7th International Conference on Reliability and Safety Engineering (ICRSE2023)

Application of Operation and Risk Study Technique (HAZOP) in Assessing Safety and Health Risks: A Case Study in CGS station

Rajabali Hokmabadi[1], Ali Karimi[2*]

1- Ph.D.Student, Department of Occupational Health Engineering, Faculty of Health, Tehran University of Medical Sciences, Tehran, Iran. Faculty member of Health School, North Khorasan University of Medical Sciences, Bojnurd, Iran. ORCID-CODE: 0000-0001-6037-4512

2*- Department of Occupational Health Engineering, Faculty of Health, Tehran University of Medical Sciences, Tehran, Iran. a_karimi@sina.tums.ac.ir. 09126431290. ORCID-CODE: 0000-0001-6924-2903

Abstract

Accurate identification of the dangers of the gas industry as part of a comprehensive safety analysis. In industrial activities, risk assessment and management techniques are used through the use of preventive approach and with the aim of improving safety to reduce the power of accidents. This descriptive study was performed in CGS station. Four principal nodes were identified across the gas depressurization process: filter, heater, regulator and odorize. Operational parameters, design limit, and possible deviations were investigated. Required information for HAZOP worksheets were gathered by operational procedures, daily report and interviews with engineers and operators working in the station. Determination of severity consequences and probability of occurrence of scenarios that were predicted and based on the risk matrix, the amount of risk was determined and the necessary suggestions were made in this regard.According to the study, the operational indicators in the pressure reducing station process included pressure, flow rate and temperature. One of the other deviations determined by the team with the keyword "other conditions" was the indicators of corrosion, abrasion, leakage, vibration and odor. 26 main deviations and 86 causes of failures were identified. The application of this methodology generated 60 recommendations to mitigate the detected problems. 7 deviations (30%) were in the low risk (green area) and 19 deviations (70%) were in the medium risk (yellow area).Causes and effects of deviations in operational parameters at four nodes in gas depressurization station were identified by HAZOP. Preventive actions were emphasized, such as consistent inspection of pipelines, preventive and timely maintenance and preparing a well-scheduled plan for inspecting the equipment in terms of corrosion, inspection, and design revision.

Keyword: Hazard Identification, HAZOP Analysis, CGS station

Introduction

In the new age, with the rapid advancement of industry and technology, there are many concerns about the negative consequences related to human life. Accidents associated with the gas industry can cause various types of damage and irreparable injuries [1]. Many serious accidents occur because of lack of an ideal Equipment to analyze knowledge precisely [2-3]. The size and complexity of industrial plants, along with the characteristics of the products used, require a study, analysis and control of the existing risks in every industrial process [4]. Systemic safety assessment must be performed in chemical units to ensure production safety because Process and chemical units are usually toxic, explosive and flammable [5].

Identifying hazards is fundamental for ensuring the safe design and operation of a system in process units and other facilities. Many techniques are available to identify hazardous situations, all of which require their rigorous, thorough, and systematic application by a multi-disciplinary team of experts. Nowadays, the most known techniques, according to the ISO 31010, are: PHA, HAZOP, What If Analysis, FMEA, FMECA, ETA, FTA, BOWTIE, BAYESIAN NETWORK, HAZID, and LOPA known already in literature [6-9].

Hazard and operability study (HAZOP) methodology is used worldwide to process hazard analyses for processing units [10-11]. It is considered an appropriate, organized, and critical checkup used to assessment the potential hazards obtained for improper performance tool and property in terms of the resultant impacts of process facilities [10, 12].

