlikely	Acceptable	
		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)	9. Test	LE3	3-Moderate	1-Highly Unlikely	Acceptable	
		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 prodction. (No safety issue) (see 2.18)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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 thermal stress and crack. Fire happens in reformer box		5 X 5 LG	Major	Remote	P3	
			4. Refactory 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 temeprature	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 temeprature	7. Plant start up procedure for stream introduction must be introduced above temperature of 450 c	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			8. Condesate 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 deposite in reformer tube. Catalyst damage immediately	9. Plant start up procedure for introducing NG at above temperature of 700 c 16. completed	5 X 5 LG	Major	Remote	P3	
		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 corrision cracking due to carbon dioxide touching with steam/ carbon dioxide in water corrosion on carbon steel	10. FV10016A,B closed when carbon dioxide not using 11. Check valve XAE010 at import line 12. Check valve at carbon dioxide compressor XAE009 13. Carbon dioxide Pipeline design for auto drain, No pocket 14. RBI (Risk base inspection) for checking non-destructive testing all welding joint at carbon dioxide feed mixing (action from PHA 2019)	5 X 5 LG	Serious	Possible	P3	
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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				8. WI 11-0012 Total reformer shut down has been prepared for plant shut down (action from PHA 2019) waiting for revised					
			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 refomer 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 12. completed	5 X 5 LG	Major	Remote	P3	
		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 9. WI I-HYCO-099 Low ponit drain open at reformer after total shutdown has been prepared for operators (action from PHA 2019) 11. completed	5 X 5 LG	Moderate	Possible	P3	
2.13	Deviation during maintenance	1. improper manage Used catalyst (Nikel) i.e. improper purging, improper disposal method	2. Generate hazardous waste. Impact to company permit license in case violation to regulatory of environment management	1. Company is only authorised vendor 4. completed	5 X 5 LG	Major			
		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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 specifically 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 specifically 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	
		4. Bomb leak during transportation from plant to laboratory	1. Personnel Expose to flammable and toxic gas	5. completed	5 X 5 LG	Moderate	Remote	P4	
2.15	Low level	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 rupture	1. Reformer tube life	1. Contamination of other fluid	4. Eddy current test at reformer test per Linde standard PdM 5. Replica test at reformer tube/ Hot collector every year 6. Visual inspection 3 time/ week	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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	
		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 deareerator vent		5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 deaerator 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. Measurement 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 deaerator 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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 -> Reformer catalyst deactivation lead to reformer hot tube and flammable gas release (see 2.10)		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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					
		5. High concentration of contaminants --> Prereformer catalyst deactivation lead to lower prodction. (No safety issue) (see 2.10)		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. PIC13006 setting 42 barg 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 12. EMOC 9149-20-22 13. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)	LE3	4-Serious	1-Highly Unlikely	Acceptable	
		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 reading low	4. High pressure in low pressure steam header	3. PIC13006 setting 42 barg 7. 'PSV1304 setting 7 barg	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				8. PAH13005 setting 6 barg					
		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 pressure steam header		LE3	4-Serious	1-Highly Unlikely	Acceptable	
		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 damage. Toxic and flammable gas emission		LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 repectively 5. PAL11027 setting 38 barg and auto select to temperature control by TI11001 instead 9. PAL13009 setting 38 barg 13. Automatic open of steam import to mixing feed XV13001 when low pressure of steam PAL11027 (EMOC 9149-04-05) 14. Test 15. Test					
			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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	
		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 exit is cascaded with plant load by ALC (auto load control program) 9. PAL13009 setting 38 barg 16. Test					
			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 respectively 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 respectively 9. PAL13009 setting 38 barg					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 13. Automatic open of steam import to mixing feed XV13001 when low pressure of steam PAL11027 (EMOC 9149-04-05)					
		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 13. Automatic open of steam import to mixing feed XV13001 when low pressure of steam PAL11027 (EMOC 9149-04-05)					
			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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 17. Tesr					
			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 17. Tesr					
			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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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. No intermittent blowdown	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	1. Conductivity measurement AI11001 setting 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 deposit in reformer tube. Leakage of waste heat boiler tube and steam leak to reform gas. More condensate recycle at E1332	1. Conductivity measurement AI11001 setting 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	
			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	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				8. Visual check sampling from deaerator for solid particle by NALCO 9. Boiler feed pump strainer (0.315 mm) with dP measurement					
			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 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	4-Serious	1-Highly Unlikely	Acceptable	P3 CAR 117. Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 (EMOC 9149-19-012 set at low alarm, will set high alarm with new MOC)
		9. Low pH condition from chemical dosing less than 8.5	8. General corrosion creates thinning material tendency to leak	1. Conductivity measurement AI11001 setting 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)	LE3	3-Moderate	1-Highly Unlikely	Acceptable	P3 CAR 117. Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 (EMOC 9149-19-012 set at low alarm, will set high alarm with new MOC)

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				4. NALCO check water quality 2 time/ weeks 7. Inspection during TA					
		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 fouling in system and could deposite 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	
		12. High concentration of contaminants - Deareator (see 5.11)	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 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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 failure	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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 before 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 Nitrogen 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 temperature rate 2. Pressure ramp rating 0.5 barg / min alarm (PI13006)	5 X 5 LG	Serious	Remote	P3	
		2. System is not connected to atmosphere. When temp is 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	
3.13	Deviation during maintenance	1. Flexible hose connection during maintenance causing steam/ hot condensate release during disconnected flexible hose	1. Hot condensate release to personnel	1. Vent valve at steam utility point (USNT01- -04)	5 X 5 LG	Moderate	Remote	P4	
		2. Confined space work	2. Asphyxiation 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 eliminated during cleaning before start up	5 X 5 LG	Moderate	Remote	P4	
3.14	Deviation during sampling	1. Person exposed to high temperature	1. Injury	1. PPEs 2. Sample cooler 3. Test	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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 4. LAHH11001 at 80% to trip LV11001	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. LSLL11002 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	
			3. High temperature (see 3.7)						
			4. Overheat and damage coil. Steam ingress to reformer tube and causing damage to reforemer 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. LIC11001 error reading high	1. Steam drum high temperature and may over design temperature leading to rupture.	2. LSLL11002 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. LSLL11002 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	
			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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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. LSLL11002 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	
			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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 3. SV10003 setting 6 barg	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 12. Test	LE3	3-Moderate	1-Highly Unlikely	Acceptable	
		7. Upset PSA causes high amount of 'PG to reformer/ cause high flow 'PG to reforemer 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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. 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			3. Process upset		5 X 5 LG	Minor			
		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 excess oxygen low 13. Test	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			
			4. Incomplete combustion leading high NOx, SOx in flue gas stack		5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		7. High flow - High flow 'PG to reforemer 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 causing tube damage	10. Limited flow FIC11004 at minimum 65 kg/hr in cascade mode	LE3	3-Moderate			
		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 reforemer 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 reforemer 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 reforemer tube	12. TIC11010	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		13. High flow - PSA plant (D) (see 19.1)							
		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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)						
		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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. ECV11057 fail open to flare (NG)	5. Low/no flow (see 4.2)	1. Insert spectacle blined in normal opeaiton					
		6. XV11005.c bleed valve fail open	5. Low/no flow (see 4.2)	8. Control loop is SIL1 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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)							
		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 irregualr 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			

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 7. 'FALL11001 trip burner management system	5 X 5 LG	Serious			
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	
		3. C1107 running speed much higher than C1109 running speed	1. High vacuum in reformer box causing reformer housing collapse	3. 'PSLL11007 A/B/C 2oo3 (SIL) setting -5 mbarg to stop C1107 5. Auto start up squence for C1107 and C1109	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. Evironmental control fluw 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. Regualr 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	
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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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)						
		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 5. Test					
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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: Deareator
Design Intent: Demin Water section: - 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 deareator (During start up) Condensate recovery - 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 Control - 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. BFW pump - BFW from P1317 recirculated by min flow to dareator			
P&ID: 13PFP01, 13PFP02, 13PFP03, 14PFP01, 14PFP02, 14PFP03, 14PFP04, 14PFP05, 14PFP06, 15PFP01, 15PFP02, 15PFP03, 15PFP04			
Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Pipat Lubiam (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (HAZOP member)			

