HAZOP Study and Safety Layers of Protection Analysis in Delayed Coker Unit

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Abstract

HAZOP study and Safety Layers of Protection Analysis were performed upon Delayed Coker Unit in order to proactively and systematically identify, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures, or equipment in delayed coker unit.

purpose of HAZOP study was to identify the potential critical effects due to the deviation of the process to people, environment and assets. The purpose of the LOPA was to assess the SIL (Safety Integrity Level) requested for safety instrumented function identified during the HAZOP.

Hazards and Operability Analysis & Layer of Protection Analysis should be integrated for safety management. As the HAZOP study alone is used to To identify hazards (HAZ) and operability (OP) issues but not a design check or provide design alternative, and Not an optimization study. (Steven T. Maher Max C. Oppedahl &, 2018)

Inappropriate SIL determination in delayed coker unit can affect the safety integrity of the asset protection envelope and unnecessary capital and operational spending. in contrary, properly determined SIL levels resulting in cost improvements. Companies that real practice PHA are finding a continuing reduction in frequency and severity of industrial accidents.

***Keywords**:* Process safety, HAZOP, LOPA, Delayed Coker Unit, PHA, PSM, DCU.

Introduction

Process Safety Management is a concern in any of the industries who store, handle and process hazardous chemicals & gases. risks related to process safety are often managed in an isolated way to integrate different aspects of risks in a facility and puts them under the control of a management system by establishing awareness based on the risk of the safety impacts of technology, personnel and the management, the system provides a dynamic state for continuous improvement. (Dowell, A. and D. Hendershoot, 2002)

Process Safety Management is an integral part of OSHA Occupational Safety and Health Standards since 1992,known formally as: Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119). (CCPS, 1987)

Delayed Coker Unit is to convert low-value, heavy vacuum residues into higher-value light hydrocarbon liquids. This is achieved through a thermal cracking process, the feed to DCU is vacuum residue from VDU is pumped to the furnace to heat the feed to the temperature necessary to initiate the coking reactions as rapidly as possible with High Pressure steam (velocity steam) is injected at the inlet of each pass of the Coker Furnace to decrease the residence time in the tubes to suppress the formation of coke in the furnace tubes, the furnace effluent flows into the bottom of Coke Drum allows sufficient time to complete the thermal cracking, or coking reaction result in conversion of oil feed to cracked hydrocarbon vapors and petroleum coke. (http://en.wikipedia.org/wiki/Bhopal_disaster – Accessed on March 20, 2015)

HAZOP is a systematic method that analyses the potential deviations of the significant parameters of the process involving fluids and evaluates the impacts of these deviations on the safety of the installations, of the people and on the environment. The HAZOP study objectives upon DCU are:

To review and highlight the potential process hazardous deviations, their causes, consequences and creditable safeguards. Thus, corrective actions and recommendations are proposed in order to improve the operability and safety.

To suggest recommendations to minimize the consequences severity and likelihood of the identified hazards. (PSM, 1992)

To study factors that promote maintainability and minimize troubleshooting where feasible, as well as define changes to the process that improve quality, operability and efficiency. (Frederickson A.,, 2003)

LOPA is a semi-quantitative technique and applies much more rigor than HAZOP's alone, as it examines the HAZOP identified Safeguards and determines if the Current safeguards are enough and if proposed safeguards are warranted, evaluatesthe effectiveness of the available Independent Protection Layers (IPLs) in mitigating the Hazardous Scenario to determine the target SIL (availability/reliability) required for each specific Safety Instrument Function (SIF). (Steven T. Maher Max C. Oppedahl &, 2018)

2. Review Method

Our methodology uses the conventional technique for HAZOP study as defined in “Guidelines for Hazard Evaluation Procedures” CCPS of the AIChE, 1992, IEC 61882 Hazard and Operability Studies (HAZOP Studies) – Application Guide, 2003 and ‘HAZOP: Guide to Best Practice’ IChemE, 2008.

HAZOP study applies a combination of a Parameters and Guide Words to generate a deviation from design intent, then the Causes and Consequences of the deviation are identified, with associated Safeguards assessed, the recommendations are identified for mitigation of the identified hazard. (Dowell, A. & T. Williams, 2005)

LOPA / SIL Determination are applied to all SIF loops within process safeguard that are considered to be preventive measures against the serious process deviations identified during previous safety HAZOP study as follows, Establish and agree the consequence severity criteria for studied area, Select Safety instrumented function (SIF) loop to be discussed, Identify the hazard accident scenario to be prevented by selected SIF, Identify and indicate the severity rating of the discussed hazard accident, Assess according to available data the likelihood/frequency of the initiating cause leading to identified scenario development and escalation, Identify and indicate the enabling factors (i.e. Probability of ignition, Occupancy, Operational), Identify and indicate the existing Independent Layers of Protection (IPL) which can reduce the risk associated with identified hazard accident, Determine and indicate the Probability to Fail on Demand (PFD) for each identified IPL, Repeat the process for each identified hazard accident scenario, Calculate and indicate the target SIL requirement for discussed SIF. (Steven T. Maher Max C. Oppedahl &, 2018).

LOPA is generally used to determine the target SIL for a given SIF, the safety Instrumented Function (SIF) is a set of sensors, logic solver and actuator that performs a single function, and protects the system against identified hazard. A SIS is a collection of safety instrumented functions implemented for a common propose. (CCPS, 2001)

Determination of the Sil Required for Assessed Sif

Total probability is the sum of all events “probability with IPL” leading to a specific scenario: Total probability = ∑ Events. probability. With IPL The required probability of failure on demand is given following this equation:

$$\text{PFD reduction} = \frac{\text{TMEL}}{\text{Total probability}}$$

3. Case study

3.1 Process Description

Delayed coking is a thermal conversion process that converts the heaviest and least desirable elements of crude oil into marketable products. The reactions that generate coke are highly endothermic, with the Coker Furnace providing the heat necessary to initiate the vaporization and to complete cracking and coking reactions. Vaporization occurs in the furnace while the cracking and coking reactions are completed in the coke drums. Solid coke is accumulated in the coke drums and is removed in a semi-batch process in which a drum is regularly removed from service and decoked while the other drum is in service. The lighter products of the coking process typically consist of fuel gas, Liquefied Petroleum Gas (LPG), naphtha, Light Coker Gas Oil(LCGO), and Heavy Coker Gas Oil (HCGO). (Brian Tyler, 2008)

3.2 The Nodes Selected for the Delayed Coker Unit HAZOP Study

DCU feed through HCGO product/feed exchangers, HCGO pump around/feed exchangers, and HHGO pump around/feed exchangers to Coker fractionator surge drum.

