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Risk assessment and management based on the process analysis of risks and their feasibility in gas-pressure reduction stations

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Abstract

Natural Gas as a cheap, clean, easy to transport & with high heating value is one of the most important sources of energies used all over the world. City Gate Stations (CGS) are one of the main and important parts of natural gas distribution systems. Considering the sensitivity of the pressure reduction stations in the gasification process, it is necessary to identify all the risks and analyze their feasibility in order to prevent potential accidents and damages, and based on that, identify the existing risks and manage them appropriately. The main goal of this research is identifying process hazards and operational difficulties in one of CGSs to develop practical pathways to prevent hazardous conditions or reducing incidents consequences. HAZOP study has done and 4 nodes have defined for the process and 47 process deviations recognized by using process parameters and guide words, 113 consequences and 97 causes have identified. Then risks have calculated and evaluated by Risk Matrix and 27 recommendations including process changes, new safeguards and protective systems have suggested.

Keywords:
Hazards Identification, Operability, Risk Assessment, Gas Pressure Regulation Station

1. Introduction

Most of the risks in a system arising from defects in design, process materials, work or human error. Various methods are used to study safety analysis in the process industry, which can be defined as quantitatively or qualitatively. For example, the following methods evaluate the risks in a qualitative: check-in, what-IF study, HAZOP study, ETA event tree, FTA error tree, Failure mode and effects analysis (FMEA) (Stroykov et al., 2020; Johnson et al., 2022; Bao et al., 2019). The quantitative evaluation methods are commonly used for accurate evaluations of the identified risks, and are also used for design and review

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evaluation in cases where the risk is higher than the permissible limit (Lazar Farokhi, 2019; Rahman and Wahid, 2021). In (Fuentes-Bargues et al., 2016) in order to assess the risks of the process of sweetening part of the gas purification unit in a gas refinery, they have identified the important risks of the process using the HAZOP method and calculated their risk. In general, 38 risk of identified risk, including the highest risk, which is 60, related to reducing the temperature of the pre -treatment unit and defects of diethanolamine cooling systems in the DE node and the lowest risk that 12 is related to the left defect (P-6), the valve defects. In the (Herrera et al., 2015), due to the importance of risk assessment studies in process units, the HAZOP study in the Furfural unit of the oil refinery has been conducted. In (Mechhoud et al., 2016), in order to improve safety to reduce accidents, identifying the risks and evaluating and controlling the risks of safety, health and environmental safety, health and environmental using the HAZOP method in the oil warehouse of the petroleum products distribution company and examined the factors affecting the risk of distribution.

In (Rimkevičius et al., 2016) identified the hazards of gas refineries by HAZOP and determined the level of safety of emergency stop systems by LOPA. In this study, the LOPA method was examined by protective layers that are capable of reducing risk and the safety integrity level (SIL) was determined. In (Xiao et al., 2021) HAZOP and ETBA methods have been used to analyze the process hazards in the chlorination unit in the treatment plant. Due to the frequent use of the chlorine and the inherent nature of the dangerous nature of this gas, this unit is one of the most critical units of a refinery. In this study, aspects related to the safety of the chlorination unit were examined using the two methods and the results compared the two methods (Xiao et al., 2021). In (Herrera et al., 2015) the HAZOP method is used to assess the risks in the new protein production system in a pharmaceutical plant. 19 critical nodes are specified in this process and the deviations and frequency of their probability and the effects of the events that result are based on the knowledge and experience of the collection experts. In addition, it is clear that in a pharmaceutical factory the most critical risks are those that have negative effects on production, such as minor or general waste or non -compliance with the rules.

In (Hassannayebi et al., 2022), a risk assessment method in industrial units based on a combination of HAZOP identification methods and risk assessment using descriptive variables and fuzzy numbers used to study in a hybrid feed unit in Spain. Studies show that the main risk in the production process of this unit is the formation of an explosive atmosphere. Therefore, corrective measurements should focus on reducing the concentration of dust in the atmosphere and reducing the potential source of combustion such as electrostatic discharge or spark in different phases of the process. In (Riemersma et al., 2022) a combination of HAZOP and FMEA methods are used to evaluate and analyze risk in petrochemical units. In addition, the evaluation of accidental scenarios has also been considered. The main advantage of applying these two methods is to accelerate the identification of risks and risk assessment and forecast of environmental effects and the consequences of these events. The process parameters of each system have been analyzed and the deviations of the operating parameters of each system are extracted in the unit, and the possible causes of these deviations, their consequences, and preventive strategies to minimize the risk and improve the system's safety.