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 11. Test 12. Pump shut off pressure is 15.09 barg which is lower than pipelibe pressure resistant 19.5 barg (150 #class)	LE3	3-Moderate	3-Unlikely	Transition	P3 CAR 124. To install restriction orifice at demin pump (P90916A/B) at min flow line to maintain minimum flow 2 m3/h according to datasheet
			7. Pump damaged due to cavitation from too high flow						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. LV13005A/B fail open more	2. Over pressure in deaerator (D1331) (see 5.7)	4. SV1303 setting 4 barg required flow 1400 kg/hr according to datasheet, max flow at condition liquid phase 43,159 kg/hr, max flow rate of P90916A/B; DMW supply pump is around 8,200 kg/hr. Max flow rate of P1371A/B; BFW pump is around 32,000 kg/hr. Total is 40,200 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. SV1303 setting 4 barg required flow 1400 kg/hr according to datasheet, max flow at condition liquid phase 43,159 kg/hr, max flow rate of P90916A/B; DMW supply pump is around 8,200 kg/hr. Max flow rate of P1371A/B; BFW pump is around 32,000 kg/hr. Total is 40,200 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. SV1303 setting 4 barg required flow 1400 kg/hr according to datasheet, max flow at condition liquid phase 43,159 kg/hr, max flow rate of P90916A/B; DMW supply pump is around 8,200 kg/hr. Max flow rate of P1371A/B; BFW pump is around 32,000 kg/hr. Total is 40,200 kg/hr 8. Deaerator design temperature is 200 c while low pressure steam supply is 156 c (Refer satuated steam at 5 barg)	LE3	2-Minor	0-Extremely Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. PV13003 fail open	2. Over pressure in deaerator (D1331) (see 5.7)	4. SV1303 setting 4 barg required flow 1400 kg/hr according to datasheet, max flow at condition liquid phase 43,159 kg/hr, max flow rate of P90916A/B; DMW supply pump is around 8,200 kg/hr. Max flow rate of P1371A/B; BFW pump is around 32,000 kg/hr. Total is 40,200 kg/hr 8. Deaerator design temperature is 200 c while low pressure steam supply is 156 c (Refer satuated 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 dearator (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 waork	5 X 5 LG	Moderate	Remote	P4	
		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	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. LAL13005 setting = 40% 4. LI13003 log by operator shiftwise					
		3. LT13005 error reading high	1. Low level in D1331 - P1371 cavitation and damage (see 5.10)	1. LSL13004 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 11. Set FAL13006 alarm low varied by plant load	5 X 5 LG	Moderate	Remote	P4	
		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 11. Set FAL13006 alarm low varied by plant load	5 X 5 LG	Moderate	Remote	P4	
		6. Blockage at orifice bore (BFW recirculation)	1. Low level in D1331 - P1371 cavitation and damage (see 5.10)	2. LIC13005 12. PI13017, PI13018 set high alarm at 54.9 barg (EMOC 9149-19-40 add alarm from PHA 2019)	5 X 5 LG	Serious	Remote	P3	
			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 block close	5. High pressure (see 5.7)	8. Manual throttle recirculation valve to control discharge pressure 10. Pump shut off pressure is 15.09 barg which is lower than pipeline pressure resistant 19.5 barg (150 #class)					
		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	LE3	3-Moderate	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. SV1301, SV1302 setting 15 barg (double protection when check valve XAE005, 008 leak while suction valve closed)					
		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 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 parellel (see 5.1)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	3. Pump shut off pressure is 15.09 barg which is lower than pipeline pressure resistant 19.5 barg (150 #class)	LE3	2-Minor	4-Possible	Transition	
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 dearator. 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 partrol checklist and excel sheet in share drive by operator daily	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 11. Alarm AI11002 low alarm set point at pH 9.0 (EMOC-9149-19-012)					
			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 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	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 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. Carbonic acid corrosion at Dearator		5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. Wrong concentration of chemical dosing (due to chemical 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 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					
			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)	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. Logsheet 4 times/day 9. PIC13003					
					5 X 5 LG	Serious	Remote	P3	
					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)	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)					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 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 acide corrosion at Dearator		5 X 5 LG	Serious	Remote	P3	
5.12	Loss of containment	1. Sight glass failure at NH3OH	1. Chemical spillage	3. Secondary bund in place 11. Test	5 X 5 LG	Moderate	Remote	P4	
			2. Diluted Chemical expose to personel		5 X 5 LG	Moderate	Remote	P4	
		2. Ammonia hydroxide/ Eleminox release during refill activity	1. Chemical spillage	1. NALCO's procedure 3. Secondary bund in place 4. PPE requirement 5. Emergecy chemical spillage kit 9. Test	5 X 5 LG	Moderate	Remote	P4	
			3. Concentrated Chemical expose to personel		5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		3. Ammonia hydroxide/ Eleminox Tank leakage	1. Chemical spillage	3. Secondary bund in place 4. PPE requirement 5. Emergency chemical spillage kit 10. Test	5 X 5 LG	Moderate	Remote	P4	P3 CAR 36. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM (SAPPM# 346894, 346895 plan in 2025 and 2030)
			2. Diluted Chemical expose to personel		5 X 5 LG	Moderate	Remote	P4	
		4. 'NH3OH pump leak (P8250A/B)	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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. To high chemical dosing since chemical pump not stop	2. Corrode dearator vessel	2. Interlock dosing pumps with BFW pump (P1371A/B) 4. Create new procedure (I-HYCO-062) to start/stop BFW process system and chemical dosing pumps (I-HYCO-060) to prevent high chemical dosing to deareator	5 X 5 LG	Serious	Remote	P3	
		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 3. Full time supervision	5 X 5 LG	Major	Remote	P3	
		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 2. completed					
		2. Samling cooler cooling water is isolated	1. Person expose to hot condensate	1. Wear PPE when sampling taken 2. completed	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum
Design Intent: Carbon dioxide removal from Reform Gas - 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. Carbon dioxide removal from Rich MDEA - 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. MDEA reboiler - 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 lean MDEA will go down to bottom. 'CO2 knockout drum (D1441) - 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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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	5 X 5 LG	Major	Improbable	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				4. Upstream pressure 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)	26. FAH14002 alarm high at 40,000 kg/hr					P3 CAR 48. Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) (EMOC 9149-19-052). Change action to re-confirm pump curve and confirm transmitter for high flow capacity
			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)	27. FT14002B for redundancy to prevent flow transmitter fail reading and voting (EMOC 9149-19-050)					P3 CAR 48. Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) (EMOC 9149-19-052). Change action to re-confirm pump curve and confirm transmitter for high flow capacity
			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 absorbtion capacity in T1401 (No safety issue)	7. Procedure for oprrate side stream filter 8. FI14004 to be monitored during adjust valve at sidestream fillter and comapre with total flow (FIC14002) to get 10% flowrate throgh filter 9. Regalar sampling Fe in monthly basis by operator	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 absorbtion capacity drop	9. Lower MDEA concentration and carbon dioxide absorbtion 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 contro with FIC14006 Cascade to drain out extra amount of liquid to sewer	5 X 5 LG	Serious	Remote	P3	
	8. FT14001 read low	9. Lower MDEA concentration and carbon dioxide absorbtion capacity drop	9. Lower MDEA concentration and carbon dioxide absorbtion capacity drop	10. PDAH14004 alarm setting 2.2 barg 11. LAH14003 setting 72.5% 25. LIC14003/ LV14003 in control, LIC14004 in contro with FIC14006 Cascade to drain out extra amount of liquid to sewer	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		9. LV14003A/B fail open	10. Syngas pas thorough T1404 and vent to atmosphere throggh PV14015 (Vent is located at low level) -> case LV14003A/B fail open	13. PIC14015 setting 0.7 barg (If D1531, D-1541 low-low level switch is not active) 14. LSL14002A/B/ PT14003 2oo3 (SIL2) to close LV14003 17. Stroke test and fuction test every turnaround 28. Implement XV14011 shut off valve to protect sysgas vent to atmosphere (EMOC 9149-21-05) incase LV14003 A/B not fully closed 29. ZAL14001A/B and ZAH14001A/B to identify CLOSE and OPEN position (EMOC 9140-19-035)	LE3	4-Serious	3-Unlikely	SIL-1	
			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 throggh PV14015 (low level vent) - > case LT14003 readding high	12. Low level alarm14003 setting 27.5% 14. LSL14002A/B/ PT14003 2oo3 (SIL2) to close LV14003	LE3	4-Serious	1-Highly Unlikely	Acceptable	
			13. Over pressure at T1404 (design 4 barg) leading to ruptur -> 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 17. Stroke test and function test every turnaround 30. Interlock to close FV14006 to prevent carbon dioxide gas contaminated in sewer (EMOC 9149-19-053)	5 X 5 LG	Moderate	Remote	P4	
			16. Low level in D1441, Carbon dioxide gas contain in D1441 might be leakout through FV14006 to CSS (Contaminated Sewer system), potential to personnel exposure (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 CSS (Contaminated Sewer system), potential to personnel exposure (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	5 X 5 LG	Serious	Improbable	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				15. LAL14010 setting 40% 16. LSL14009 trip pump P1473A/B 30. Interlock to close FV14006 to prevent carbon dioxide gas contaminated in sewer (EMOC 9149-19-053)					
			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 ssafety issue)	21. Compressor control logic to open recycle valve to suction to maintain 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 CSS (Contaminated Sewer system), potential to personnel exposure (see 6.10)	22. LSL14005 A/B/C 2003 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 adsorbion 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					
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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% 38. Test	5 X 5 LG	Serious	Remote	P3	P3 CAR 60. To create procedure for mitigation by manual local control with observe level sight glass in case LT14003 read low or read high (Abnormal) (WI-I-HYCO-022 revised procedure to manual adjust setpoint)
			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 34. TAH14006 at 110 c, TAL14006 at 95 c, and TAH14008 at 100 c (EMOC 9149-19-043)	5 X 5 LG	Serious	Remote	P3	P3 CAR 57. Create procedure for bypass FV13002 steam feed mixing valve (WI I-HYCO-022)
			7. Low temperature (see 6.6)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 available	5 X 5 LG	Serious	Remote	P3	P3 CAR 57. Create procedure for bypass FV13002 steam feed mixing valve (WI I-HYCO-022)
			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 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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)						
		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)	26. Lean MDEA exit E1413A/B (T114003A) alarm high at 100degree C (EMOC 9146-20-23 To create alarm set point of MDEA)	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				35. Alarm PDAH14005 across E1413 on rich MDEA set at vary load setpoint (EMOC 9149-20-33 Create alarm for monitoring E1413A/B to predict blockage)					
				36. Rich MDEA inlet E1413A/B pressure alarm high (PAH14023) set at vary load setpoint (EMOC 9149-20-33 Create alarm for monitoring E1413A/B to predict blockage)					
				37. Overall heat transfer coefficient (CI14132A/B) for E1413A/B equipped with alarm low at 1.1 kw/m2 K					
			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(Lean 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 26. Lean MDEA exit E1413A/B (TI14003A) alarm high at 100degree C (EMOC 9146-20-23 To create alarm set point of MDEA)	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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. Lean MDEA exit E1414 high temperature alarmTAH14021 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 fillter and comapre with total flow (FIC14002) to get 10% flowrate throgh filter 24. Regalar sampling Fe in monthly basis by operator					
			16. Impurity of furrir iron will induce corrosion faster (No safety 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 atmosphere vent (see 5.3)	1. Check valve at P1371A/B (Safety relevant lift check valve) 2. P1371A/B automatic swtiching	LE3	4-Serious	2-Very Unlikely	Transition:	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				11. Interlock fully closed valve FV14001 when boths P1371A/B trip to prevent reformed gas revert into boiler feed system (EMOC 9149-19-046)					
		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 126. To add interlock to close FV14002A and B when MDEA recycle pum (P1474A and B) both stopped/tripped after 20 sec (to protect reverse flow) P3 CAR 127. To review WI I-HYCO-022 for manual close FV14002A and B (By removing step to close manual valve)
		4. NG reverse though carbon dioxide compressor when shutdown (While Plant is running)	4. High pressure T1404 and MDEA equipment keading 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 keading 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			5. Toxic and flammable gas release through PV14015 to atmosphere		LE3	4-Serious	1-Highly Unlikely	Acceptable	
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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. Foaming in T1404 due to overheating of MDEA. MDEA entrained with carbon dioxide	4. More condensate in D1441/ Contain MDEA in condensate/ Risk to overflow into carbon dioxide compressor (see 6.9)	12. TAH14006 setting 130 c 13. TAH14008 setting 100 c 14. LAH14010 setting 60 c 15. Demister of D1441 16. LIC14010, LV14010A/B in control 19. TAH14006 at 110 c, TAL14006 at 95 c, and TAH14008 at 100 c (EMOC 9149-19-043)	5 X 5 LG	Serious	Remote	P3	
		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 design temperature 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	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				6. Standard operating procedure for increaisng MDEA recirculation flow to 38000 Nm3/hr to handle high heat capacity during No carbon dioxide load and 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 seting 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 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 design 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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: WI I
		5. Misdirected flow - MDEA pass through any manual 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 deisgn pressure leading to rupture (4 barg)	3. WI I-HYCO-056 has been identified 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 breakthorugh.	LE3	4-Serious	1-Highly Unlikely	Acceptable	
6.8	Low pressure	1. Low/ No flow (PV14026 failed close - Oxygen ingress due to vacuum condition through leaking joint causing MDEA degraded/ combustible mixture in reformer feed) (see 6.2)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 condesate 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 condesate in D1441/ Contain MDEA in condensate/ Risk to overflow into carbon dioxide compressor (see 6.4)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		8. High temperature - MDEA overheat and carried 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. LSLL14009 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. LSLL14005 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. LSLL14005 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. LSLL1507 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: WI I
			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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
6.11	High concentration of contaminants	1. PV14026 fail open or setting too high or leak passing through	5. Nitrogen ingress to carbon dioxide line and feed to reformer and contaminated with CO product	8. Product purity analyser 'A116011 AAL = 98% (%CO) ASLL = 97.5% (trip product valve)	5 X 5 LG	Major	Remote	P3	
		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 inspectino of MDEA color to change filter	5 X 5 LG	Serious	Remote	P3	P3 CAR 62. Review and Update I-HYCO-098 for reference color to replace new MDEA by reference with supplier recommnedation
		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 diviation 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			4. Corrosion in column/ more Fe Ion / More possibility blockage in E1413, E1414		5 X 5 LG	Major	Improbable	P3	
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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 cartidge 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 meassurement 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 openning 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		5. MDEA vapor exposure during MDEA preparation	7. Toxic chemical exposure	7. Haft mask with organic filter cartidge available as additional PPE	5 X 5 LG	Moderate	Remote	P4	
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 sampling	1. High temperature exposure during sampling lean MDEA	1. High temperaature exposure causng hot burning injury	1. Standard PPE 2. Sampling WI for MDEA sampling I-HYCO-012	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 cartridge 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 CO ₂ / 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 foaming and fouling in system, tray damage	3. Manual analysis 2 times/ week for concentration, 1 time/ month for Fe Ion 4. Abnormal deviation 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. 'CO ₂ in lean MDEA will be higher due to rich MDEA mixing, reduce performance of carbon dioxide adsorption, 'CO ₂ 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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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. PDAHH15006.A/B setting alarm 3 barg to hold step 5. PDAH15006.A/B setting at 0.9 barg (EMOC 9149-19-043 Implement tag and revise setting alarm) 6. Test	5 X 5 LG	Serious	Remote	P3	P3 CAR 65. Update sequential document PMC0110-007 follow real actual logic of TSA unit to explain about logic of PDAHH15006 A/B and update PID for PDAHH15006 A/B
			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 7. PAH15001 alarm at 33 barg (In case PIC12001 cannot detect due to transmitter problem (EMOC 9149-19-40))	5 X 5 LG	Serious	Remote	P3	
			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 8. Test	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
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 8. Test	5 X 5 LG	Moderate	Remote	P4	
		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 7. Test	5 X 5 LG	Moderate	Remote	P4	
		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. KV15010, KV15011 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					
		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				4. Design temperature range of equipment can cover max 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			4. Low/no flow - Coldbox (T1601: Methan wash 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)						
7.10	Loss of containment	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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	2. Test	5 X 5 LG	Serious	Remote	P3	
			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 4. PPEs 5. Personal gas detector	5 X 5 LG	Major	Remote	P3	
7.14	Deviation during sampling	1. High pressure Syngas release during sampling	1. Fire and explosion	1. WI I-HYCO-013 2. PPEs	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. Sampling is design for closed loop to prevent release of flammable or Toxic 4. Personal gas detector					
			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. Cleanning 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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 0.9 barg 7. Test	5 X 5 LG	Major	Remote	P3	
		2. PT15013 error reading high	1. Adsorbent support collapse/ Seived damage	3. PAL18001 setting 27 barg 7. Test	5 X 5 LG	Major	Remote	P3	
		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 2. PDAH 15002.B, PDAH15004.B setting 0.9 barg	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 0.9 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 10. WI 15-006 to identify manual increasing flow in Warm purging step	5 X 5 LG	Serious	Remote	P3	
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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)	11. Test					
		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					
		16. Low/no flow - PSA plant (A1,2,3) (see 15.2)							
8.3	Reverse flow	1. Hydrogen back to nitrogen header	1. Hydrogen fraction entrained to nitrogen and contaminated. Risk to fire and explosion (see 8.10)	1. Check valve 2. Doulbe block and bleed valves	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. Spectacle blind 4. WI I-HYCO-056 for switch regeneration gas from hydrogen fraction to nitrogen					
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	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				2. TSL15003, 005 setting 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		3. Low/no flow --> KV15017 regeneration gas heater bypass malfunction close in cooling step (see 8.2)							
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/ Sieved 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)	5. Test 6. To follow WI I-HYCO-056 in case of PT15003 failure while replacing spare part 7. Test					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				8. TAH15007 setting at 185 c to warn high temperature at adsorber					
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 before start up 2. PSSR	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 remained open	1. Misdirected flow (see 8.4)	1. Level indication LI15004 2. LAL15004 3. Operator log condensate level in D1541 2 times/shift					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	
			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/ 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)						
		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/ 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)						
		3. LV16002 failed closed	1. Low/no flow - Drier (TSA) (see 7.2)	2. LAH16002 setting 60%					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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)						
		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/ 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)						
		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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			5. Partially low syngas to coldbox causing product off spec (CO, hydrogen)		5 X 5 LG	Minor	Remote	P4	
			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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		11. High flow - Coldbox (Liq Methan pump) → FV16003 fail open (see 12.1)	2. No refrigerant to E1612. CO and Methane are not condensed/ Impurty in TSA regeneration	1. LAH16001 setting 60% 2. LAH16002 setting 60% 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	
			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 freezed. 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/ Impurty 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 safet 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 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				5. Standard operating 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 safet 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 7. PAH16032 in T1601 pressure vent valve set at 33 barg (EMOC 9149-19-40)	LE3	4-Serious	1-Highly Unlikely	Acceptable	
			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 7. PAH16032 in T1601 pressure vent valve set at 33 barg (EMOC 9149-19-40)	LE3	4-Serious	1-Highly Unlikely	Acceptable	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 barg 5. SV1501,2,3 setting 35 barg 6. PV15001 setting 31.75 barg	LE3	4-Serious	1-Highly Unlikely	Acceptable	
		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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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% 3. PDAH16001 setting 280 mbar	5 X 5 LG	Minor	Remote	P4	
		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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				8. WI I-HYCO-080 has updated to have troubleshooting when no level in T1601. operator must manually shutdown coldbox to prevent damage to CO turbine and CO compressor. 9. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)					
			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)						
	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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				6. LV16001 mechanical limitation 80%OV matching with downstream relief valve capacity 7. LV16001 mechanical limitation 75%OV matching with downstream relief valve capacity 8. WI I-HYCO-080 has updated to have troubleshooting when no level in T1601. operator must manually shutdown coldbox to prevent damage to CO turbine and CO compressor. 9. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)					
			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 trip at 100% load	5 X 5 LG	Serious	Remote	P3	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 7. All temperature indicators of coldbox (both heat exchanger and column) are equipped with high differential ramp rate alarm set at ± 25 °C/hr to indicate abnormal heating up and cooling down rate.	5 X 5 LG	Major	Remote	P3	P3 CAR 128. Create standard operating procedure for operators to manage temperature rate of change alarm for start up, thawing, and normal operation
		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 7. All temperature indicators of coldbox (both heat exchanger and column) are equipped with high differential ramp rate alarm set at ± 25 °C/hr to indicate abnormal heating up and cooling down rate. 8. TAH16002 set at -180 c for start up case (EMOC 9149-19-040)					