Table (1) Process Parameter: Flow

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
More Flow	1. Hot VR FIC failure Driving FV fully open	1.1 Level build up in fractionator causes trays damage and potential flooding of tower resulting in increased ΔP and loss of integrity.	1.1.1 HHGO tray LIC quench oil back up to blowdown header to prevent flooding of tower. 1.1.2 PDI between trays with high differential pressure alarm. 1.1.3 VDU column LIC to control the level. 1.1.4 VDU column LI with low level alarm and low low level to trip hot VR pump and closing suction valve	3/III	4/B	12/BIII	1.Provide high level alarm on surge drum level indicator.
More Flow	2.Cold VR FIC failure Driving FV fully open	2.1 Level build up in fractionator causes trays damage and	2.1.1 surge drum LIC to control the level. 2.1.2 HHGO tray LIC	3/III	4/B	12/BIII	2. Provide high level alarm on surge drum level indicator.

		potential flooding of tower resulting in increased ΔP and loss of integrity.	quench oil back up to blowdown header to prevent flooding of tower.				3. Surge drum LI with high high level to trip cold VR pump and closing suction valve.
Less/No Flow	3. Cold VR FV fails closed / surge drum LIC failure Driving cold vacuum residue FV fully closed	3.1 Decreased flow of feed to Fractionator resulting in loss of level and loss of DCU process.	3.1.1 Surge drum LI with low level alarm.	3/III	3/C	9/CIII	4. Provide Instrument failure alarm.
		3.2 Potential damage to the Furnace.	3.2.1Safety protection of Furnace combined of low flow interlock (heater partial trip) and emergency steam.	4/II	2/D	8/DII	5. Provide Instrument failure alarm.
Less/No Flow	4. Loss of Hot Vacuum Residue	4.1 Decreased flow of feed to	4.1.1 surge drum LIC to increase feed from	3/III	3/C	9/CIII	

		Fractionator resulting in loss of level and loss of DCU process. 4.2 Potential damage to the Furnace.	cold VR tank. 4.2.1 Safety protection of Furnace combined of low flow interlock (heater partial trip) and emergency steam.	4/II	2/D	8/DII	
Less/No Flow	5. HCGO product, HCGO PA, HHGO PA /feed exchangers Blocked.	5.1 Decreased flow of feed to Fractionator resulting in loss of level and loss of DCU process. 5.2 Potential damage to the Furnace	5.1.1 Surge drum LI with low level alarm. 5.2.1 Safety protection of Furnace combined of low flow interlock (heater partial trip) and emergency steam.	3/III 4/II	2/D 2/D	6/DIII 8/DII	6. Provide PDI between inlet /outlet of exchangers with high pressure differential alarm.

Misdirected flow	6. HCGO product /feed exchangers tube failure.	6.1 Ingress of HCGO in Vacuum residue feed.	6.1.1 Equipment inspection.	2/IV	3/C	6/CIV	7. Sampling and testing.
	7. HCGO PA/feed exchangers Tube failure.	7.1 Ingress of VR feed in HCGO PA and impact in downstream operation.	7.1.1 Equipment inspection.	4/II	3/C	12/CII	8. Sampling and testing.
	8. HHGO PA/feed exchangers tube failure	8.1 Ingress of HHGO PA in Vacuum residue feed.	8.1.1 Equipment inspection.	2/IV	3/C	6/CIV	9. Sampling and testing.

DCU furnace charge from Coker fractionator surge drum through furnace charge pump through Coker furnace through switch valve to coke drum.

Table (2) Process Parameter: Flow

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
More Flow	1. Two Pumps running.	1.1 Increased flow through heater passes resulting in process upset, pressure build up in piping resulting in potential loss of	1.1.1 Furnace passes inlet FIC.	4/II	3/C	12/ CII	10. Pump stop when the pressure approaches to piping design pressure.

		integrity and leak					
More Flow	2. Furnace passes inlet FV fails open	2.1 Increased flow through heater passes resulting in process upset.	2.1.1 Main FIC to six passes with ΣPV to adjust flow through other five passes.	3/II I	3/C	9/C III	11. Provide high flow alarm on Furnace passes FIC.
Deviation	Causes	Consequences	Safeguards	S	L	R	Recommend ations
Less/No Flow	3. Strainer at suction of charge pump blocked.	3.1 Interruption to VR flow resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture, loss of containment, fires, explosions, injuries, fatalities, asset damage and environmental impact.	3.1.1 strainer PDI with high differential pressure alarm. 3.1.2 Spare Pump with clean strainer is provided. 3.1.3 Furnace passes inlet FIC with low flow alarm.	5/I	3/C	15/ CI	12. ESD FI (SIL assessment) to Partial trip furnace and inject emergency steam to heater passes. 13- Provide high skin temperature alarm
Less/No Flow	4. charge pump suction valve fails closed.	4.1 Interruption of flow to furnace resulting in interruption of process and damage to furnace, dry run of Pump resulting in	4.1.1 trip Pump on signal suction valve not open.	5/I	3/C	15/ CI	14. ESD FI (SIL assessment) to Partial trip furnace and inject emergency

		mechanical damage.					steam to heater passes. 15.Provide high skin temperature alarm, and high coil outlet temperature alarm.
Less/No Flow	5. Furnace passes inlet FIC failure driving FV fully closed	5.1 Interruption of flow to passes of furnace resulting in tubes rupture and potential fire and explosion.	5.1.1 provide explosion door on the heater to prevent severe damage to heater in case of fire and explosion in the box.	5/I	2/ D	10/ DI	16. ESD FI (SIL assessment) to Partial trip furnace and inject emergency steam to heater passes.
Less/No Flow	6. furnace charge pump trip.	6.1 Interruption of flow to passes of furnace resulting in tubes rupture and potential fire and explosion.	6.1.1 pump trip alarm is provided.	5/I	3/C	15/ CI	17. ESD FI (SIL assessment) to Partial trip furnace and inject emergency steam to