Natural gas can be the cause of major accidents due to the ability of the flammable and explosion. Therefore, recognizing the risks from it will be an important factor in reducing financial and life damage. The Gas Company must have a complete understanding of these risks, risks and controls. Performing this study can be an effective step in identifying more precise recognition factors and evaluating the effectiveness of existing controls and ultimately helping to increase the safety level of gas pressure reduction stations.

2. Method

In order to evalute the risk quality the probability and intensity graph used which is called as "risk matrix". According to Figure 1, the intensity is shown on the horizontal axis and the probability on the vertical axis. The parameters or numbers are attributed to qualitative probability and severity and indicate their ascending and descending order. The arrays within the matrix are qualified and show the value of risk, and the matrix depends on the number of definitions of probability and severity. For example, figure 1 relates to a 4x4 matrix. It should be noted that the matrix order is directly related to its accuracy. If several risk matrix are used, the maximum risk value is finally reported.

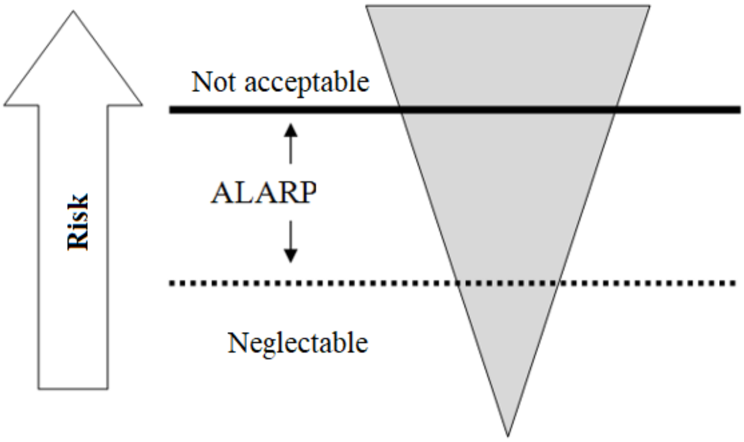

Figure 1: Risk Schematic

The risk matrix should not necessarily be symmetrical. The asymmetric risk can also be defined as needed. It is also common for using colors instead of numbers and letters for arrays within the matrix. Figure 2 provides an asymmetric matrix sample (Fuentes-Bargues et al., 2016).

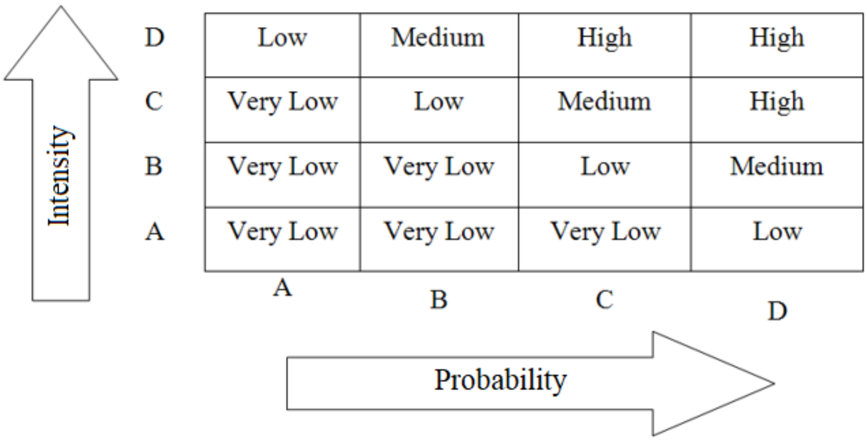

Figure 2: Matrix Risk

HAZOP study is a fully systematic method that identifies other process hazards with the help of a team with different specialties and the use of guidance system. One of the most important components of the study of HAZOP is to determine the risk of risk due to their aberration and interpretation. To determine the risk of risk, the qualitative concepts of the intensity of the error and the probability of occurrence are used and specified according to the resulting number and comparison with the defined criterion of the type of risks (Fuentes-Bargues et al., 2016).