		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 7. All temperature indicators of coldbox (both heat exchanger and column) are equipped with high differential ramp rate alarm set at ± 25 °C/hr to indicate abnormal heating up and cooling down rate.	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		6. Too differential between Hot/ cold stream in E1611, E1612	2. Thermal stress from high differential temperature >50 c in heat exchanger leading plate exchanger crack. Major release of toxic/ flammable gas (see 9.17)	1. WI 16-0007 coldbox start up 7. All temperature indicators of coldbox (both heat exchanger and column) are equipped with high differential ramp rate alarm set at ± 25 °C/hr to indicate abnormal heating up and cooling down rate.	5 X 5 LG	Major	Remote	P3	
		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 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	
		10. Too fast pressurization > 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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					
			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. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown	5 X 5 LG	Serious	Remote	P3	
		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. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown	5 X 5 LG	Serious	Remote	P3	
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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 5. SAP Tasklist TLAS0017 for overhaul FV16004 has been set up (SAPPM# 346896 latest SAP order)	LE3	4-Serious	1-Highly Unlikely	Acceptable	P3 CAR 82. To limit opening of FV16004 to prevent methane pump cavitate. To raise EMOC for reviewing the optimum set point (Cavitation phenomena will not happen in recipocating pump type)
			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 thorough 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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				5. SAP Tasklist TLAS0017 for overhaul FV16004 has been set up (SAPPM# 346896 latest SAP order)					
			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 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		4. Low/no flow → FV16004 fail close, FT16004 error reading high (see 10.2)	1. Loss CO/ CH ₄ . 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)						
		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 (T1601: 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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. TSL16016A/B/C (SIL1) setting 10 c 3. TAL16016 setting 20 c warning alarm 4. PAL16003 warning alarm setting 6 barg 5. PIC16004 pressure control downstream E1611 to flare	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)						
		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 downstream 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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. SAP Tasklist TLAS0017 for overhaul FV16004 has been set up (SAPPM# 346896 latest SAP order) 6. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)	5 X 5 LG	Minor	Remote	P4	
			2. Overflow T1602, Lower hydrogen stripping causinsg hydrogen entrainment with CO/CH4. Results is coldbox upset		5 X 5 LG	Serious	Remote	P3	
		2. Low level (bottom) - Coldbox (T1601: Methan wash column) (see 9.10)	2. Overflow T1602, Lower hydrogen stripping causinsg 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) 8. WI I-HYCO-080 has updated to have troubleshooting when no level in T1601. operator must manually shutdown coldbox to prevent damage to CO turbine and CO compressor.	5 X 5 LG	Serious	Remote	P3	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			2. Overflow T1602, Lower hydrogen stripping causing 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) 6. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)	5 X 5 LG	Minor	Remote	P4	
			2. Overflow T1602, Lower hydrogen stripping causing 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 causing 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 causing 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% 4. LV16003 mechanical limitation 88%OV					
			2. Low pressure in T1602 (see 10.8)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 5. Logic for reading value freezing, alarm to warn operators to inspect and solve the problem according to I-HYCO-080 (EMOC 9149-20-22 Add logic for check instrument reading value freezing)					
			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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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) 6. TAL16032 setting -170 c (Tail gas)	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			10. High flow - Coldbox (CO 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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		7. FV16006 failed open	3. CO compressor discharge low pressure (see 14.8)	1. PDAH16005 setting 210 mbarg 2. FIC16007 3. TAL16023 Setting -183 c 4. TSL16024A/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 compressor (see 14.7)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 6. TAH16022 set -179 c to protect warm (EMOC 9149-19-40)	5 X 5 LG	Moderate	Remote	P4	
			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 6. TAH16022 set -179 c to protect warm (EMOC 9149-19-40)	5 X 5 LG	Moderate	Remote	P4	
			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	5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				4. PDAH16005 setting 210 mbarg					
			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	
					5 X 5 LG	Moderate	Remote	P4	
		7. FV16006 failed close	1. CH4 slip from T1603. Product off spec (see 11.5)	4. PDAH16005 setting 210 mbarg 5. FIC16007 6. TAH16022 set -179 c to protect warm (EMOC 9149-19-40)	5 X 5 LG	Moderate	Remote	P4	
					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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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)						
		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 CH ₄ freezing and block in E1615 (see 12.6)	3. Mechanical lock opening value at HV16009 at 80% OV. 5. To limit flow not over Safety valve capacity (EMOC 9149-17-021)					
			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 CH ₄ 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 reflux to T1603 (see 11.1)	2. Methane contaminated 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 new setting 2.5 barg from 2.9 barg (EMOC 9149-19-043) 3. PI16033 4. Test	LE3	4-Serious	1-Highly Unlikely	Acceptable	
		2. PT16033 reading low	1. Over pressure T1603	1. SV1603 setting 3 barg 2. PAH16033 new setting 2.5 barg from 2.9 barg (EMOC 9149-19-043) 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 new setting 2.5 barg from 2.9 barg (EMOC 9149-19-043) 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	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				2. CO Compressor suction pressure PAL16300 0.85 barg 3. CO Compressor suction pressure PSL16300A/B/C 0.8 barg trip CO compressor					
			2. Coldbox upset CO off spec		5 X 5 LG	Moderate	Remote	P4	
			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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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. LSLL16005A/B/C 2oo3 trip P1671A/B setting 5 %	5 X 5 LG	Serious	Remote	P3	
		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. LSLL16005A/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. LSLL16005A/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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 → Recirculation of Nitrogen at too low temp in CO circuit (see 9.13)	1. Toxic/ flammable leak to atmosphere (see 12.14)		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 (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. Flab 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		3. Too differentail 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 4. Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown	5 X 5 LG	Major	Remote	P3	
		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 system. Delay schedule for start up		5 X 5 LG	Serious	Remote	P3	
		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 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	
		6. Too fast pressirization > 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. TAL16026, and TAL16067 setting -175 c in order to detect freezed liquid methane at E1615 (EMOC 9149-10-040)	5 X 5 LG	Major	Remote	P3	
			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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	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 4. Planned maintenance for doing calibration of safety valve with major turnaround 5. Portable Gas detector	5 X 5 LG	Major	Remote	P3	
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 opn (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 reprocating 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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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. Overpresurized 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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 4. Portable detector	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 trip turbine					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			2. Low pressure - CO compressor + CO supply line (see 14.8)						
13.2	Low/no flow	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 turbine (see 13.7)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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 4. Test	5 X 5 LG	Minor	Remote	P4	
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 separation column) (see 11.2)	1. Discharge turbine high temp. T1602 high temp (see 10.5)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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. TSL16059A/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. Test	5 X 5 LG	Serious	Remote	P3	
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 thawing	5 X 5 LG	Moderate	Remote	P4	
13.11	Loss of containment	1. Leakage turbine seal	1. Personnel expose to Toxic gas	1. Fixed CO detectors	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				2. CO turbine enclosure vent linbe connected with flare					
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 92. Add content for completely purge CO turbine in I-HYCO-0037 CO turbine start up and shutdown (updated only start up, no update for shutdown: purge CO before maintenance)
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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 6. WI I-HYCO-070 for soot filter purging/ carbon dioxide adsorber purging	5 X 5 LG	Major	Remote	P3	
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 2003D (SIL2) setting 50 c (stage 4) 2. TAH16040 setting 45 c (stage 4)	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. CO product pipeline is 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 2oo3D (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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	
			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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			5. Loss suction to stage#4 causing 'HP CO to Turbine (see 13.2)						
14.9	High concentration of contaminants	1. High concentration of 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 94. Update CO compressor start procedure for open gas line at lowest point to check for any water leak from cooling tube (update WI -I-HYCO-070 to cover for starting CO comp
		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 release	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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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 bomb	5 X 5 LG	Serious	Remote	P3	
			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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 (cap 738 kg/hr)	LE3	4-Serious	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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. TAAH18001 setting 50 c trip FN18001 (SIL1) 3. Test					
			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	
		3. PV18002.B fail close when required to open	2. High pressure to pipeline and Vessel	3. PAH18001 setting 30 barg	LE3	2-Minor	1-Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				4. Safety valve at bed setting 32 barg					
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 off spec (CO/CH4)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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/CH ₄)						
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 6. WI 18-005 confirm %Nitrogen in Hydrogen before supplying to customers					
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 during Shutdown	1. Saturated adsorbent leading to adsorbent degradation		5 X 5 LG	Minor	Possible	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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. 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
15.14	Deviation during sampling	1. Gas leakage from samplg valve/ Flexible hose connection	1. People exposureToxic 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: PSA plant Node (E1/R1)
Design Intent: Adsorption step (E1,R1) - 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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 78. 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 diviation end step trip bed	5 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 78. 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 78. 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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: PSA plant Node (E2/R2)
Design Intent: Adsorption step (E2,R2) - 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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 diviation end step and Valve position feedback alarm → trip bed 2. FAH18001 setting 750 kg/hr	5 X 5 LG	Serious	Remote	P3	P3 CAR 78. 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 diviation end step and Valve position feedback alarm → trip bed					P3 CAR 78. 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 diviation end step and Valve position feedback alarm → trip bed 2. FAH18001 setting 750 kg/hr	5 X 5 LG	Serious	Remote	P3	P3 CAR 78. 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 diviation end step trip bed and valve position feedback command to trip Bed 2. PAH18003 setting 0.8 barg 3. PIC18003 high pressure vent	LE3	4- Serious	1- Highly Unlikely	Acceptable	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: PSA plant (P1/PP1 and P5/PP5)
Design Intent: Adsorption step (P1/PP1 and P5/PP5) - 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), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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	
					5 X 5 LG	Minor	Remote	P4	
			4. Impurity in feedgas contaminate to another bed						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 CO in hydrogen	5 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 comtamination		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 comtamination		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 comtamination		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 vent	5 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 - Amorphous Alumina oxide - Activated carbon - Aluminosilicate			
P&ID: 18PFP03, 18PFP01			
Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 deviation end step and Valve position feedback alarm → trip bed					P3 CAR 78. 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 deviation end step and Valve position feedback alarm → trip bed					P3 CAR 78. 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 deviation 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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	
					LE3	4- Serious	1- Highly Unlikely	Acceptable	
			4. Rupture D1832 and pipeline over pressure than design through step P1, Flammable gas release/ Fire and explosion (see 19.5)						
			5. Low pressure - PSA plant (A1,2,3) (see 15.8)						
			6. Misdirected flow (see 19.4)						
			3. Incompleted regeneration (D) causing product contamination						
		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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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)						
		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					
19.2	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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: PSA plant (R0/R01)
Design Intent: Adsorption step (R0/R01) - 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 - Amorphous Alumina oxide - Activated carbon - Aluminosilicate			
P&ID: 18PFP03, 18PFP01			
Participating Team Members (including roles): Napakorn Chalee (HAZOP member), Santi Chonabot (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Jumphot Jindaphol (HAZOP member), Varinda Sakulpacharoen (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 deviation 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 deviation end step and Valve position feedback alarm → trip bed					
		2. XV18015-55 failed close	1. PSA step interruption (No safety issue)	1. PT180X0 - Pressure deviation 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 deviation 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	
			2. Low pressure - PSA plant (A1,2,3) (see 15.8)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: Warm, Cold Flare
Design Intent: Cold flare - 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 - 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 - 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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			4. High level (see 21.9)						
		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) 2. SAPPM# 346897 for checking leak of 2 XAH001 (Dead man valve) at every 5 years	5 X 5 LG	Serious	Remote	P3	
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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. High temperature upstream manual vent valve of 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	
		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 laidng 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 drain out condensate 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	
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							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
21.15	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	5 X 5 LG	Major	Remote	P3	
			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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (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	
			2. Water hammer in dearator		5 X 5 LG	Moderate	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 at local panel 5. LI0105,7 dearator level monitor by operator every shift	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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. LSSL900102 trip burner 2. LSSL900103 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. LSSL900102 trip burner 2. LSSL900103 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 99. To create PM schedule to ensure PSV1202 (Diesel recirculation pressure control) is properly function together with yearly Recertify (removed Diesel unit out in 2020)
		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					
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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					P3 CAR 100. To revise WI-I-HYCO-040 to include isolation of steam from process reverse to package boiler (revise I-HYCO-040 to cover steam from process reverse to package boiler)
		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					
			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)	9. Test					
		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 X 5 LG	Serious	Improbable	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				5. PSV1205 setting 10.5 barg					
			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)	4. Test					
		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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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 dosing 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 measuring 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	Major	Remote	P3	
		2. Servomotor controller malfunction	1. NOx, SOx emission to atmosphere	1. Flame detector in burner 4. PM servomotor every TA 5. TAL900105 set at 100 c to prevent afterburner (EMOC 9149-19-040)	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	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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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	P3 CAR 36. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM (SAPPM# 346894, 346895 plan in 2025 and 2030)
			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 36. Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM (SAPPM# 346894, 346895 plan in 2025 and 2030)
		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	6. Test	5 X 5 LG	Moderate	Remote	P4	
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 102. To revise WI I-HYCO-048 to include flushing for removing Fe before start up (Revise and add flushing in I-HYCO-048)
		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	
		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 prvent 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							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (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 PCV10594-1 is lock open to ensure functioning of PVC10954-1,2 5. NG booster suction line PAH10594-3 setting 33 barg 6. Test 7. PAH901301 set at 45 barg and PAL901301 set 36 barg at NG booster discharge pressure to warning operator (EMOC 9149-19-040)	5 X 5 LG	Major	Remote	P3	
			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 6. Test	5 X 5 LG	Major	Remote	P3	
			2. Short NG supply to Hyco plant (No safety issue)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			3. Low pressure downstream (No safety issue)						
			4. Low pressure (see 23.8)						
		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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
23.4	Misdirected flow	1. Operator error - misoperating	1. Short supply to Hyco plant (No safety issue)	1. Checklist that specifies 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. TAAH10543, 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 compressor	5 X 5 LG	Major	Improbable	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				3. PSV10531,34 at discharge compressor 6. PAH901301 set at 45 barg and PAL901301 set 36 barg at NG booster discharge pressure to warning operator (EMOC 9149-19-040)					
			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 6. PAH901301 set at 45 barg and PAL901301 set 36 barg at NG booster discharge pressure to warning operator (EMOC 9149-19-040)	5 X 5 LG	Major	Improbable	P3	
			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 3. PAH901301 set at 45 barg and PAL901301 set 36 barg at NG booster discharge pressure to warning operator (EMOC 9149-19-040)					
		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)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 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					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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	2. WI I-HYCO-081 and 087 to update valve checklist for hydrogen mix feed to NG booster	5 X 5 LG	Serious	Remote	P3	
		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)							
24.8	Low pressure	1. Low/no flow (see 24.2)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 of compressor. Oxygen feed to reformer		5 X 5 LG	Major	Improbable	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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, setting 260 mm	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 when discharge 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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 compressure. Lower efficiency and damage compressure 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 suction pressure plus shutoff pressure exceeding compressor casing design pressure)		3. Relief valve 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	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				7. Fix gas detector with warning alarm at carbon dioxide compressor house					
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. Electrcal 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 98. Provide narative description for 6KV motors (C1408, C1608) interlock logic for starting cycle protection and communicate to maintenance and operation team (relay protection system changed, so curret logic are not the same as current procedure)
		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 3. Lockout/tagout procedure	5 X 5 LG	Major	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (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 opened (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 procedure to check the purity of feed carbon dioxide from tanker before filling					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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. TAAH851A-1, TAAH851B-1 to prevent pump dry run setting 0 c 2. TAAH851A-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)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	5. Low flow to T85B (No safety issue)						
			6. Low pressure (see 27.5)						
		1. N851A-2, N851B-2 failure	1. High pressure warm gas leaks back through pump	1. Pump suction valve ECV85A-1, ECV85B-1 2. The cold liquid in tank will condense incoming has 3. Tank PSVs 5. PSV851A-2,B-2 setting 22.5 barg 6. Suction pipe rating > discharge pressure of pump	5 X 5 LG	Serious	Remote	P3	P3 CAR 122. Recheck that PSV851A-1, 851B-1 can cover full flow rate in case of reserve flow from running pump: Irrelevant case by design of reciprocating pump reverse flow of running pump cannot overpressure of stand-by pump
			2. Overpressure of suction side of pump and suction pipe		5 X 5 LG	Serious	Improbable	P4	
			3. Potential overpressure of T85A		5 X 5 LG	Serious	Remote	P3	
		2. Reverse 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	
27.4	High pressure	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	
		4. High flow (see 27.1)							
27.5	Low pressure	1. T85A low pressure	1. Pump lost of prime or cavitation	1. Tank 85A PAL9085A-1 setting 15 barg	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				2. TAAH90851A-1, TAAH90851B-1 setting 0 c (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. TAAH90851A-1, TAAH90851B-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. TAAH90851A-1, TAAH9085B-1 set point -5 c 4. TAAH90851A-1, TAAH90851B-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 113. To revise standard operating procedure 10-0013 for mentioning slowly open vent/drain valve to prevent dry ice blockage due to rapid depressurizing (Need to update in I-HYCO-041)