							heater passes.
Less/No Flow	7. inlet motorized valves to drum/ isolation valveinadvertent closure during switching.	7.1 increase pressure down stream of Pump (Heater passes tube pressure will increase) leading to coil rupture, loss of containment, fires, explosions, injuries.	7.1.1 Consider delay time of 10 Minutes as a permissive for closing of isolation valve after switching to new drum. 7.1.2 provide explosion door on the heater to prevent severe damage to heater in case of fire and explosion in the fire box.	5/I	3/C	15/ CI	18. ESD FI (SIL assessment) to Partial trip furnace and inject emergency steam to heater passes.
Misdirected Flow	9. back warming motorized valve left open till switching by operator error	9.1 Hot VR feed delivered to Fractionator resulting in upset in fractionator, potential damage to equipment.	9.1.1 Close position of back warming motorized valve is permissive for switching sequence.	3/III	2/D	6/ DIII	

Reverse Flow	10. Flow from Duty Pump to Spare Pump	10.1 stand by pump reverse impeller rotation cause Potential mechanical damage to Pump.	10.1.1Warming up line designed to provide heat to Pump without causing counter rotation	4/II	2/D	8/DII	19. reduce the warming up valve to the appropriate opening.

<u>DCU furnace fuel gas, pilot natural gas and flue gases system. Fuel gas to furnace burners, Pilot burners natural gas and flue gas through firing box to arch dampers including relevant forced fan, induced fan, piping and instrumentation.</u>

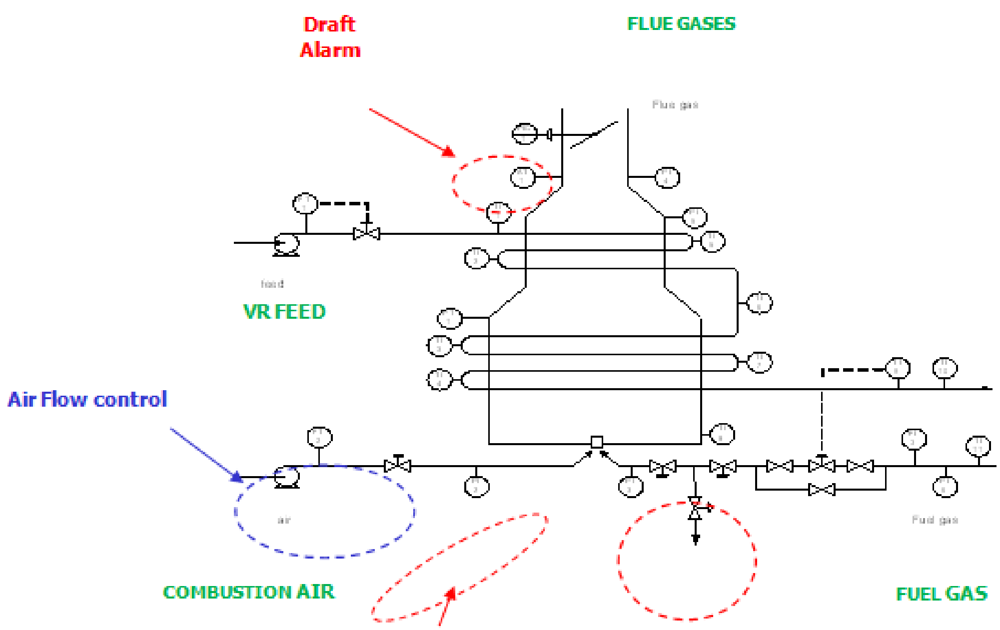


Fig 1. Furnace Fuel Gas, Pilot Natural Gas and Flue Gases System

Table (3) Process Parameter: Pressure

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
High pressure	1. combustion air damper malfunction open.	1.1 High pressure in fire box, the burners flame out followed by explosion.	1.1.1 inlet air register is installed for each burner. 1.1.2 Flame detector rod. 1.1.3 oxygen analyzer with high oxygen content alarm.	5/I	3/C	15/CI	34. ESD PI (SIL assessment) to switch the heater mode from balanced draft mode to natural draft mode.
High pressure	2. Forced fan inlet valve fails open.	2.1 High pressure in fire box, the burners flame out followed by explosion. And the cold air supply through air preheater resulting in condensation of sulphuric acid and consumption a large amount of fuel gas, the heater efficiency will decrease.	2.1.1 steam air preheater is installed upstream the flue gases air preheater. 2.1.2 Combustion air individual controller for each cell to control the amount of air for each cell. 2.1.3 inlet air register is installed for each burner. 2.1.4 individual arch damper for each cell to control the draft	5/I	3/C	15/CI	35. ESD PI (SIL assessment) to switch the heater mode from balanced draft mode to natural draft mode. 36. air preheater flue gases side TIC to control the flue gases outlet temp to prevent the sulphuric acid condensation. 37.provide high pressure alarm on the discharge of forced draft. fan.
High	3. Main	3.1 High	3.1.1 Flame				38. ESD PI (SIL

pressure	stack /Arch damper malfunction close.	pressure in fire box, the burners flame out followed by explosion.	detector rod. 3.1.2 oxygen analyzer with low oxygen content alarm.	5/I	3/C	15/CI	assessment) to switch the heater mode from balanced draft mode to natural draft mode.
High pressure	4. Induced fan trip/ induced fan inlet valve fails close.	4.1 High pressure in fire box, followed by the potential back fire and explosion.	4.1.1 Natural draft provided by opening the main stack /arch dampers, and stop forced fan, open the air doors.	5/I	2/D	10/DI	39. when PDI on induced fan with low low differential pressure alarm, the induced fan will be stopped and the heater switch to natural draft mode. 40. switch to partial trip if the fire box pressure high high after switched to natural draft.