Table 1: Risk Calculation Table (Risk Matrix).

Increased possibility						Consequences				Intensity
Level6	**Level5**	**Level4**	**Level3**	**Level2**	**Level1**	**Credit**	environment	Fund	**Human**	
						No effect	No effect	Harmless	Partial injury and injury	(1)
		Planning in the direction of continuous improvement				Mild effects	Mild effects	Mild injury	Surface Healthy Injuries or Effects	(2)
						Minor effects	Minor effects	Minor injury	Serious health injuries or effects	(3)
		ALARP				Topical effects	Topical effects	Local damage	Major health injuries or effects	(4)
						Major effects	Major effects	Severe damage	Member defect and permanent disability	(5)
	Unbearable					Wide effects	Wide effects	Extensive damage	death	(6)

Table 2. Risk grading.

The necessary activities	Risk Grade	Risk status
Requires review and attention as soon as possible	High	UN[2]
The risk should be removed without delay	Mild	CO[3]
The risk should be resolved without delay but the emergency is not	Low	[4]AC

The hazards identified in HAZOP studies are at one of the above levels, and one of the goals of the HAZOP study team is to provide suggestions such as protective and control systems to reduce the degree of identified risks so that these suggestions can be used to help the unit. Led the low risk area. It should be noted that in HAZOP studies, all risks are identified and evaluated, but only by doing this study, the

[2] Unacceptable
[3] Conditionally
[4] Acceptable

risk of identified risks and risks can be eliminated, so some risks in HAZOP studies that have a moderate risk degree may be registered without an offer (Fuentes-Bargues et al., 2016).

3. Results

In this section HAZOP method was used for identifying risks in CGS stations and evaluating their risk.

3.1 Identify and evaluate risk in a CGS using the HAZOP method

According to the available method, HAZOP studies at the CGS pressure reduction station are done in three steps as follows: - identifying nodes; - check and identify deviations; - Complete the worksheets. Also, the risk assessment matrix is used to evaluate the calculated risks in accordance with Table 3.

Table 3. Risk assessment matrix

Increase the probability						Consequences				Intensity
Level6	**Level 5**	**Level 4**	**Level 3**	**Level 2**	**Level 1**	**Credit**	environment	Fund	**Human**	
						No effect	No effect	harmless	Partial injury and injury	(1)
			Planning in the direction of continuous improvement			Mild effects	Mild effects	Mild injury	Surface Healthy Injuries or Effects	(2)
						Minor effects	Minor effects	Minor injury	Serious health injuries or effects	(3)
			ALARP			Topical effects	Topical effects	Local damage	Major health injuries or effects	(4)
						Major effects	Major effects	Severe damage	Member defect and permanent disability	(5)
	Unbearable					Wide effects	Wide effects	Extensive damage	death	(6)

Identify nodes: The nodes identified in the CGS process are presented in Table 4.

3.2 Check and identify deviations

In this section, process deviations are identified in each of the nodes specified. First Node deviations: the separator filter. In this node, the type of equipment is the pipeline, tank, dry gas filter and conditions and parameters of current design, pressure, temperature, surface, commissioning, operations and repairs. The possible deviations are described as Table 5.

Table 4: Nodes identified in CGS

Node	Type of equipment	Design conditions/parameters
Filter Separator	Pipeline	Flow, pressure, temperature, level, setup, operation, repairs
	Reservoir	
	Filter	
Heater	Pipeline	Flow, pressure, temperature, level, composition of materials, operations, commissioning, repairs
	Heater	
	Filter	
	Coil	
Pressure reduction equipment	Pipeline	Flow, pressure, temperature, commissioning, operations, repairs
	regulator	
	Cutting valve	
	Gauge	
Gas Odorizer	Pipeline	Flow, pressure, temperature, level, operation, repair
	Tank	
	Pump metering	