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		2. V851A-1, V851B-1 and V7 is not fully opened	3. Low flow suction P851A,B. Pump cavitate	1. TAH90851A-1, TAH9085B-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	
		3. V851A-1, V851B-1 and V7 is fully closed	2. Pump damaged due to loss suction	1. TAH90851A-1, TAH9085B-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 4. Anti whip regular inspection check every shift 5. To have anchor point to protect hose wip (EMOC 9149-23-09)	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (HAZOP member), Somchai Thavonrattanavanit (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 overfill/ 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 during filling	3. T85B overfilled	1. PSV17A/B, PSV18A/B, high level alarm, LAHH85B-1, PAHH851-1, PAH85B, PI85B-1					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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					
28.6	Low temperature	1. Low/No level (see 28.2)							

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (**cont'd**)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
28.7	High concentration of contaminants	1. Contaminated from T85A (see 26.7)	1. High concentration of contaminants - CO2 vaporizer E852 (see 29.8)						

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 openned/ 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 4. PSV852-1 setting 45 barg 5. TAH901202 setitng 90 c					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 6. To add hot water sampling valve at E852 (CO2 vaporizer) with needle valve 1/4" to protect water in bath low level					
		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 2. To add hot water sampling valve at E852 (CO2 vaporizer) with needle valve 1/4" to protect water low level 3. WI I-HYCO-085 SOP to cover sampling water from hot waterbath E852	5 X 5 LG	Moderate	Possible	P3	
			2. Low level water in hot waterbath (see 29.6)						

Table A.1 Hazard Analysis Worksheets for the HyCO plant (**cont'd**)