Table (4) Process Parameter: Level

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
High Level	1. fuel gas coalescer LIC failure driving LV fully close.	1.1 Liquid HCs level build up in fuel gas coalescer and carry over to fuel gas line resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture ,fire and explosion.	1.1.1 fire box is provided with explosion doors. 1.1.2 Fuel gas coalescer with high level alarm.	5/I	3/C	15/CI	41. ESD LI (SIL assessment) to Partial trip furnace (Closes Fuel Gas ESD valves)

Table (5) Process Parameter: Flow

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
Less/ No Flow	1.fuel gas FIC failure driving fuel gas FV fully close.	1.1 Decrease fuel gas flow to furnace burners resulting in decrease heat duty, decrease coil outlet temp, process upset (in fractionator and coke drum). capacity reduced, and potential flame out.	1.1.1 fuel gas PI with low pressure alarm. 1.1.2 Provided low flow alarm on fuel gas FIC.	4/II	4/B	16/B II	42. ESD PI (SIL assessment) to Partial trip furnace (Closes Fuel Gas ESD valves) and keep pilot gas open) when fuel gas pressure reach to low low pressure alarm. to prevent the flame out.
Less/ No Flow	2.fuel gas coalescer LIC failure driving LV fully open.	2.1 the flow of fuel gas to burners will reduce resulting in decrease coil outlet temp, capacity reduced, loss of fuel gas to flare.		4/II	3/C	12/C II	43.provid pressure differential transmitter with high alarm on fuel gas coalescer.
Less/ No Flow	3. fuel gas strainer blocked.	3.1 Decrease fuel gas flow to furnace burners resulting in	3.1.1 Pressure differential indicator.	5/I	3/C	15/C I	44. ESD PI (SIL assessment) to Partial trip furnace (Closes Fuel Gas ESD

		decrease heat duty, decrease coil outlet temp, capacity reduced and potential flame out.	3.1.2Provided with stand by strainer.				valves) and keep pilot gas open) when fuel gas pressure reach to low low pressure alarm. to prevent the flame out.
Less/ No Flow	4.fuel gas UV fails closed.	4.1Decrease fuel gas flow to furnace burners resulting in decrease heat duty, decrease coil outlet temp, capacity reduced and potential flame out.		5/I	3/C	15/C I	45. ESD PI (SIL assessment) to Partial trip furnace (Closes Fuel Gas ESD valves) and keep pilot gas open) when fuel gas pressure reach to low low pressure alarm. to prevent the flame out.
Less/N o Flow	5. natural gas Strainer Blocked, Pilot Nozzles blocked. 6. pilot natural gas UVs fails closed.	5.1 Potential Pilot burners flame out resulting in loss of pilots followed by fire and explosion.	5.1.1 low pressure alarm on natural gas line. 5.1.2 providing with Flame detectors.	5/I	2/D	10/ DI	46. ESD PI (SIL assessment) to Heater total shutdown (Closes pilot Natural Gas ESD valves) and (Closes fuel Gas ESD valves) when pilot natural gas pressure reach to low low pressure alarm.

Other parameter:

Table (6) Flame out

Deviation	Causes	Consequences	Safeguards	S	L	R	Recommendations
Flame out	1. combustion air damper malfunction open/ Forced fan inlet valve fails open.	1.1 High pressure in fire box, the burners flame out followed by explosion.	1.1.1 inlet air register is installed for each burner. 1.1.2 Flame detector rod. 1.1.3 oxygen analyzer with high oxygen content alarm.	5/I	3/C	15/CI	47. ESD flame detector rods (SIL assessment) to activate heater total shutdown. (Closes Pilot Gas line ESD valves) (Closes Fuel Gas ESD valves)
Flame out	2. Induced fan inlet valve fails open.	2.1 the draft will increase resulting in flame out followed by fire and explosion.	2.1.1 PDI on air preheater flue gases side with high differential pressure alarm. 2.1.2 Flame detectors rod.	5/I	3/C	15/CI	48. ESD flame detector rods (SIL assessment) to activate heater total shutdown. (Closes Pilot Gas line ESD valves) (Closes Fuel Gas ESD valves)
Flame out	3. Main stack damper fails open during balance draft mode.	3.1 the draft will increase resulting in flame out followed by fire and explosion. 3.2 cold combustion air supply through air	3.1.1 PDI on induced fan with low alarm. 3.2.1 fully open alarm on main stack	5/I 3/III	3/C 4/B	15/CI 12/BIII	49. when PDI on induced fan with low low differential pressure alarm, the induced fan will be stopped and the heater switch to natural draft mode.

		preheater resulting in condensation of sulphuric acid, consumption a large amount of fuel gas, the heater efficiency will decrease.	damper.				50. ESD flame detector rods (SIL assessment) to activate heater total shutdown. (Closes Pilot Gas line ESD valves) (Closes Fuel Gas ESD valves)
Flame out	4. Inadvertent Combustion air valves fully closed.	4.1 the draft will increase resulting in flame out, accumulation of fuel gas lead to potential back fire and explosion.	4.1.1 low oxygen content alarm. 4.1.2 low draft alarm.	5/I	3/C	15/CI	51.ESD flame detector rods (SIL assessment) to activate heater total shutdown. 52. ESD PI fire box pressure low low (SIL assessment) to activate heater total shutdown.

4. Results and Discussion

53 scenarios were studied upon 5 nodes are selected for the Delayed Coker Unit HAZOP study to identify safety related hazards and significant operability problems related to the design and operation of the systems and 52recommendations are suggested to eliminate a cause of scenarios, prevent or mitigate the consequence and reduce the likelihood that the scenario will occur. 15scenarios are related to "red area" on risk matrix (unacceptable zone) so LOPA examine the HAZOP identified Safeguards and determines if the Current safeguards are enough and if proposed safeguards are warranted.15 scenarios are included in 5 Safety Instrumented Functions (SIFs) identified in the delayed coker unit HAZOP Study

Table (7) Safety Instrumented Functions

Hazard ID	Safety Instrumented Functions Description
1	FALL- Heater passes feed flow low low closes fuel gas ESD valves

2	PAHH-Heater Firebox Pressure High High activate N.D mode.
3	Flame Detectors Off activate Heater total shutdown.
4	LAHH-Fuel gas coalescer level High High closes fuel gas ESD valves .
5	PALL- Fuel gas pressure low low closes fuel gas ESD valves .