Table 5: Possible deviations in the separating filter group

Deviation	Guide word	Parameter	Concept
1. More Flow	More	Flow	The flow of more than expected
2. No/Less Flow	No/Less	Flow	Disconnecting or reducing flow
3. High Pressure	High	Pressure	Pressure higher than expected
4. Low Pressure	Low	Pressure	Pressure less than expected
5. High Temperature	High	Temperature	Higher temperatures above expectation
6. Low Temperature	Low	Temperature	Temperature lower than expected
7. High Level	High	Level	Increase the fluid level over expectation
8. No/Less Level	No/|Less	Level	Reducing levels to a lower extent than expected
9. Start-up Hazards	Other than	Start-up	Startup Risks
10. Environmental Aspects	As well as	Operation	Environmental considerations
11. Maintenance Hazards	Other than	Maintenance	Maintenance risks
12. Leakage	As well as	Flow	Leakage simultaneously with fluid flow
13. Loss of Performance	Other than	Performance	Performance deficiency

Second Node Deviations: Heater: In this node, the type of equipment is the type of pipeline, heater, coil, filter and conditions and parameters of pressure design, temperature, and surface, composition of materials, operations, operations, commissioning, and repairs. The possible deviations are described as Table 6.

Table 6: Possible deviations in the heater node

Deviation	Guide word	Parameter	Concept
1. No/Less/More Flow of Fuel Gas	No/Less/More	Flow	Cut/decrease/increase the flow of fuel gas
2. No/Less/More Flow of Pilot Gas	No/Less/More	Flow	Cut/Reduce/Increasing Pilot Gas Flow
3. High Pressure of Fuel Gas	High	Pressure	Pressure higher than expected gas
4. Low Pressure of Fuel Gas	Low	Pressure	Pressure less than expected of fuel
5. High Pressure of Pilot Gas	High	Pressure	Pressure higher than expected pilot gas
6. Low Pressure of Pilot Gas	Low	Pressure	Pressure less than the waiting limit of pilot
7. High Temperature	High	Temperature	Higher temperatures above expectation
8. Low Temperature	Low	Temperature	Temperature lower than expected
9. High Level	High	Level	Increasing liquid levels over expectation
10. No/Less Level	No/Less	Level	Reducing levels to a lower extent than expected
11. Wrong Composition	Other than	Composition	Inappropriate water / glycol concentration
12. Tube Leak	As well as	Flow	Pipe leakage
13. Environmental Aspects	As well as	Operation	Environmental considerations
14. Loss of Performance	Other than	Performance	Performance deficiency
15. Maintenance Hazards	As well as	Maintenance	Maintenance risks
16. Start-up Hazards	As well as	Start-up	Startup Risks

Third Node Deviation - Popcorn -reducing equipment: in this node, the type of equipment includes pipeline, regulator, pressure cutting milk, gas flow measurement and pressure design conditions, temperature, current, commissioning, operations, and repairs. The possible deviations have been described as Table 7.

Table 7- Possible aberrations in the node of pressure reduction equipment

Deviation	Guide word	Parameter	Concept
1. More Flow	More	Flow	The flow of more than expected
2. No/Less Flow	No/Less	Flow	Disconnecting or reducing flow
3. High Pressure	High	Pressure	Pressure higher than expected
4. Low Pressure	Low	Pressure	Pressure less than expected
5. High Temperature	High	Temperature	Higher temperatures above expectation
6. Low Temperature	Low	Temperature	Temperature lower than expected
7. Environmental Aspects	As well as	Operation	Environmental considerations
8. Leakage	As well as	Flow	Leakage simultaneously with fluid flow
9. Maintenance Hazards	As well as	Maintenance	Maintenance risks

Fourth node deviations - Gas Odorizer: In this node, the types of equipment are pipelines, tanks, metering pumps, and design conditions and parameters of flow, pressure, temperature, level, operation, and repairs. Possible deviations are defined as described in Table 8.