HAZOP methodology was on studies in chemical process facilities and related units. Compared to the other risk analysis methods: Failure Modes and Effects Analysis (FMEA), Facilities Risk Review (FRR), Fault Tree

Analysis (FTA) and Quantitative Risk Analysis (QRA), HAZOP methodology is a means-term among them because, in addition to identifying and estimating risks, like most, it is an excellent method for recommendations [2, 6, 13, 14]. HAZOP methodology is the most studied Preliminary Hazard Analysis (PHA) method. Based on the revised documents, HAZOP was found to be the foundation of process safety and risk management programs [2, 6]. Literature presents many applications of the HAZOP methodology as a risk analysis method. For example, a study performed a risk analysis of the start-up procedures of an IEA-R1 reactor applying the HAZOP technique, analyzed 53 reactor start-up instructions and determined 74 possible procedural deviations [15]. Although HAZOP methodology is an efficient and well-organized method, it has its limitations. Trujillo explains that HAZOP methodology is time-consuming because it requires the participation of a multi-disciplinary team over extended timeframes. This investment of time and personnel, often involving third parties, means that the performance of the HAZOP needs to be optimized to maximize its value [16]. Depending on the size of the unit, it can take from 1-8 weeks for a team of at least five members to implement the method. HAZOP analysis shows that loading and unloading areas are the most sensitive areas of the plant and where the most significant danger is a fuel spill [6,17].Less experienced Persons do not have the necessary and sufficient knowledge to perception the problems associated with each guide word [6,18]. Fuentes-Bargues [18] performed a risk analysis at a fuel storage terminal using HAZOP. Marhavilas [19] performed a collaborative framework by the synergy of Hazard and Operability (HAZOP) process and the Decision-Matrix Risk Assessment (DMRA) in association with safety-color mapping (SCM) is presented, in order to identify critical points and prioritize risks, and also to visualize the occupational safety and health (OSH) situation. In view of the results, both of the HAZOP pattern (for identifying the hazards) and also the DMRA one (for assessing and ranking the risks), SCMs have been derived for the specific workplaces of the SCOPI and the MRS/GTS station, which could be a precious means for safety managers to appraise the urgency of investing limited budgets in measures preventing particular types of deviations, and also protecting the employees.

This paper is a critical analysis of the HAZOP methodology used to describe a case study of city gate station (CGS) that, for the first time, performed HAZOP methodology as a risk analysis methodology in its facilities. The study contributions show from the results presented that, despite the classic HAZOP being questioned by various researchers, it still remains an effective method for detection, analysis and mitigation of risks. However, the paper also suggests that the methodology can be improved when combined with other event anticipation methods. HAZOP methodology also aided the decision-maker of the company's top management team to continue using HAZOP as the standard method for risk analysis of the production unit. This study aims to apply HAZOP methodology in a real case of city gate station (CGS) to identify potential hazards that may result from operational problems and how this method is useful in providing essential knowledge for decision-makers, company leaders and operations managers. This method was the first test carried out after Establish of the unit operation. This paper is organized into five sections: (1) the introduction, (2) process description and methodology, (3) case study, (4) results and discussion, and (5) conclusions.

Materials and Methods

This descriptive study was performed in CGS station. This section gives a brief technical description of the CGS and its main equipment.

- **Station Description**

After extraction and refining, natural gas travels through transmission lines with a pressure equivalent to 1000 Psi to reach different parts of the country and consumption points. But obviously this pressure is by no means a good pressure to use in industry, facilities and equipment. Therefore, in order to make it usable, we have to reduce its pressure as much as needed. This pressure reduction operation is performed in stations called "pressure reduction stations". Gas pressure reducing stations are an important part of the gas supply system that are designed and installed with different shapes and equipment, and with the advancement of science and technology, the construction of this equipment is constantly changed and upgraded.

CGS stations usually branch off from transmission lines, so their inlet pressure is the same as the transmission line pressure, which can be considered as large stations in terms of branching from transmission lines. These stations have regulators or reducing devices and by reducing the pressure from 1000 psi to about 250psi, they are mostly used at the entrances of cities.

- **Pressure reduction process**

A gas pressure reducing station, depending on the type of reduction (inlet to outlet pressure) and its capacity, has special physical and geometric details in its components; but at the same time and in general, all these station models are the same in terms of appearance and type of components. The main components of these stations include the following:

Filtration system: The filters separate the gas impurities before they enter the system.