SIL assessment of Safety Instrumented Functions identified in the delayed coker HAZOP Study:

- FALL- Heater passes feed flow low low closes fuel gas ESD valves:

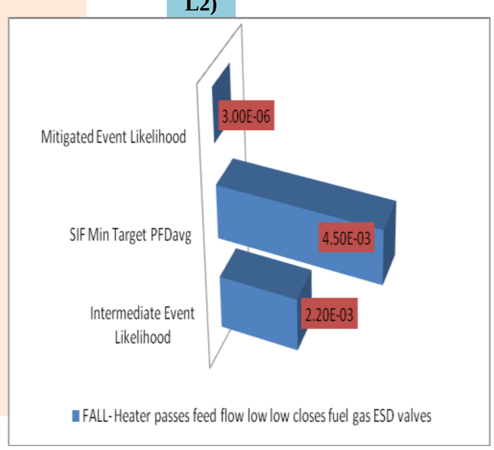
Interruption to VR flow resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture, loss of containment, fires, explosions, injuries, fatalities, asset damage and environmental impact.

Table (8) FALL- Heater passes feed flow low low closes fuel gas ESD valves

Hazard ID Reference: 1 Delayed Coker Unit

Short Description: FALL- Heater passes feed flow low low closes fuel gas ESD valves.

Impact Event Assessment	1 Impact Event Description or Demand Scenario	2 Assessed Severity Level	3 Initiating Cause	4 Initiating Likelihood /yr	5 Enabling Factor Ignition Probability	Occupancy	Operational	6 Independent Protection Layers 5A General Process Design	5B Basic Process Control System	5C Alarms & Response Failure	5D Additional IPL Giving Protection / Mitigation Another SIF	7 Additional Mitigation	8 Intermediate Event Likelihood /yr	9 SIF Min Target PFDavg Target SIL	10 Mitigated Event Likelihood /yr based on worst case PFDavg	11 Notes / Remarks
Safety Risk	Interruption to VR flow resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture, loss of	Ss Serious	Pump Suction strainer blockage	0.1 Based on best practice	1 Material released above its auto ignition temperature	0.1 People are present for less than 1-2 hours per day	1	1	0.1 DCS FIC to open FV As per LOPA - CCPS Guideline	0.1 Flow Alarm low As per CCPS Guideline	1	1	2.2E-03	4.5E-03 (SIL2)	3.0E-06	
			Charge pump suction valve fails closed.	0.10 BPCS instrument failure	1 Material released above its auto ignition temperature	0.1 People are present for less than 1-2 hours per day	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1					
			Furnace charge	0.10 Pump	1 Material	0.1 People	1	1	1	0.1 Flow	1					

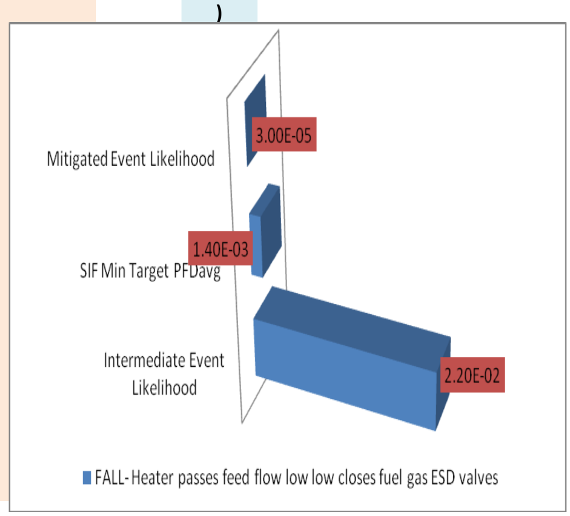


	containment, fires, explosions, injuries, fatalities, asset damage and environmental impact.		pump trip.	s seal failure	released above its auto ignition temperature	are present for less than 1-2 hours per day				Alarm low As per CCPS Guideline	
			inlet motorized valves to drum/ isolation valve inadvertent closure during switching	0.01 Human Error - Routine Procedure- Well trained- unstressed	1 Material released above its auto ignition temperature	0.1 People are present for less than 1-2 hours per day	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1

Table (9) FALL- Heater passes feed flow low low closes fuel gas ESD valves

Hazard ID Reference:	1	Delayed Coker Unit
Short Description:	FALL- Heater passes feed flow low low closes fuel gas ESD valves.	

Impact Event Assessment	1 Impact Event Description or Demand Scenario	2 Assessed Severity Level	3 Initiating Cause	4 Initiating Likelihood /yr	5 Enabling Factor Ignition Probability	Occupancy	Operational	6 Independent Protection Layers 5A General Process Design	5B Basic Process Control System	5C Alarms & Response Failure	5D Additional IPL Giving Protection / Mitigation	7 Additional Mitigation	8 Intermediate Event Likelihood /yr	9 SIF Min Target PFDavg ____ Target EIL	10 Mitigated Event Likelihood /yr based on worst case PFDavg	11 Notes / Remarks
Environmental Risk	Interruption to VR flow resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots	Ee Extensive	Pump Suction strainer blockage	0.10 Based on best practice	1	1	1	1	0.1 DCS FIC to open FV As per LOPA-CCPS Guideline	0.1 Flow Alarm low As per CCPS Guideline	1	1	2.2E-02	1.4E-03 (EIL2)	3.0E-05	
			Charge pump suction valve fails closed.	0.1 BPCS instrument failure	1	1	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1					
			Furnac	0.1	1	1	1	1	1	0.1	1					

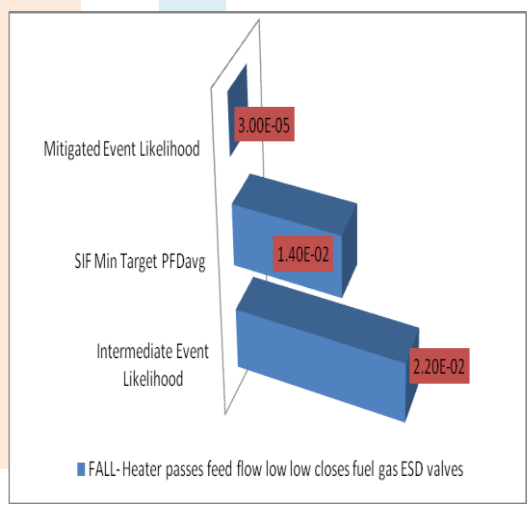


	leading to coil rupture, loss of containment, fires, explosions, injuries, fatalities, asset damage and environmental impact.		e charge pump trip.	Pumps seal failure						Flow Alarm low As per CCPS Guideline		
			inlet motorized valves to drum/ isolation valve inadvertent closure during switching.	0.01 Human Error - Routine Procedure- Well trained- unstressed	1	1	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1	

Table (10) FALL- Heater passes feed flow low low closes fuel gas ESD valves

Hazard ID Reference:	1	Delayed Coker Unit
Short Description:		FALL- Heater passes feed flow low low closes fuel gas ESD valves.