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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), Khanit Jiamtaweewiboon (HAZOP Leader), Varinda Sakulpacharoen (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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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)					

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Linde PLC	HYCO	MTP1	Name: utilities and services
Design Intent:			
Participating Team Members (including roles): Attapong Campbell (HAZOP member), Napakorn Chalee (HAZOP member), Khanit Jiamtaweewiboon (HAZOP Leader), Pipat Lubiam (HAZOP member), Varinda Sakulpacharoen (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 13. DCS back up by UPS (Control system, Safety system PLC) supply 45 mins	5 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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 logic 10. PM for transformer condition monitoring (oil sampling, etc) 11. Thermoscan inspection of switchgear	5 X 5 LG	Minor	Remote	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
				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)						
		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 22. Test	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)						
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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)							
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
		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 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 temerature indicator with local high temp alarm 6. Room temerature indicator with high temp alarm link to DCS 9. Standby air condtion 1 unit running 3 units	5 X 5 LG	Serious	Improbable	P4	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Item	Deviation	Causes	Consequences	Safeguards	Matrix	S	ML	MR	Action Items
			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 13. Test	5 X 5 LG	Serious	Remote	P3	
		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	
		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	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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	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	Shut down & start up procedure to ensure all remain condensate are drained out and not remain in the low point of carbon steel material Survey remaining similar issue for thinning material of high temperature carbon steel Survey gas leak and keep record daily monitoring Change new leak reducer in next shutdown Fabricate new spool if found less thinning Behaviour & Communication Test completed	
PMIR-13-07 (Thailand) : HYCO steam reformer wall burnout (Synergi#51702)	Hot reformer tube due to overheat	1. Syngas leak and impingeto reformer walls 2. Inner insulation damage 3. Reformer wall damage	Review trouble shooting for 1) Reformer 2) Pre-reformer 3) HDS 4) Overheating tube Increase frequency of reformer tube visual inspection (1 x shift) Review position of Min. stop estimate position with valves (FV10011/FV10012) Removal of process steam solenoids, adding mech. stop disk (FV10012) Modify interlock on Flare valve PV10009 during Cold start up Use of PV10009 (Emphasize risks around operation of PV10009) - Ignition procedure - Hot start procedure - Mitigation in case of lack of H2 recycle at HDS - High CH4 slip	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Review of previous incident reports				
Incident	Initiating Events/Factors	Consequences	Investigation Results	Action Items
			S/C ratio (refer new material balance) - CO2 ratio - Composition changing - Burner operation - Cold box operation - 110% for CO product Re-design burner (Detail&Quotation): Already issued LOI to Sela Linde for new burner design Review SD procedure if no H2 recycle available 1) High H2 pressure source (Tube trailer, Pack) 2) Redundant H2 compressor Detail of HDS purging procedure and training Review sampling/analysis procedure (HDS) Add variable PDAH HDS reaction (vs. load) Pre-reformer activation level alarm	
Synergi#43687 Methan pump disc flexible hose damage	Thermal stress to CH4 flexible hose	1. CH4 leakage during start up pump	Hydro test every 1 years (8000 hrs) Replace discharge flexible hose every 5 years Apply thermoscan compare between pump A,B 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 Retighten both pump&motor Compare discharge temperature Review WO to change from liq to gas colddown and cooldown rating temp SAP PM# 346898 and 346899 schedule for replacing methane pump discharge flexible hose every 5 years (SAP PM# 346898 and 346899 for unit A and B)	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Review of previous incident reports				
Incident	Initiating Events/Factors	Consequences	Investigation Results	Action Items
Synergi#175756 Gas leak flange E1122(Syngas, temp 400 deg C) and fire at insulation	Pipe stress and misalignment from thermal expansion	1. Reformed gas release and contact with hot surface at 400 c. Fire in insulation 2. HYCO plant emergency shutdown due to Syngas leaked and fired at WHB outlet flange	Modify pipe support (no.1) to allow correct movement Recheck pipe movement to ensure no stress after action 1 complete Replace gasket at E1122 every TAR	Rec 6. Reformed gas pipe outlet E1122 needed to recalculate stress 3rd party vendor since there was repeated leakage in 2019. Synergi#270526 P3 CAR 107. Recalculation from 3rd party vendor results of Reformed gas pipe outlet E1122, Recommendations to be implemented within TAR2020

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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 treatment chemical vendor	5 X 5 LG	Serious	Remote	P3	

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

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
33.2	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 tempeature alarm at end equipement '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 tempeature alarm at end equipement	5 X 5 LG	Serious	Remote	P3	
		Overflow cooling water basin	1. Cooling water lost causing equipment downstream high temperature	High tempeature alarm at end equipement 'LIC9091C control at 85-90% LAH9091 setting 90% warning alarm DCS LAHH9091 setting 95% warning alarm DCS	5 X 5 LG	Serious	Remote	P3	

Company: Linde Thailand
 Location: Map Tha Phut Site 1
 Facility: HYCO plant

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Node: 1. HAZOP GLOBAL ISSUES Checklist
 (MS-10070) - HYCO plant
Parameter: Global Node

Deviations	Causes	Consequences	Consequences	Safeguards	Risk After All Safeguards			Recommendations			Remarks
			Type		S	L	R	Recommendations	Priority	By	
No / Less Plant Wide Power	1.1. Plant-wide power failure due to weather or equipment malfunction.	1.1.1. Potential loss of basic process controls, external equipment lighting, and distributive control system resulting in a possible total plant shutdown	FI	1.1.1.1. Control and shutdown whole plant after power failure.	4	1	2				
		1.1.2. Possible safety issues related to sudden loss of cooling, loss of power to safety systems, etc.	PI	1.1.1.2. UPS system backup for 6 hours for control system of HYCO plant. 1.1.1.3. Independent power generation system for HyCO plant (manual switching after power failure)	4	1	2				
No / Less Insulation	1.2. Failure to specify that hot surfaces be insulated during design/ construction. Failure to maintain insulation during life of the equipment	1.2.1. Potential for thermal contact burn injury due to personnel exposure to un-insulated surfaces of piping or equipment in service with temperature >140 °F	PI	1.2.1.1. Adequate personal protection for hot/ cold surfaces (e.g. caging, signage) considered in HYCO Plant design. 1.2.1.2. Insulation of piping/ equipment will be reinstated following each maintenance program.	3	1	2				
	1.3. Failure to specify that cold surfaces be insulated during design/ construction. Failure to maintain insulation during life of the equipment	1.3.1. Potential for thermal contact freeze burn injury due to personnel exposure to un-insulated surface of piping or equipment in service with temperature <-40 °F	PI	1.3.1.1. Adequate personal protection for hot/ cold surfaces (e.g. caging, signage) considered in HYCO Plant design. 1.3.1.2. Insulation of piping/ equipment will be reinstated following each maintenance program.	3	1	2				
No / Less Sample Cooler(s) Mechanical Integrity	1.4. Cooling water valve closed	1.4.1. Potential personnel injury due to hot surface/sampling	PI	1.4.1.1. Sampling procedure (WI# I-HYCO-013)	3	1	2				
	1.5. Cooling water tube blockage by deposition or fouling	1.5.1. Potential personnel injury due to hot surface	PI	1.5.1.1. Sampling procedure (WI# I-HYCO-013)	3	1	2				
No / Less Safety and Pressure Relief Device Reliability	1.6. Safety and Pressure relief devices installed without auditable and documented routine maintenance records	1.6.1. Potential to compromise the piping and equipment overpressure protection, resulting in a possible damage and energy release, loss of primary containment, and personnel fatalities in the event of an overpressure excursion.	PI	1.6.1.1. Current SAP PM program captures the requirements (based on Linde's guidelines) on PSV calibration and maintenance. 1.6.1.2. Package boiler and Process gas boiler have to follow regulatory guideline (Yearly report)	4	1	2				
	1.7. Isolation valve(s) left closed to inlet or from outlet of safety or pressure relief device.	1.7.1. Potential to compromise the piping and equipment overpressure protection resulting in a possible damage and energy release, loss of primary containment, and personnel fatalities in the event of an overpressure excursion	PI	1.7.1.1. For HYCO plant, there is no inlet/ outlet manual valve for individual PSV.	4	1	2				
No / Less Inerting	1.8. Start up/ shutdown and maintenance procedures for HYCO plant clearly define the requirements for purging/ inerting. No significant issue of concern identified.										
No / Less Labeling	1.9. No significant issue of concern identified with respect to tagging/ labeling for HYCO plant.										
No / Less Machinery Guarding	1.10. All compressors and pumps are equipped with machinery guarding. No significant issue of concern identified for HYCO plant.										

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Deviations	Causes	Consequences	Consequences Type	Safeguards	Risk After All Safeguards			Recommendations			Remarks
					S	L	R	Recommendations	Priority	By	
No / Less Grounding	1.11. Use of incorrect gauge wire or not connecting properly or not providing supplementary grounding.	1.11.1. Potential for electrical hazards to introduce an ignition source and contribute to possible personnel fatalities.	PI	1.11.1.1. Grounding of all fixed and rotating equipment are provided as per design standard.	4	1	2				
				1.11.1.2. Every 3 months, checking grounding connection for physical connection by Maintenance team							
				1.11.1.3. Yearly for visual inspection on electrical grounding conditions.							
				1.11.1.4. Every 5 years, checking earth resistance referred to PLM-10-14 Plant Earthing Maintenance Test Report							
No / Less Fire Protection	1.12. Main supplied from plant shut down or out-of service	1.12.1. Potential loss of primary fire fighting protection in the facility, resulting in heightened human factor effects and potential personnel exposure to hazardous scenarios.	PI	1.12.1.1. GUSCO supplied backup to fire water system.	4	1	2				
				1.12.1.2. Automatic electronic fire pump system with pressure switch. Pump#2 is working at 80 psig, once pressure drop to 70 psig, Pump#1 will start. Electronic system's power supply by battery equipped with charger (drived with fire pump engine							
				1.12.1.3. Annual fire drill conducted with external team for the firefighting drill.							
				1.12.1.4. Annual external verification by Maptaphut municipal conducted by Rayong Fire Co.,Ltd (authorized agency) of firewater system							
	1.13. Main Fire water pump out of service	1.13.1.	PI	1.13.1.1. Redundant fire pump (pump 1/2)	4	1	2				
				1.13.1.2. Weekly test fire pump							
				1.13.1.3. Yearly PM and performance test							
No / Less Compatible Material(s) of Construction [Fabrication, Installation / Maintenance]	1.14. No significant issue of concern identified for HYCO plant.										
No / Less Basic Process or Emergency Controls	1.15. Logic bypass jumpers left in place after checking, testing or calibrating equipment during normal operation. Jumpers include, but not limited to, the following: Software jumpers in the BPCS or SIS; "Forced" inputs or outputs within the BPCS or SIS; Simulated values within the BPCS, SIS or transmitter(s); Hard wired jumpers.	1.15.1. Potential to compromise the effectiveness of the Critical Safety Systems (CSS) to function in the event of an excursion resulting in possible equipment damage, energy release, loss of primary containment, fire, and personnel fatalities.	PI	1.15.1.1. Override Record sheet is required for any bypassing of Critical Safety Systems. In case of more than 12 hours bypass demand, Temporary MOC is required.	4	1	2	1.15.1.1. To implement jumper log form (MS-84780/ 84781) by Jan 2026			
No / Less Purge Panel Safety	1.16. Instrument gas (N2) regulator malfunction open to purge panel	1.16.1. No significant consequences as excessive instrument air pressure (~7 barg) will be leaking out from the panel via cable glands.									
	1.17. Instrument gas (N2) to purge RIO panel disrupted due to human error or regulator malfunction (fails closed).	1.17.1. Potential to introduce an ignition source to an electrical classification area, resulting in a possible fire, energy release, and personnel fatalities	PI	1.17.1.1. N2 supply comes from network (ASU700, MIGP and MIG) 1.17.1.2. Plant patrol checklist to check N2 purge I/O Base panel pressure (Barg) shiftly	4	1	2				
No / Less Site Security	1.18. Unauthorized personnel permitted onsite and/or inside operating battery limits.	1.18.1. Potential for injury to unauthorized and untrained personnel.	PI	1.18.1.1. Contractors Safety training 100% before working within the plant	3	1	2				
				1.18.1.2. Site security							
				1.18.1.3. PTW system for all works performed on site							
Ambient Temperature	1.19. Not applicable for Thailand weather conditions										
More Flow to Atmosphere	1.20. No significant issue of concern identified for HYCO plant.										
More Noise	1.21. All high noise areas have been identified as part of noise contour mapping study every 3 years and noise monitoring every year with noise protection requirement defined. No significant issue of concern identified for HYCO plant.										