Heater system: Gas heating can be done using electrical energy or heat energy from the combustion of part of the natural gas in the pipeline. Combustion heat can be transferred directly from the combustion gases to the high pressure gas or through another fluid (such as water). Under safe conditions, gas heaters heat distilled water inside the chamber by means of atmospheric burners, and the gas is heated by passing through indirect gas baths (spiral pipes are installed inside the chamber).

Regulator (to break the pressure): A regulator is a device that can control the gas pressure to a certain extent during changes in gas flow.

Safety valve: In the event of a malfunction in the regulators of the gas pressure reducing system, there is a possibility of increasing the gas pressure. These automatic valves are known as safety valves, which close again after draining the gas and reducing the pressure to the desired level.

Shut off valve: If the safety valves do not respond and the pressure is still high, the pressure shut-off valves shut off the station gas automatically and start manually.

Counter: the meters of a gas pressure reducing station to measure the volume of gas from the rate of gas velocity and the amount of motion transmitted to the blades of a turbine.
Odorize system: a device that adds an odorant to a gas. The most common type is one that adds a mercaptan liquid into natural gas distribution systems so that leaks can be readily detected.

- **HAZOP Methodology**

One of the analysis methods used is Hazard and Operability Study (HAZOP) to identify hazards and hazardous events. From these, functional safety requirements are developed to mitigate the hazards and hazardous events identified. HAZOP can be performed at any level of abstraction (system to item level) and at any point in the Safety Engineering Process (SEP) as the design gets more defined and detailed [6, 20].
HAZOP study has identified all possible deviations in parameters from design intent (level, flow, and pressure), which could finally lead to oil leakage or extra pressure and consequently result in undesirable events such as fire and explosion. The HAZOP methodology can be divided into four phases [6, 21-23]:
1-Definition: is the step where HAZOP team sets the scope and objectives of the analysis, establishes responsibilities, and selects the team.
2-Preparation: in this step the study is planned by the team, agree on the style of recording, essential data are collected, agree on the style of recording, the time is estimated and the schedule is ordered.
3-Examination: this step involves dividing the system into Sections, selecting a section and defining design determination, identifying deviation by using guide words, identifying causes and consequences and identifying mitigating measures (optional).
4-Documentation: here, the team records the examination, signs off on the documentation, produces the report of the study and produces the final output report.
For authentic HAZOP study whole process design was done on the basis of Process flow diagram (PFD), Piping and Instrumentation diagram (PID) and standard guide words [24].
In the preparation phase of the HAZOP study, the team leader must propose a list of guide words (Table 1) to be used to examine the facilities. The choice of words must be made carefully, as a poorly chosen guide word can significantly limit or generalize the study's focus. The following table, some examples of guide words studies and the associated deviations frequently used in the process [6, 21, 23, 25-28]:

Table 1: Lists of Guidewords

words	Meaning	Example
none	None of the objectives is achieved	No flow
more	Quantitative increase in a parameter	More pressure
less	Quantitative decrease in a parameter	Less temperature
Part of	Just part of the objectives is achieved	Part of the yield
reverse	Occurs the opposite of what one expects	Reverse flow
other	Full replacement	Liquids in a gas pipe

The HAZOP team uses the guide words to check the potential hazards. First, a node is analyzed until all the forecasting possibilities are founded. Then, the method moved to the next node and made the same process until all the nodes were analyzed. The causes are identified, the consequences are estimated, and recommendations are made to mitigate the problem. [6, 19, 27].

Case Study: HAZOP Analysis of a CGS

Engineers from the operating company (safety, occupational health, production engineer, maintenance engineer and a facility engineer) also participated in the study. The complete examination of the facilities took two weeks to be carried out, with an average duration of 4h of analysis per day. In the first session, the PIDs and PFDs of the CGS station were exposed, and the main equipment operating in that station and the entry and exit lines were identified, as well as the devices attached to them. The nodes or nodes around the equipment and the surrounding region were marked using dashed lines with different colors, one color for each node to facilitate the distinction.
The steps that comprise a HAZOP analysis are described below [6]:
1-Selection of nodes: This procedure is applied to critical points of the system control point known as "nodes", which is the separation system to be studied in small sections susceptible to malfunction and defect, to ensure that all equipment and lines are analyzed. The nodes were defined according to the functioning and operation of the equipment and accessories in their neighborhood. The results of four nodes were presented and analyzed in this paper. Table 2 describes Station nodes, node components and indicators /parameters studied briefly.