	1	2	3	4	5			6				7	8	9	10	11
								Independent Protection Layers								
Impact Event Assessment	Impact Event Description or Demand Scenario	Assessed Severity Level	Initiating Cause	Initiating Likelihood /yr	Enabling Factor			5A General Process Design	5B Basic Process Control System	5C Alarms & Response Failure	5D Additional IPL Giving Protection / Mitigation	Additional Mitigation	Intermediate Event Likelihood /yr	SIF Min Target PFD avg ____ Target CIL	Mitigated Event Likelihood /yr based on worst case PFDavg	Notes / Remarks
					Ignition Probability	Occupancy	Operational									
Commercial Risk	Interruption to VR flow resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture, loss of	Cc Catastrophic	Pump Suction strainer blockage	0.10000 Based on best practice	1	1	1	1	0.1 DCS FIC to open FV As per LOPA - CCPS Guideline	0.1 Flow Alarm low As per CCPS Guideline	1	1	2.2E-02	1.4 E-02 (CIL1)	3.0E-05	
			Charge pump suction valve fails closed.	0.1 BPCS instrument failure	1	1	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1					
			Furnac	0.1	1	1	1	1	1	0.1	1					

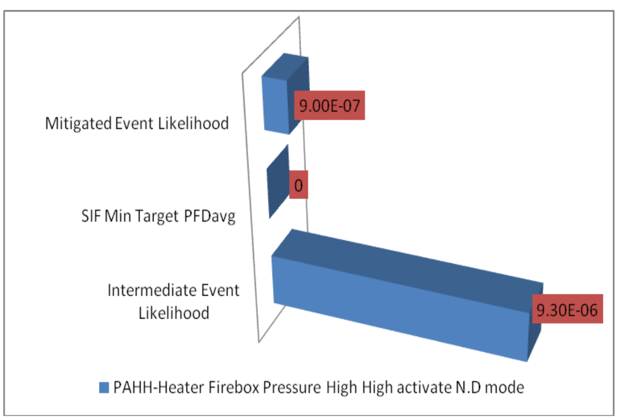


	containment, fires, explosions, injuries, fatalities, asset damage and environmental impact.		e charge pump trip.	Pumps seal failure						Flow Alarm low As per CCPS Guideline	
			inlet motorized valves to drum/ isolation valve inadvertent closure during switching.	0.01 Human Error - Routine Procedure- Well trained- unstressed	1	1	1	1	1	0.1 Flow Alarm low As per CCPS Guideline	1

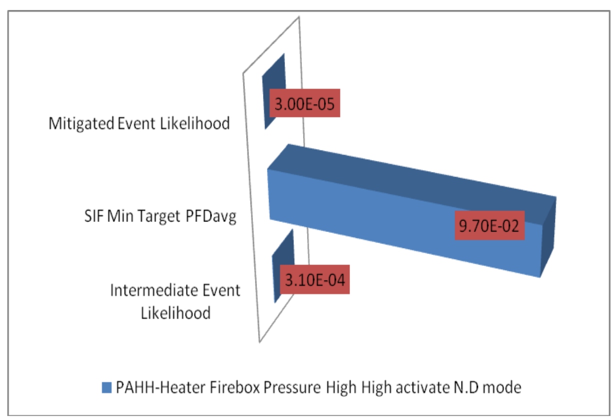
- PAHH-Heater Firebox Pressure High High activate N.D mode:

High pressure in fire box, potential flame out followed by potential back fire and explosion, loss of containment, injuries, fatalities, asset damage and environmental impact.Initiating Cause(combustion air damper malfunction open,Forced fan inlet valve fails open,Main stack /Arch damper malfunction close,Induced fan trip (balanced draft)).