Table 8: Possible deviations in the Gas Odorizer

Deviation	Guide word	Parameter	Concept
1. More Quantity of Odorant	More	Quantity	Higher value than expected of the gas odorizer
2. Less Quantity of Odorant	Less	Quantity	The amount of less than expected of the odorizer
3. Pump Discharge High Pressure	High	Pressure	Pressure higher than expected pump outlet
4. Pump Discharge Low Pressure	Low	Pressure	Pressure less than expected pump outlet
5. High Pressure of Odorizer Drum and Barrel	High	Pressure	Pressure higher than expected odorizer
6. Low Pressure of Odorizer Drum and Barrel	Low	Pressure	Pressure less than expected odorizer reservoir
7. High Level of Odorizer Drum	High	Level	Higher level than expected of the odorizer reservoir
8. No/Less Level of Odorizer Drum	No/Less	Level	Lower level than expected odorizer reservoir
9. Leakage	As well as	Flow	odorizer leak

According to studies by the HAZOP method, the process was divided into 4 nodes and 47 deflections, 97 causes and 113 consequences were identified. Also, there are 209 safety inhibitors. Charts of 2 to 5 demonstrate the deviations, causes, identified consequences, and existing safety inhibitors by each node.

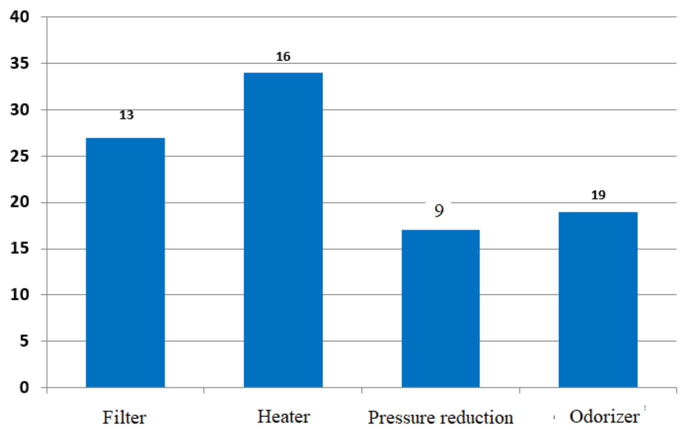

Figure 2: Deviations detected in each node

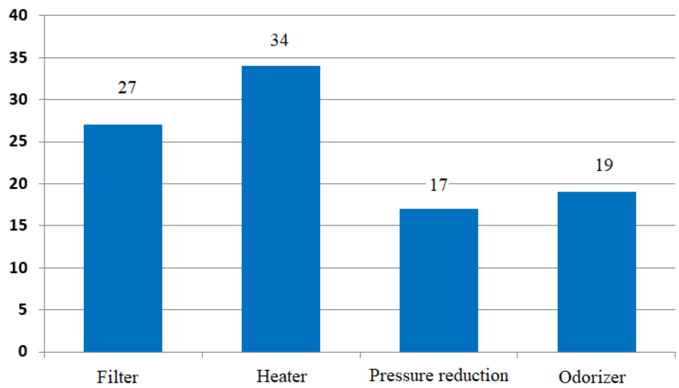

Figure 3: Causes identified in each node

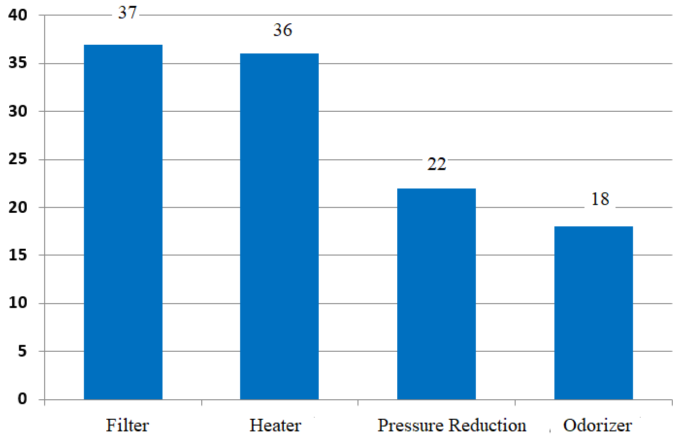

Figure 4: Consequences identified at each node

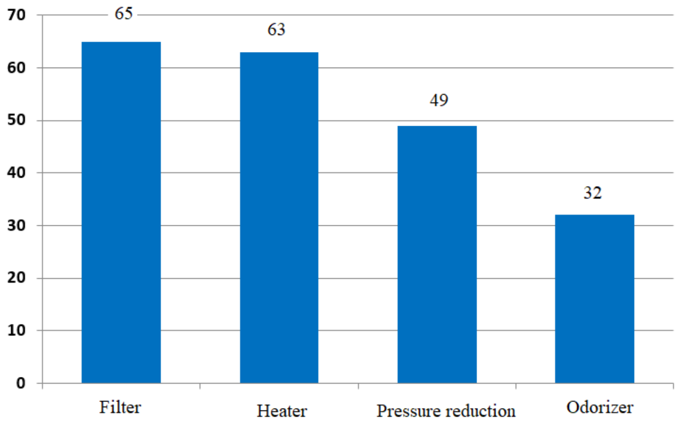

Figure 5: Safety inhibitors identified in each node

The possible causes of each of the identified deviations in different nodes are also presented in Table 9.