Table 2: Station nodes, node components and indicators studied

node	node components	Indicators/parameters
Filtration system	Pipeline, plug valve, filter, ball valve	Pressure, flow, temperature, corrosion, abrasion, leakage
Heater system	Pipeline, ball valve, heater, coil	Pressure, flow, temperature, corrosion, abrasion and leakage
Regulator	Pipeline, ball valve, shut off valve, safety valve, regulator, counter	Pressure, flow, temperature, corrosion, abrasion, leakage, vibration
Odorize system	Pipeline, plug valve, tank, metering pump	Oder, Pressure, flow, level, corrosion, abrasion, leakage

2-Choice of guide words and process limits: words that describe the unit's process parameters (pressure, temperature, flow, level, corrosion,) associated with words that indicated deviations in the normal operation of the unit, called guide words (high, low, none and other). The combinations of these words used throughout the analysis/study that assigned indicators of equipment

functioning (nodes), showing whether they would be operating inside/outside the standard (deviations) of operation, allowing the identification of hazards—for example, high pressure, low temperature, or none flow.
3-Identification of the source of deviations or causes of hazards: with the system divided into smaller sections and each one with the parameters and keywords adequately identified, the risk analysis was carried out by testing the hypothesis of improper functioning of the equipment. Based on the probable trends of deviations observed, it was sought to predict the result, that is, the consequences. If the variation in the parameter represented a hazard, that problem was documented, and its impact was later estimated.
4-Risk frequency analysis: the frequency analysis was made based on estimates of the probability of occurrence of scenarios that were predicted to be dangerous (Table 3).
5-Determination of severity consequences: the analysis of the consequences was based on measuring the level of impact of the consequences in association with safety, environment, and economy (Table 3).
6-Recommendations: at the end of the assessment, recommendations were made on the potential hazards identified in the previous steps to reduce the level of risks analyzed and discussed by the HAZOP team.

Table 3: Risk matrix

Risk Classification Matrix		Frequencies				
		A	B	C	D	E
Severities	V	M	M	H	H	H
	IV	M	M	M	H	H
	III	L	M	M	M	H
	II	L	L	M	M	M
	I	L	L	L	M	M

Severity		Frequency		Risks
I	Low	A	Unlikely	
II	Moderate	B	Remote	(1) Low
III	Average	C	Casual	(2) Moderate
IV	Critical	D	Likely	(3) High
V	Catastrophic	E	Frequent	