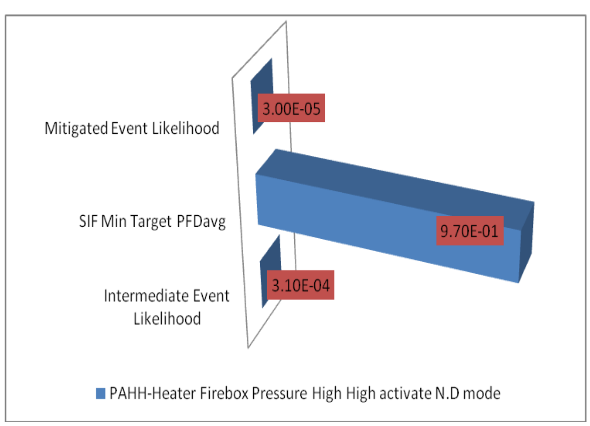
Safety Risk



Environmental Risk



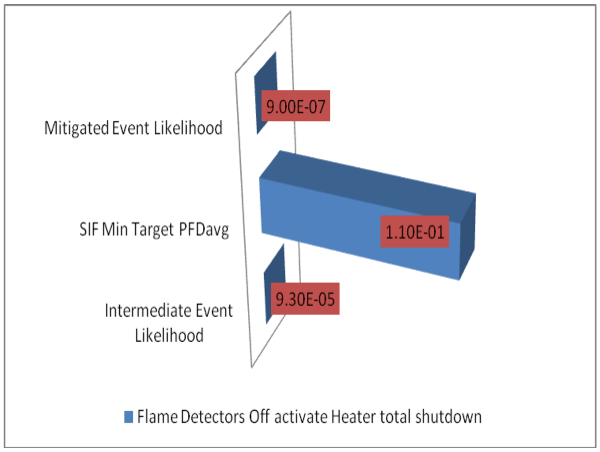
Commercial risk



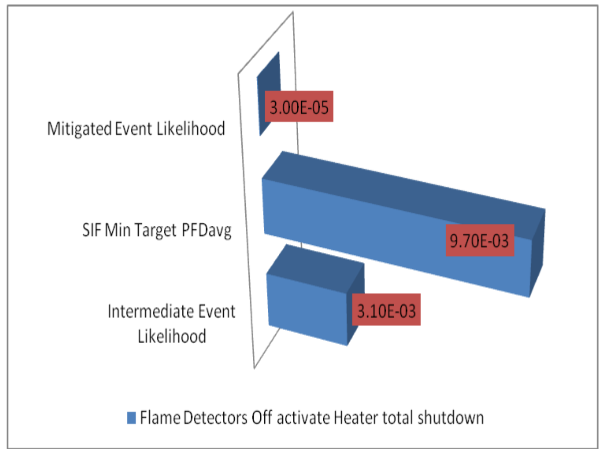
- Flame Detectors Off activate Heater total shutdown.

Potential flame out followed by potential back fire and explosion, loss of containment, injuries, fatalities, asset damage and environmental impact. Initiating Cause (combustion air damper malfunction open/ Forced fan inlet valve fails open, Induced fan inlet valve fails open, Main stack damper fails open during balance draft mode, Inadvertent Combustion air valves fully closed).

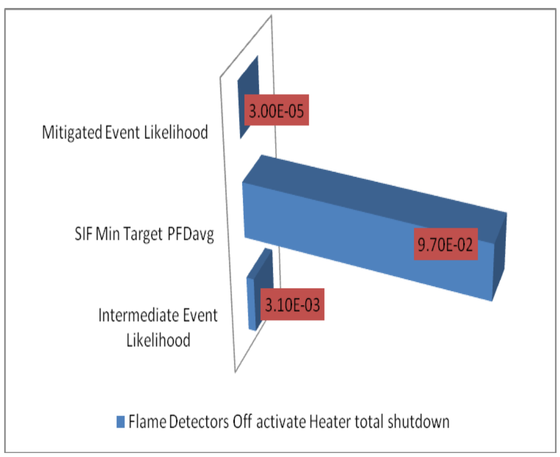
Safety Risk



Environmental risk



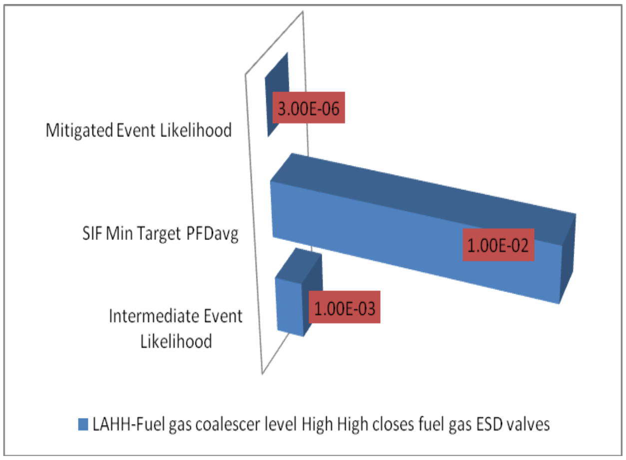
Commercial Risk



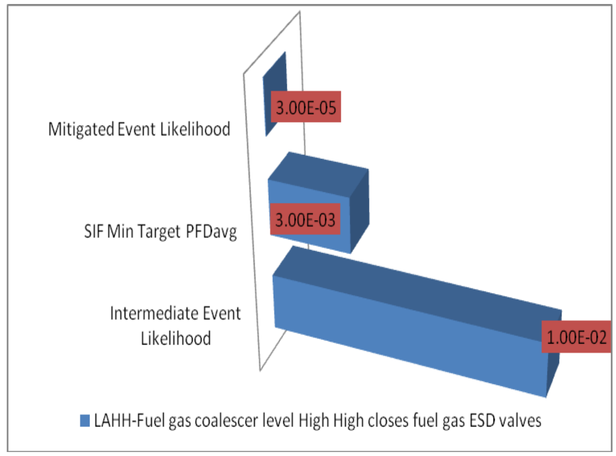
- LAHH-Fuel gas coalescer level High High closes fuel gas ESD valves:

Liquid HCs level build up in fuel gas coalescer and carry over to fuel gas line resulting in potential over temperature leading to coke formation inside the heater coils and potential hot spots leading to coil rupture,fire and explosion, injuries, fatalities, asset damage and environmental impact.Initiating Cause(fuel gas coalescer LIC failure driving LV fully close)