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Deviations	Causes	Consequences	Consequences	Safeguards	Risk After All Safeguards			Recommendations			Remarks
			Type		S	L	R	Recommendations	Priority	By	
More Electrical Hazards	1.22. Authorized Licensed Electrical Worker (ERP: Electrical responsible person and ECP: Electrical Competency person) to perform any electrical works. Adherence to electrical PPE requirement. No significant issue of concern identified for HYCO plant.										
More Atmospheric Instabilities	1.23. The plant metal structures are linked with the main ring earthing (equivalent to lightning arrestor). No significant issue of concern identified for HYCO plant.										
Misdirected Flow	1.24. Abrupt vehicular contact with process lines or equipment within battery limits.	1.24.1. Potential for line rupture or equipment damage, resulting in the loss of primary containment of hazardous material to atmosphere, possibly leading to fire, energy release, and personnel injury.	PI	1.24.1.1. PTW requirement to employ bankman 1.24.1.2. Approved contractors for vehicle operation inside the facility. 1.24.1.3. Bollards placed at strategic location.	3	2	2				
		1.24.2. Potential line rupture for CO2 imported system/ N2 loading line/ Packaged boiler control panel	PI	1.24.2.1. Linde contractors training	3	2	2	1.24.2.1. Recommend to install barriers/bollards at CO2 VIE tank and Packaged boiler			
		1.24.3. Potential line rupture for MIG pipeline/ H2 pipeline overhead on pipe rack/ Switchgear cable entry/ transformer 115KV	PI	1.24.3.1. Bollards placed to protect MIG pipeline 1.24.3.2. H2 pipeline overhead higher than vehicle height	3	2	2	1.24.3.1. Recommend to install bollards at Switchgear and pipeline. Install bollards at Demin plants			
		1.24.4. Potential incident/accident during turnaround	PI	1.24.4.1. PTW requirement to employ certified bankman, rigger, controller and supervisor according to Thai law and regulation 1.24.4.2. Approved contractors for vehicle operation inside the facility. 1.24.4.3. Lifting plan is in place for PTW and JSA	3	2	2				
		1.24.5. Potential incident/accident during forklift around Chemical warehouse (warehouse/CO compressor attenuation building/ CO-CO2 absorber, CO piping)	PI	1.24.5.1. Billards are in place for CO-CO2 absorber 1.24.5.2. Forklift drivers have been certified by Linde forklift committee	3	2	2				
		1.25. Misaligned low point drain or high point vent valves.									
		1.26. Improper tightening of flanges.	PI	1.26.1.1. Torquing procedure for main equipment: Heat exchanger/ vessel/ reactor. Piping and all equipment have pressure test	3	2	2				
		1.27. Improper, incomplete, or faulty weld.	PI	1.27.1.1. QA/QC program in place (e.g. welding procedure, NDT etc.)	3	2	2				
		1.28. Removable spool piece left in line following start up operations.	PI	1.28.1.1. Start up/ shutdown procedure and PSSR.	3	2	2				

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Deviations	Causes	Consequences	Consequences Type	Safeguards	Risk After All Safeguards			Recommendations			Remarks
					S	L	R	Recommendations	Priority	By	
Other Than Instrument Gas (N2)	1.29. Contamination of the instrument gas with (particulates) due to corrosion of carbon steel headers.	1.29.1. Potential blockage of gas filter regulators (AFR), resulting in the loss of instrument gas to the basic process control valves, leading to plant shutdown. Major Operability Issue. No issue for HyCO plant because of using dry instrument gas from ASU700									
Other Than Proper Catalyst Handling	1.30. Insufficient oversight and/or supervision during reactor catalyst loading / unloading operations.	1.30.1. Potential for personnel contact with fresh catalyst or hazardous waste (spent catalyst), resulting in possible injury.	PI	1.30.1.1. Method statement, risk assessment and SDS for catalyst handling by authorized vendor.	3	2	2				
				1.30.1.2. WI for catalyst loading/unloading is in place							
				1.30.1.3. Competent vendors /contractors for loading/unloading catalyst							
Other Than Resetting of Solenoids	1.31. Opening of control valves when not expected or not ready	1.31.1. Refer to individual HAZOP nodes for maloperation or failure of valves.									
Other Than Safe Entry into Confined Space	1.32. Not following procedures /training or confined space not adequately posted or confined space not identified	1.32.1. Potential for hazardous environment, leading to personnel injury	PI	1.32.1.1. PTW for confined space entry, including buddy system and PPE.	3	2	2				
				1.32.1.2. Trained personnel for confined space entry							
Other Than Working in a Safely Controlled Environment	1.33. No Facility Siting Study conducted on the job site.	1.33.1. Potential personnel exposure to hazardous materials and to a potentially hazardous environment without sufficient controls in place.	PI	1.33.1.1. QRA study for HYCO plant covers occupied building risk.	3	2	2				

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Node: 2. HUMAN ERROR AND HUMAN FACTORS CHECKLIST (MS-10069) - HYCO plant

Parameter: Human Error Node

Deviations	Causes	Consequences	Consequences Type	Safeguards	Risk After All Safeguards			Recommendations			Remarks
					S	L	R	Recommendations	Priority	By	
As Well As Human Factors Involving General Work Environment	2.1. Are Alarms audible above background noise both inside the control room and in the process area?	2.1.1. No significant issue of concern identified for HYCO plant.									
	2.2. Are there concerns with pooling of liquid in process area leading to slips, trips, or falls (e.g., algae growth, flooding, ice patches)?	2.2.1. Potential for personnel injury.	PI	2.2.1.1. Housekeeping practices 2.2.1.2. Planned Workplace inspection (PWI) 2.2.1.3. Unsafe condition/ Unsafe act reported in LIDAP	2	2	1				
	2.3. Is the lighting sufficient for all area operations, including during emergencies?	2.3.1. Potential inability for personnel to respond to or take appropriate action for an operation or excursion. Process upset.	FI	2.3.1.1. Lighting sufficient for all areas during operation 2.3.1.2. UPS (6 hrs) will start automatically during main power failure 2.3.1.3. Power Generator is backup during main power failure	3	2	2				
	2.4. How is the control room manned?	2.4.1. Potential inability for personnel to respond to or take appropriate action for an operation or excursion. Process upset.	FI	2.4.1.1. Control room is continuously manned	2	1	1				
	2.5. How is the control room manned during outside activities?	2.5.1. Potential inability for personnel to respond to or take appropriate action for an operation or excursion. Process upset.	FI	2.5.1.1. Control room is continuously manned	2	1	1				
	2.6. Are the number of work stations sufficient in order to monitor the process.	2.6.1. Potential inability for personnel to respond to take appropriate action for an operation or excursion. Process upset.	FI	2.6.1.1. Sufficient personnel in the field and control room. Work stations in control room are sufficient for monitoring	2	1	1				
As Well As Accessibility Availability of Controls and Equipment	2.7. Are adequate supplies of protective gear available for routine and emergency use?	2.7.1. Potential inability for personnel to respond to or take appropriate action for an operation or excursion. Potential for injury.	PI	2.7.1.1. Common PPE will be used. Special PPE (e.g. SCBA) is also available.	3	2	2				
	2.8. Are operators able to perform either routine or emergency tasks safely while wearing protective equipment?	2.8.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury.	PI	2.8.1.1. Common PPE will be used. Special PPE (e.g. SCBA) is also available. 2.8.1.2. Practical fit test and SCBA practical test quarterly	3	2	2				
	2.9. Are operators/ maintenance workers able to safely perform all required routine/emergency actions, considering the physical arrangement of equipment (e.g., access to equipment and valves, or proximity of tasks to rotating equipment, hot surfaces, and hazardous discharge points) or during adverse weather conditions?	2.9.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury..	PI	2.9.1.1. Common PPE will be used.	3	2	2				
	2.10. Is routine maintenance performed on equipment?	2.10.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Process upset.	FI	2.10.1.1. Maintenance routine complies with PTW	2	2	1				

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Node: 2. HUMAN ERROR AND HUMAN FACTORS CHECKLIST (MS-10069) - HYCO plant
Parameter: Human Error Node

Deviations	Causes	Consequences	Consequences Type	Safeguards	Risk After All Safeguards			Recommendations			Remarks
					S	L	R	Recommendations	Priority	By	
As Well As Component Labeling	2.11. Is labeling of process equipment adequate, including critical equipment (vessels, pipes, manual valves, instruments, controls, etc.) and/or signs and markings in the area?	2.11.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury.	PI	2.11.1.1. Site-wide plant labeling is in place. No specific concern identified.	2	2	1				
	2.12. Are drums, chemical totes, samples, and other containers having hydrocarbons or chemicals (including those used for testing) stored safely, and clearly/accurately labeled?	2.12.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury (Chemical for water treatment, Chemical house: catalyst, MDEA)	PI	2.12.1.1. Labeling and SDS are in place	2	2	1				
As Well As Controls /Feedback /Displays	2.13. Is there adequate information about normal and upset process conditions displayed in the control room (e.g., alarm summary for computer/electronic systems)?	2.13.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Process upset.	FI	2.13.1.1. No specific concern identified by operations with respect to HMI in control room.	3	2	2				
	2.14. Has alarm rationalization/ management been performed? Are alarms prioritized for criticality?	2.14.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury.	PI	2.14.1.1. Alarm prioritization is in place (P1 Fixed gas detector alarm, P2 tripped function, P3 warning alarm and need actions, P4 warning alarm and no action).	3	2	2				
	2.15. Have alarm metrics been within targeted bounds?	2.15.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Potential for injury.	PI	2.15.1.1. Alarm prioritization is in place.	3	2	2				
	2.16. Are there any calculations that operators perform when reading displays that need to be simplified or automated?	2.16.1. No significant issue of concern identified for HYCO plant.									
	2.17. Is there a system in place to prevent wrong set points from being entered that could adversely affect the process (e.g., enter 4000 °F versus 400 °F)?	2.17.1. Potential inability for personnel to safely perform job, respond to or take appropriate action for an operation or excursion. Process upset	FI	2.17.1.1. DCS is equipped with feature to prevent erroneous input of set point.	3	2	2				

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Table A.1 Hazard Analysis Worksheets for the HyCO plant (cont'd)

Deviations	Causes	Consequences	Consequences Type	Safeguards	Risk After All Safeguards			Recommendations			Remarks
					S	L	R	Recommendations	Priority	By	
As Well As Procedures and Training	2.18. Are there current and accurate written procedures for all operating phases (e.g., normal operations, temporary operations, emergency shutdown, normal shutdown, and start up following a turnaround or after an emergency shutdown)?	2.18.1. No significant issue of concern identified for HYCO plant. Output from HAZOP will be used for procedure development/ improvement.									
	2.19. Do the procedures provide enough time for operators to control an upset condition?	2.19.1. The current procedures and alarm/trip setpoints are deemed to be adequate, however the output from HAZOP will be used for procedure development/ improvement. Where relevant, recommendations to review alarm set point and define adequate operator response to alarm have been identified.	PI	2.19.1.1. Procedures for plant troubleshooting are in place (I-HYCO-080)	3	2	2				
	2.20. Do adequate engineering or administrative controls exist to ensure that start up and shutdown activities are performed in the correct sequence?	2.20.1. Provision is provided for engineering start up and shutdown control sequence, and is supplemented with startup/ shutdown procedures. No significant issue of concern identified for HYCO plant.	PI	2.20.1.1. Procedures and checklist for plant start up and shut down are in place. PSSR for startup is in place.	3	2	2				
	2.21. Is refresher training performed for infrequently performed operations? Is the training performed for plant modification?	2.21.1. Training requirement for personnel is identified based on role and responsibility. No significant issue of concern identified for HYCO plant.									
	2.22. Are the control board/ displays constantly monitored?	2.22.1. DCS is continuously manned. No significant issue of concern identified for HYCO plant.									
	2.23. Are the current procedures reviewed or updated as necessary?	2.23.1. Procedures are reviewed and updated periodically (every 3 years). Procedures are also updated based on MOC and HAZOP findings. No significant issue of concern identified for HYCO plant.									
	2.24. Are the daily shift logs being passed from shift to shift?	2.24.1. Daily shift logs are used for shift handover, and will be cascaded to critical personnel. No significant issue of concern identified for HYCO plant.									