Table 9: Summary of the results by separation of deviations and their causes in different nodes of the pressure reduction process at the CGS station

Node	Deviation	Causes
1. Filter separator	1. More Flow	High consumption downstream of the filter
		Rupture of the pipeline downstream of the filter
	2. No/Less Flow	Stopping or reducing the flow from above
		Clogging of the filter due to the accumulation of solid or liquid particles
		Leakage or rupture in equipment, connections and installations
		Valve closing due to human or mechanical error
	3. High Pressure	More pressure from the upper arm
		Presence of external flame and fire
	4. Low Pressure	The causes are similar to those mentioned in No/Less Flow.
	5. High Temperature	improbable
	6. Low Temperature	Lowering the ambient temperature

Node	Deviation	Causes
	7. High Level	The operation of setting up new lines or running the ball above and not draining the accumulated liquids in the filter at the right time
		Failure to drain accumulated liquids during normal operation
	8. No/Less Level	not important
	9. Start-up Hazards	Not purging the air before starting
		The filter door is not completely closed during startup
		Mechanical error of the filter door and lack of resistance
	10. Environmental Aspects	Replacement of filter elements and other consumable parts
		Gas leak
		Gas discharge in pit drain
		Discharge of filter gas during riveting
	11. Maintenance Hazards	Opening the filter door before completely draining the gas
		Doing exothermic reaction between iron sulfide and air oxygen when opening the filter door
		Removing the filter cartridges
		Gas discharge to the drain
	12. Leakage	Leaks in flanges, fittings and filter valves
	13. Loss of Performance	Improper or insufficient filter performance in isolation for any reason
2. Heater	1. No/Less/More Flow of Fuel Gas	The causes are similar to those mentioned in the filter.
	2. No/Less/More Flow of Pilot Gas	The reasons are similar to those mentioned in the pilot.
	3. High Pressure of Fuel Gas	Incorrect operation of the flame control valve
		Incorrect operation of the shut-off valve
		Failure of the main regulator
	4. Low Pressure of Fuel Gas	Incorrect operation of the burner flame control valve
		Incorrect operation of the shut-off valve
		Malfunction of the main regulator
		Closing manual valves in the fuel line due to human error
		Clogged fuel line filter
	5. High Pressure of Pilot Gas	Incorrect operation of the regulator on the pilot gas flow line
	6. Low Pressure of Pilot Gas	Malfunction of the regulator on the pilot gas flow line
	7. High Temperature	Incorrect operation of the burner flame control valve
		Incorrect operation of the shut-off valve
	8. Low Temperature	Cut off or reduce heater fuel line pressure
		Other causes such as Low Pressure of Fuel Gas
	9. High Level	Expansion of water due to increase in temperature
		Heater overfilling due to human error
	10. No/Less Level	Evaporation of water due to the increase in temperature in the heater
		Evaporation of water due to insufficient amount of ethylene glycol
		Leakage from tank heater
	11. Wrong Composition	Wrong ratio of glycol to DM water
		DM water out of spec
		Glycol out of spec
	12. Tube Leak	Corrosion or wear in fuel line gas flow preheater coils
		Corrosion or wear in coils containing gas flow
		Corrosion in Fire Tubes
	13. Environmental Aspects	Improper air-fuel ratio in the combustion chamber
		Spilling of water containing antifreeze due to expansion
	14. Loss of Performance	Improper air-fuel ratio in the combustion chamber