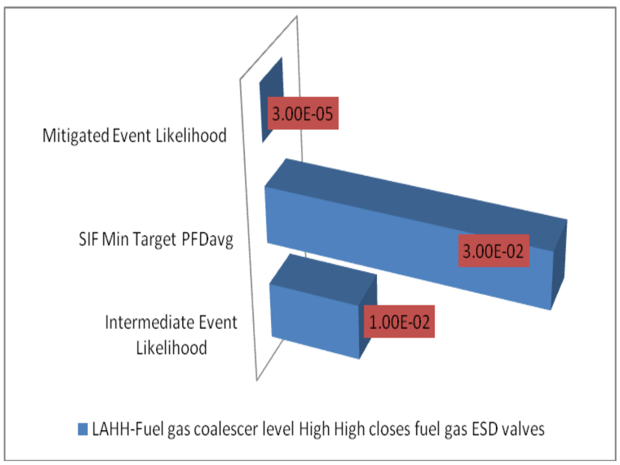
Safety Risk



Environmental risk



Commercial Risk

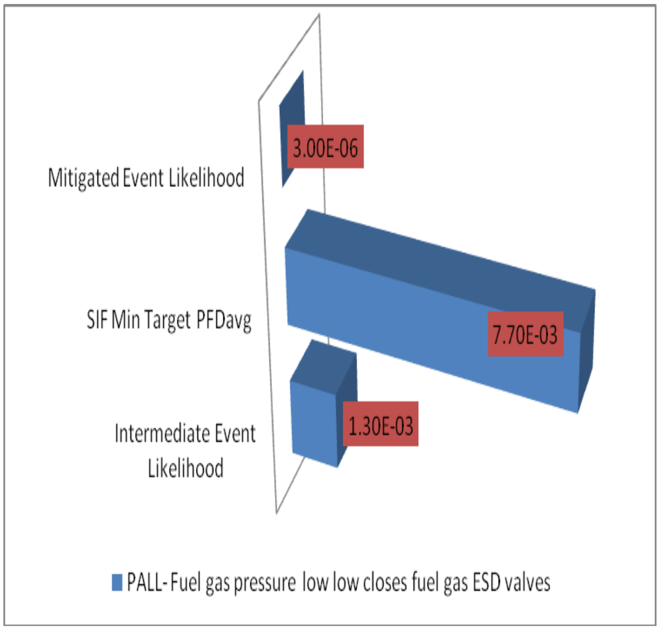


- PALL- Fuel gas pressure low low closes fuel gas ESD valves:

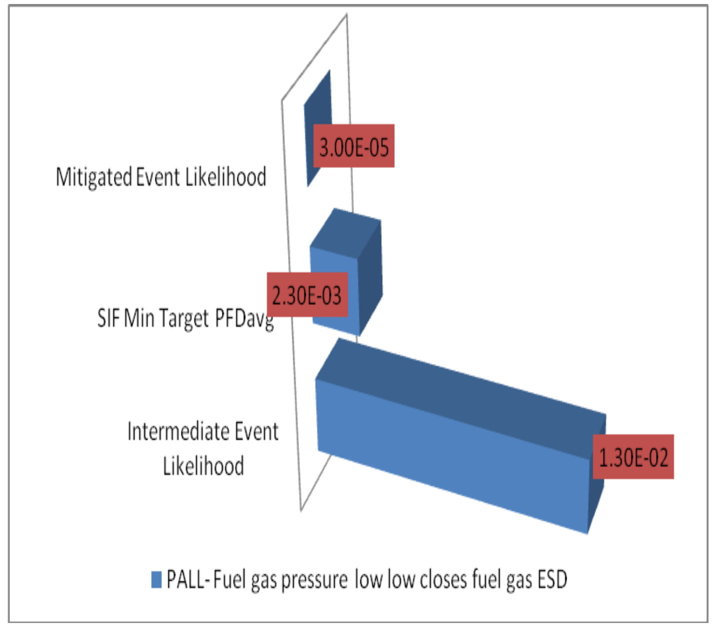
Decrease fuel gas flow to furnace burners resulting in decrease heat duty, decrease coil outlet temp, process upset (in fractionator and coke drum). capacity reduced, and potential flame out,fire and explosion, injuries, fatalities, asset damage and environmental impact.Initiating Cause(fuel gas FIC failure driving fuel gas FV fully close,fuel gas coalescer LIC failure driving LV fully open,fuel gas strainer blocked,fuel gas UV fails closed).

Commercial Risk

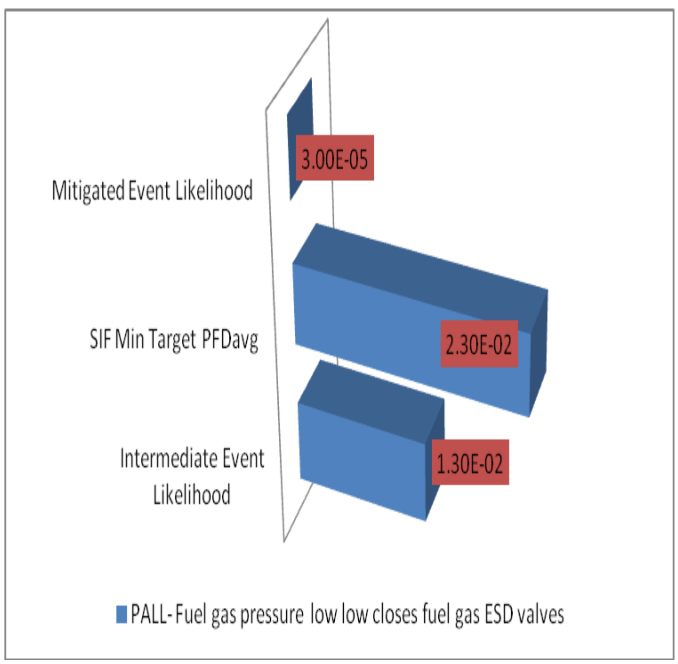
Safety Risk



Environmental risk



Commercial Risk



5. Conclusions

Hazards and Operability Analysis & Layer of Protection Analysis should be integrated for safety management. As the HAZOP study alone is used to identify hazards (HAZ) and operability (OP) issues but not a design checks or provide design alternative, and Not an optimization study. The HAZOP study and Safety Layers of Protection Analysis are integrated and performed upon 5 selected nodes in Delayed Coker Unit in order to proactively and systematically identify, evaluation, and mitigation or prevention of potential critical effects due to the deviation that could occur as a result of failures in process, procedures, or equipment in delayed coker unit. the LOPA was to assess the SIL (Safety Integrity Level) requested, determine the required reliability for a Safety Instrumented System (SIS), taking into account the severity of the hazardous event and other independent layers of protection that are contributing to the overall risk reduction for the safety instrumented function identified during the HAZOP study. Inappropriate SIL determination in delayed coker unit can affect the safety integrity of the asset protection envelope and unnecessary capital and operational spending. in contrary, properly determined SIL levels resulting in cost improvements. Companies that real practice PHA are finding a continuing reduction in frequency and severity of industrial accidents. where the LOPA study set the five SIFs SIL target requirements as below:

Table (11) five SIFs SIL Target Requirements

Classification	No. of SIF(s)	Target PFDavg
Classified as SIL-2	4	FALL heater passes flow 1.4E-03
		Flame Detectors Off 9.7E-03
		LAHH fuel gas coalescer 3.0E-03
		PALL- Fuel gas pressure 2.3E-03
Classified as SIL-1	1	PAHHHeater Firebox 9.7E-02
Non-classified SIL	0	-
Total Studied SIFs	5	-

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