APPENDIX B

Actions from Previous PHA in 2019

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
Rec	2.5 Misdirected flow – Pre-reformer & Reformer + Gas Cooling + Waste heat boiler	To study reliability for control of TIC11002 by using voting between TT11002 and TT11028????	Recommendation			
Rec	6.7 High pressure – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum 6.10 Low level – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To perform review design of water trap to be able to change online. Spare part of water trap to be available for replacement: WI I	Recommendation			
Rec	3.15 High level – Stream drum + steam system + Steam back up from package boiler	Install additional LT11001 and 1002 voting interlock either trip LV11001 or trip BFW pump. (P3 CAR issued during previous Process Safety audit)	Recommendation			
Rec	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To put interlocking close FV10016B when 'CO2 compressor trip	Recommendation			
Rec	8.2 Low/no flow – Regeneration gas + hydrogen fraction bypass	Study FI15003 to change from vortex type to be changeable type during online	Recommendation			
Rec	32.4 Synergi#175756 Gas leak flange E1122(Syngas, temp 400 deg C) and fire at insulation – previous incidents	Reformed gas pipe outlet E1122 needed to recalculate stress 3rd party vendor since there was repeated leakage in 2019. Synergi#270526	Recommendation			
Conf	1.7 High pressure – NG supply	To add troubleshooting for high pressure alarm PAH10019	Confirmation			
P2 CAR		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 refer DMW-TIG-M-01-rev2 has been updated	P2 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P2 CAR		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 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	P2 Recommendation		Completed	
P3 CAR		PAH-901308 to be implemented. Setting at 45 barg	P3 Recommendation		Completed	
P3 CAR		Implement 2oo3 voting with PT901308 and PT10002A/B for control PV901308	P3 Recommendation		Completed	
P3 CAR		To set limit of set point for 'PIC901308 to be 45 barg	P3 Recommendation		Completed	
P3 CAR		To raise EMOC to cover disconnection of LPG feed	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		To implement measurement of 'H ₂ S in 'CO ₂ in 'CO ₂ recycle to reformer	P3 Recommendation		Completed	
P3 CAR		To remove PAHH10019 and concerned logics of Hydrogen recycle compressor	P3 Recommendation		Completed	
P3 CAR		To remove hydrogen recycle C1008A from service and pipeline connecting to existing hydrogen feed. To be done by approved EMOC	P3 Recommendation		Completed	

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Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Review set point of PD111028 (existing 40 Barg) to be varied by plant load	P3 Recommendation		Completed	
P3 CAR		Check actual interlock function of PV10009 lock close with burner management system to remain close during burner is on regardless with operation mode	P3 Recommendation		Completed	
P3 CAR		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 this pipeline	P3 Recommendation		Completed	
P3 CAR		DP catalyst tube loading measurement procedure to be converted from method statement to local procedure	P3 Recommendation		Completed	
P3 CAR		Review and separate steaming procedure from plant start up procedure	P3 Recommendation		Completed	
P3 CAR		To put alarm of opening on FIC10004 NG trim fuel during normal operation if opening is lower than 5%	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		To calculate approach temperature of E1015 after cleaning and compare with condition before shutting down to be the data base for next cleaning next 2 years	P3 Recommendation		Completed	
P3 CAR		To add TAL10014 setting 300 c same as TAL10003	P3 Recommendation		Completed	
P3 CAR	2.1 High flow – Pre-reformer & Reformer + Gas Cooling + Waste heat boiler	Limit set point of HIC10517 and HIC10535. Low S:C ratio at 2.2	P3 Recommendation		In Progress	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	1.20 Low reaction rate – NG supply	To improve NG feed sampling test by including Methyl mercaptan, Ethyl mercaptan and hydrogen sulfide	P3 Recommendation		In Progress	
P3 CAR		To review troubleshooting of desulphurization unit in case low inlet temperature	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		Implment Dragger tube for meassring 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.	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		Need to list low point drain location and update to shutdown procedure	P3 Recommendation		Completed	
P3 CAR		Review and update emergency shutdown to inlcude Nitrogen purging reformer within 30 mins to be done to avoid catalyst damage	P3 Recommendation		Completed	
P3 CAR		To convert method statement for load/ unloading CoMo catalyst to operating procedure	P3 Recommendation		Completed	
P3 CAR		Confirm vendor's apporved procedure is acceptable for diposal of used catalyst. Reconfirm with site safety coordinator	P3 Recommendation		Completed	

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Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Review point of sampling condensate drain and sampling procedure at D1231, D1232. To install sample panel with cooler	P3 Recommendation		Completed	
P3 CAR		Review procedure for bomb transportation to laboratory	P3 Recommendation		Completed	
P3 CAR		To implement automatic open of steam import to mixing feed XV13001 in early condition from PAL11027 warning alarm	P3 Recommendation		Completed	
P3 CAR		To update PID to show limit opening of PV11027 (5-7%) for interlocking with TV11001. TV11001 is controlled by PIC11027B when steam production is low (PIC11027B output < 5%), and by TIC11001 when steam production is high (PIC11027B output > 7%).	P3 Recommendation		Completed	
P3 CAR		To revise Note13 in PID 11PFP01 to specific HIC11027 set point at 5% then system will use TIC11001 function instead of PIC	P3 Recommendation		Completed	
P3 CAR		To transfer cascade set point TIC11010 following load from ALC to DCS (EMOC 9149-21-36)	P3 Recommendation		Completed	
P3 CAR		Include PPE requirement for response with relief valve pop up at steam drum ie. Gloove, face shield, ear muff in existing WI (WI 11-0018)	P3 Recommendation		Completed	
P3 CAR		Aspirator with proper catidge must be provided for operators. Expiry date of cartidge to be checked and replce if required	P3 Recommendation		Completed	
P3 CAR	5.12 Loss of containment – Deareator 22.13 Loss of containment – Package boiler	Set plan for replace tank NH3OH, Eleminox every 5 years and include in SAP PM (SAPPM# 346894, 346895 plan in 2025 and 2030)	P3 Recommendation		In Progress	
P3 CAR		Set schedule to replace new UPVC pipline of dosing every 15 years (EMOC 9149-19-019)	P3 Recommendation		Completed	