Node	Deviation	Causes
	15. Maintenance Hazards	Repair of fuel line gas preheat coil
		Filling or emptying the heater tank to carry out repairs
	16. Start-up Hazards	Turn on the heater manually
3. Pressure Reducing Equipment	1. More Flow	High consumption downstream
		Rupture of the pipeline downstream
	2. No/Less Flow	Cut off or reduce flow from upstream
		Damage or rupture in equipment, connections and installations
		Closing regulators due to human error
		Closing of any valve due to human or mechanical error
		Opening the safety valve
		Closing the shot off valve due to an error in the tripping unit system
	3. High Pressure	Failure of pressure regulation regulators to function correctly
	4. Low Pressure	Similar to current deviations
	5. High Temperature	Increase heating in heaters
	6. Low Temperature	Pressure reduction in regulators
		Less heating in heaters
	7. Environmental Aspects	Activation of the safety valve
		Gas leakage in other equipment
	8. Leakage	Leakage in flanges, fittings and valves
	9. Maintenance Hazards	Equipment repair
4. Odorizer	1. More Quantity of Odorant	Incorrect operation of the injection pump
	2. Less Quantity of Odorant	Incorrect operation of the injection pump
		Partial clogging of the inlet strainer to the injection pump
		Lack of sufficient amount of fragrance material in the fragrance tank
	3. Pump Discharge High Pressure	Choking of the pump output line due to the failure of the one-way valve or manual valve
	4. Pump Discharge Low Pressure	Less Quantity of Odorant
	5. High Pressure of Odorizer Drum and Barrel	fire
		Improper operation of the regulator at the inlet of the storage tank
		Improper operation of the regulator at the entrance of the barrel containing the fragrance
	6. Low Pressure of Odorizer Drum and Barrel	Improper operation of the regulator at the inlet of the storage tank
		Improper operation of the regulator at the entrance of the barrel containing the fragrance
	7. High Level of Odorizer Drum	Overfilling due to equipment failure and human error
	8. No/Less Level of Odorizer Drum	Timely filling of the tank and consumption of materials
		Similar to leakage deviation
	9. Leakage	Open or damaged PSV
		Pipe leakage from fittings
		Errors in equipment and connections related to loading operations
		Human Error
		Leakage in barrels containing perfumes due to storage problems including rotting

Based on the severity (s) and probability (L) of the occurrence of each of the identified risks, the risk level (RR) of each of them was evaluated using the risk matrix, and 94 risks with a low degree (AC), 17 risks with a moderate degree (CO) and 2 high risk (UN) have been identified as shown in Figure 6.

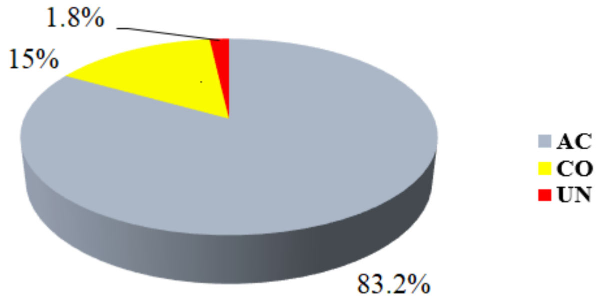

Figure 6: The percentage of identified risks with different degrees

In addition, based on the studies conducted, 27 proposed control measures aimed at improving the safety level and reducing weaknesses in the sections related to safety and control systems, operating operations, repairs and technical inspections, which include the addition of control systems and precision instruments, emergency valves and Their peripheral systems, adding equipment with greater reliability and safety, correcting P&ID drawings or adding new commands in software systems, etc., were identified.

4. Conclusion

Based on the studies, the pressure reduction process at the CGS station was divided into 4 nodes, and according to the guide words, 47 deviations were identified, which can be caused by 97 causes and have 113 possible consequences. Based on the investigations, there are currently 209 factors preventing and securing the process. The studies conducted show that most of the identified risks, about 83.2%, were low-grade risks that did not have an emergency situation, and only about 15% of the risks were medium-grade risks that should be resolved without delay, and 8.8 1% of the risks have a high degree of risk, requiring immediate consideration and attention. The results show that according to the strict compliance with safety standards and conditions in the design and construction of CGS stations, the presence of regular controls and inspections, as well as the presence of precision instruments and control equipment, the desired process in the studied CGS station has a relatively high level of safety, and if Implementation of the proposed control measures, the risk level of all the identified risks will be low.

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