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Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Create new condensate sampling procedure # I-HYCO-085 for sampling collection. (sampling bag I-HYCO-018)	P3 Recommendation		Completed	
P3 CAR		Provide fire apron for operators for inspecting inside reformer (CCR)	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		Implement FAL13006 follow by plant load (EMOC 9149-20-34)	P3 Recommendation		Completed	
P3 CAR		To put pump alarm high pressure with set point of shut off pressure of P1371A/B at PI13017, PI13018 (EMOC 9149-19-40 add alarm from PHA 2019)	P3 Recommendation		Completed	
P3 CAR		Implement steam drum pH online analysis with alarm to CCR (EMOC-9149-19-012)	P3 Recommendation		Completed	
P3 CAR		Check volume of secondary bund to cover 110% volume of chemical tank at Boiler package	P3 Recommendation		Completed	
P3 CAR		Create new procedure (I-HYCO-062) to start/stop BFW process system and chemical dosing pumps (I-HYCO-060) to prevent high chemical dosing to deareator	P3 Recommendation		Completed	
P3 CAR		Implement FAH14002 in case FV14002A/B error open more	P3 Recommendation		Completed	
P3 CAR		Install second flow transmitter at FE14002 to prevent flow transmitter fail reading low/ pump cavitation due to high flow	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	6.1 High flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Implement Soft limit FV14002 valve position for high flowrate capacity (1 valve case + 2 valve case) (EMOC 9149-19-052). Change action to re-confirm pump curve and confirm transmitter for high flow capacity	P3 Recommendation		In Progress	
P3 CAR		Consult with LE for scenario of LV14003 A/B remain open when interlock functioning since in SDE1003 page 12 mention relief valve is not design for syngas (we could not put interlock of PV14015 close to prevent presonel exposure of CO and Flammable gas release). Any recommendation from LE to be implemented (EMOC 9149-21-05)	P3 Recommendation		Completed	
P3 CAR		To put closing positioner for LV14003A/B to feedback close/ open position to DCS (EMOC 9149 19-035 Install proximity switch at LV14003A/B to detect CLOSE/OPEN position)	P3 Recommendation		Completed	
P3 CAR		To put interlock to close FV14006 drainline at discharge condensate pump P1473A/B when LSL14009 to prevent CO2 gas leak into sewer (EMOC 9149-19-053)	P3 Recommendation		Completed	
P3 CAR		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 (EMOC 9149-19-043)	P3 Recommendation		Completed	
P3 CAR		Implement alarm PDAH14005, PAH14023 to predict blockage in E1413A/B (EMOC 9149-20-33 Create alarm for monitoring E1413A/B to predict blockage)	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Implement interlock close valve FV14001 when both P1371A/B trip (EMOC 9149-19-046)	P3 Recommendation		Completed	
P3 CAR	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To perform manually close FV14002A/B by operator when both P1474A/B trip or failure to auto start. Update in work instruction (WI I-HYCO-022)	P3 Recommendation		Completed	
P3 CAR	6.2 Low/ No flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To configure alarm high temp of TI14003A at suitable set point (EMOC 9146-20-23 To create alarm set point of MDEA)	P3 Recommendation		Completed	
P3 CAR	6.2 Low/ No flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Create procedure for bypass FV13002 steam feed mixing valve (WI I-HYCO-022)	P3 Recommendation		In Progress	
P3 CAR		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. (WI I-HYCO-056)	P3 Recommendation		Completed	
P3 CAR	6.7 High pressure – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	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)	P3 Recommendation		Completed	
P3 CAR	6.2 Low/ No flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To create procedure for mitigation by manual local control with observe level sight glass in case LT14003 read low or read high (Abnormal) (WI-I-HYCO-022 revised procedure to manual adjust setpoint)	P3 Recommendation		In Progress	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		To keep spare pare of LT14003 to be avialble due to criticality	P3 Recommendation		Completed	
P3 CAR	6.11 High concentration of contaminants – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Review and Update I-HYCO-098 for reference color to replace new MDEA by reference with supplier recommnedation	P3 Recommendation		Rejected	
P3 CAR		Add warning alarm PDAH15006.A/B setting at 0.9 barg (EMOC 9149-19-043 Implement tag and revise setting alarm)	P3 Recommendation		Completed	
P3 CAR		Revise tag PDAH15006.A/B to PDAHH15006.A/B (Replace from existing PDAH15006A/B in both DCS, P&ID)	P3 Recommendation		Completed	
P3 CAR	7.1 High flow – Drier (TSA)	Update sequential document PMC0110-007 follow real actual logic of TSA unit to explain about logic of PDAHH15006 A/B and update PID for PDAHH15006 A/B	P3 Recommendation		In Progress	
P3 CAR		To configue alarm PAH15001 at 33 barg (In case PIC12001 cannot detect due to transmitter problem (EMOC 9149-19-40)	P3 Recommendation		Completed	
P3 CAR		To update PID to add PAH16032 in page 16PFP10 at 33 barg(already in DCS) (EMOC 9149-19-40)	P3 Recommendation		Completed	
P3 CAR		To update shutdown procedure WI 11-0012 including nitrogen blanketing during shutdown	P3 Recommendation		Completed	
P3 CAR		Change set point of alarm PDAH15002.B, PDAH15004.B setting 0.9 barg to prevent high differential pressure at regeneration bed	P3 Recommendation		Completed	
P3 CAR		Create troubleshooting case FV15003,4 malfunction close in warm step whether operator should manually operarate or required to shutdown plant (WI 15-006)	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Consider to treat PDIT15009 as the critical spare part	P3 Recommendation		Completed	
P3 CAR		Install pressure gauge at location of PT15003 for verifying (EMOC 9149-19-061)	P3 Recommendation		Completed	
P3 CAR		To provide dedicated spare part for ready to replace in case of PT15003 failure	P3 Recommendation		Completed	
P3 CAR		To establish standard operating procedure in case of PT15003 failure to replace spare part (WI I-HYCO-056)	P3 Recommendation		Completed	
P3 CAR		Add TAH15007 setting 185 c	P3 Recommendation		Completed	
P3 CAR		To change TAAH18001 to voting 1oo2D from T118001A,B (EMOC 9149-19-062)	P3 Recommendation		Completed	
P3 CAR		Revise start up procedure to include hydrogen product purity check with GC before supply to customer	P3 Recommendation		Completed	
P3 CAR	16.1 High flow – PSA plant Node (E1/R1) 16.2 Low/no flow – PSA plant Node (E1/R1) 17.1 High flow – PSA plant Node (E2/R2) 17.2 Low/no flow – PSA plant Node (E2/R2) 17.3 Reverse flow – PSA plant Node (E2/R2) 17.4 Misdirected flow – PSA plant Node (E2/R2) 18.1 High flow – PSA plant (P1/PP1 and P5/PP5) 19.1 High flow – PSA plant (D)	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	P3 Recommendation		In Progress	
P3 CAR		Add PAH16032 T1601 pressure vent valve at setting 33 barg (EMOC 9149-19-40)	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Add calculation page for differential temperature and cooling down rate in HMI (Alarms for warning) for coldbox start up and shutdown	P3 Recommendation		Completed	
P3 CAR		Add TAH16002 setting - 180 c for start up case (EMOC 9149-19-040)	P3 Recommendation		Completed	
P3 CAR	10.1 High flow – Coldbox (T1602 : hydrogen stripper column)	To limit opening of FV16004 to prevent methane pump cavitate. To raise EMOC for reviewing the optimum set point (Cavitation phenomina will not happen in recipocating pump type)	P3 Recommendation		Rejected	
P3 CAR		Set PM for overhaul FV16004 (SAP Tasklist TLAS0017, SAPPM# 346896)	P3 Recommendation		Completed	
P3 CAR		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 and CO compressor. Updated information need to be trained to all operators	P3 Recommendation		Completed	
P3 CAR		Update existing operating procedure that operator should cut feed to coldbox if there is sign of column's bottom level transmitter failure	P3 Recommendation		Completed	
P3 CAR		Add logic for check instrument reading value freezing (Failed lock value) (EMOC 9149-20-22 Add logic for check instrument reading value freezing)	P3 Recommendation		Completed	
P3 CAR		Add TAH16022 setting - 179 c (EMOC 9149-19-40)	P3 Recommendation		Completed	
P3 CAR		To change PAH16033 set point at 2.5 barg (EMOC 9149-19-043)	P3 Recommendation		Completed	
P3 CAR		Add TAL16026, TAL16067 setting -175 c in order to detect freezed liquid methane at E1615 (EMOC 9149-10-040)	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		Revise existing plant P&ID at turbine section (16PFP01) with correct details reference with vendor package P&ID (identified in PID to see vendor PID)	P3 Recommendation		Completed	
P3 CAR		Confirm lower critical speed with turbine manufacturer (Air liquid) and change set point SAL1601 if any deviation found	P3 Recommendation		Completed	
P3 CAR	13.13 Deviation during shutdown – Coldbox (CO turbine)	Add content for completely purge CO turbine in I-HYCO-0037 CO turbine start up and shutdown (updated only start up, no update for shutdown: purge CO before maintenance)	P3 Recommendation		In Progress	
P3 CAR		Create WI for soot filter purging/ carbon dioxide adsorber purging and train to all operators (WI I-HYCO-070)	P3 Recommendation		Completed	
P3 CAR	14.10 Deviation during startup – CO compressor + CO supply line	Update CO compressor start procedure for open gas line at lowest point to check for any water leak from cooling tube (update WI -I-HYCO-070 to cover for starting CO comp	P3 Recommendation		In Progress	
P3 CAR		Update all information sent from LE for flow limitation in SLE-1003 list of safety relevant control valves and orifices (EMOC 9149-17-021)	P3 Recommendation		Completed	
P3 CAR		To create PM inspection for check leak of 2 XAH001 (Dead man valve) at every 5 years (SAPPM # 346897 for XAH001 maintenance)	P3 Recommendation		Completed	
P3 CAR	21.15 Deviation during maintenance – Warm, Cold Flare	Add I-HYCO-032 (Start up and shutdown flare system) for purging NG pilot header before maintenance (Revise I-HYCO-032)	P3 Recommendation		In Progress	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	25.11 Deviation during startup – Carbon dioxide compressor	Provide narrative description for 6KV motors (C1408, C1608) interlock logic for starting cycle protection and communicate to maintenance and operation team (relay protection system changed, so current logic are not the same as current procedure)	P3 Recommendation		In Progress	
P3 CAR	22.2 Low/no flow – Package boiler 22.8 Low pressure – Package boiler	To create PM schedule to ensure PSV1202 (Diesel recirculation pressure control) is properly function together with yearly Recertify (removed Diesel unit out in 2020)	P3 Recommendation		Rejected	
P3 CAR	22.3 Reverse flow – Package boiler	To revise WI-I-HYCO-040 to include isolation of steam from process reverse to package boiler (revise I-HYCO-040 to cover steam from process reverse to package boiler)	P3 Recommendation		In Progress	
P3 CAR		To add TAL900105 setting 100 c below normal operating temperature and active with burner running signal (EMOC 9149-19-040)	P3 Recommendation		Completed	
P3 CAR	22.14 Deviation during startup – Package boiler	To revise WI I-HYCO-048 to include flushing for removing Fe before start up (Revise and add flushing in I-HYCO-048)	P3 Recommendation		In Progress	
P3 CAR		To install sneak guard around substation fence	P3 Recommendation		Completed	
P3 CAR		Set up air condition spare part for analyzer room as critical spare part (MM TH914907009 for air condition explosion proof spare part)	P3 Recommendation		Completed	
P3 CAR		Reconfirm existing schedule for replacing methane pump discharge flexible hose every 5 years (SAP PM# 346898 and 346899 for unit A and B)	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		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) (EMOC 9149-19-067)	P3 Recommendation		Completed	
P3 CAR	32.4 Synergi#175756 Gas leak flange E1122(Syngas, temp 400 deg C) and fire at insulation – previous incidents	Recalculation from 3rd party ventdor results of Reformed gas pipe outlet E1122, Recommendations to be implemented within TAR2020	P3 Recommendation		In Progress	
P3 CAR		Reconfirm V-51 of impulse line to PCV10594-1 is locked open to ensure functioning of PCV10594-1,2	P3 Recommendation		Completed	
P3 CAR		Add alarm set point PAH901301 setting 45 barg, PAL901301 setting 36 barg at NG booster discharge pressure to warning operator (EMOC 9149-19-040)	P3 Recommendation		Completed	
P3 CAR		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	P3 Recommendation		Completed	
P3 CAR		To revise standard operating procedure I-HYCO-081, 087 to provide valve status checklist for start-up hydrogen mix feed	P3 Recommendation		Completed	
P3 CAR		To change hot water sampling valve at E852 (CO2 vaporizer) to needle valve 1/4" (WI I-HYCO-085)	P3 Recommendation		Completed	
P3 CAR	27.8 Deviation during start up – CO2 pump (P851A/B)	To revise standard operating procedure 10-0013 for mentioning slowly open vent/drain valve to prevent dry ice blockage due to rapid depressurizing (Need to update in I-HYCO-041)	P3 Recommendation		In Progress	
P3 CAR		Add hose anti whip regular inspection check in monthly basis	P3 Recommendation		Completed	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR		To rearrange anchor point for hose restraint against standard (EMOC 9149-23-09)	P3 Recommendation		Completed	
P3 CAR		To update sampling procedure to cover sampling water from hot waterbath E852 (WI I-HYCO-085)	P3 Recommendation		Completed	
P3 CAR	3.9 High concentration of contaminants – Stream drum + steam system + Steam back up from package boiler	Install online pH measurement at boiler water sampling. pH alarm is lower than 9 and more than 10.5 (EMOC 9149-19-012 set at low alarm, will set high alarm with new MOC)	P3 Recommendation		In Progress	
P3 CAR		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 (change to PCV901202)	P3 Recommendation		Completed	
P3 CAR		Check SV1303 flow capacity that it can cover max input flow from Demin pump 90916A/B reduct with output flow from BFW P1371A/B ?	P3 Recommendation		Completed	
P3 CAR		SV-1001 has capacity at 1,673 Nm ³ /hr while max capacity of FV-10002 could be higher. Need to confirm relief capacity of SV-1001 at 45 barg compared to maximum flow rate from FV-10002	P3 Recommendation		Completed	
P3 CAR		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 Nm ³ /hr at 45 barg, it is subjected to be much higher flowrate at 50 barg)	P3 Recommendation		Completed	
P3 CAR	27.3 Reverse flow – CO2 pump (P851A/B)	Recheck that PSV851A-1, 851B-1 can cover full flow rate in case of reserve flow from running pump: Irrelevant case by design of reciprocating pump reverse flow of running pump cannot overpressure of stand-by pump	P3 Recommendation		Rejected	

Table B.1 Actions from Previous PHA in 2019

Type	References	Action	Type	Due Date	Status	Responsibility
P3 CAR	2.6 High temperature – Pre-reformer & Reformer + Gas Cooling + Waste heat boiler	Revise WI I-HYCO-080 to handle FIC10004NG fuel lower than 5%	P3 Recommendation			
P3 CAR	5.1 High flow – Deareator	To install restriction orifice at demin pump (P90916A/B) at min flow line to maintain minimum flow 2 m3/h according to datasheet	P3 Recommendation			
P3 CAR	6.1 High flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	Update and add Work instruction HYCO-I-080 for feedback failure case. If feedback closed, what operators have to do (Troubleshooting case)	P3 Recommendation			
P3 CAR	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To add interlock to close FV14002A and B when MDEA recycle pum (P1474A and B) both stopped/tripped after 20 sec (to protect reverse flow)	P3 Recommendation			
P3 CAR	6.3 Reverse flow – MDEA-Wash unit, MDEA Reboiler, 'CO2 knockout drum	To review WI I-HYCO-022 for manual close FV14002A and B (By removing step to close manual valve)	P3 Recommendation			
P3 CAR	9.13 Deviation during startup – Coldbox (T1601: Methan wash column)	Create standard operating procedure for operators to manage temperature rate of change alarm for start up, thawing, and normal operation	P3 Recommendation			
P3 CAR	13.9 Critical Speed – Coldbox (CO turbine)	Update speed critical to be the same DCS both tag# and setting (page D-4040-A-002 rev 01) and keep a mail PHA 2019#276918 and original Air liquid PID together. Add mail to confirm current operation at 470-510 Hz to close this action	P3 Recommendation			
P3 CAR	1.7 High pressure – NG supply	Change setpoint alarm trip of NG discharge compressor:PI10535 and PI10537. Alarm high at 46 barg and alarm HH at 47 barg (existing H at 48 barg and HH at 49 barg). SV NG booster at 51 barg	P3 Recommendation			