Results

According to the results in the filter study node, deviations such as reported in this node increase of pressure gas before this unit and defect of the inlet valve cause disruption of gas filtration. Preventive and scheduled repairs of the main valve can be effective in this regard. Increased gas flow due to increased gas flow at the entrance of the station and a defect in the flow control valve and its excessive opening, leads to impaired gas filtration. Increased temperature gas due to Increase the temperature gas before the filter unit leads to impaired gas filtration. Fast telephone connection with the gas pressure boosting station to reduce the inlet gas temperature and the operator monitors the temperature gauge can be effective in this regard. Decrease pressure gas due to reduce gas pressure before the filter unit, the filter is dirty and the filter drain valve is open, leads to gas pressure drop in the unit, in which case due to low efficiency of gas purification operations and gas not reaching urban areas, rupture of the filter element, damage to equipment and gas cut-off. Measures to prevent these effects can be made by quick telephone communication with the gas booster station to increase the inlet gas pressure, operator monitoring of the pressure gauge, implementation of filter maintenance instructions and regular and periodic filter replacement.
According to the results in the heater study node, the operational indicators in the pressure reducing station process included pressure, flow rate and temperature. Increased pressure gas due Defects in pressure gas instrumentation systems, Defects in pressure breakers, Increase the pressure before the heater unit and Defective inlet valves, that lead Leakage in pipe connections, Increased pressure in the heater and the possibility of leakage, Damage to the heater and In the worst conditions of fire and explosion. Decrease flow gas due defects in flow control valves, two gas phases, Causing fleas and clogged pipes and existence of moisture and high concentration of sulfur compounds, that lead Reduce gas flow and customers cut off gas. Increased temperature gas due heater flame is not adjusted, excessive increase of gas heater capacity and chimney outlet valve is not adjusted, that lead increasing the exhaust gas temperature, perforation of helical tubes, creating sediment in spiral pipes, rust and perforation of the wall and leak.
According to the results in the Regulator study node, Increased pressure gas due Failure of filters to work properly and impurities to pass, Erosion and corrosion in equipment inside regulators and pipes and Regulator malfunction, that lead Ensure high pressure gas passage and gas wastage through the valve, Disconnect the gas through the pressure shut-off valve, damage to station equipment and leak. Increased flow gas due high consumption downstream and Increase the wear rate, that lead making noise and vibration, dirty gas and Customer dissatisfaction. Decrease pressure gas due Pilot failure or spring force in the regulator and Pilot insensitivity to downstream pressure. That led Reduce gas pressure for the consumer. Increased vibration due unregulated consumption of lines, Burnout of parts, Lack of proper inhibition of piping and sensing and Lack of proper foundation, that lead equipment breakdown, reduce station life and leakage.
According to the results in the Odorize system study node, increased Injection of deodorant due Improper operation of the injection pump and Injection device is not adjusted, that lead Toxic and harmful gas leakage for the consumer and Losing your mercaptan. Decrease Injection of deodorant due Increase consumption by the consumer, improper operation of the injection pump and Injection device is not adjusted, that lead Possibility of not detecting gas leakage and Possibility of fire and explosion. Excess tank capacity due Equipment breakdown and Human errors, that lead Possibility of toxic material leakage into the environment. Less than the outlet pressure of the pump due Lack of sufficient liquid in the odor tank and Partial clogging of the inlet strainer into the deodorant injection pump (clogging of the deodorizer path), that lead Leaks, fires and explosions. Excessive gas velocity due Inadequate orifice diameter,

that lead Possibility of orifice wear, Less injections of Advent, Possibility of pipe wear and Leaks, fires and explosions.

According to the results in all nodes studied, the indicators of corrosion, abrasion, and leakage were examined. The corrosion due to the increase of carbon disulfide, carbon dioxide, humidity and oxygen in the air. This is important to reduce the thickness of the pipes. The abrasion, which is caused in the system for reasons like high amount of solid particles in the gas, Turbulent gas flow, Existence of elbows, transformations, tees, inadequate pipe material and improper diameter of the pipe. The leak due Defects in pipelines, valves and fittings, that lead Gas leakage into the environment, Possibility of fire and explosion and Customer gas cut-off.

Discussion

According to the study, the operational indicators in the pressure reducing station process included pressure, flow rate and temperature. One of the other deviations determined by the team with the keyword "other conditions" was the indicators of corrosion, abrasion, leakage, vibration and odor. Corrosion, abrasion and leakage indices in all nodes and vibration in Pressure reducing equipment were examined. Thus, the HAZOP sheet serves as a guiding document for implementing measures to mitigate hazards by the operation/maintenance teams of the facilities.

- **Pressure :**

The "high pressure" deviation would be caused by a failure of the pressure gauge, failure of filters to work properly and impurities to pass, erosion and corrosion in equipment inside regulators and pipes and regulator malfunction, which, in turn, would cause Disruption of gas filtration, Increased pressure in the filter and the possibility of leakage, Damage to the filter body and the worst conditions of fire and explosion. For this reason, as a safeguard, it is advisable that Fast telephone connection with gas pressure boosting station, Preventive repairs and scheduling of valves, Install the safety valve on the filter, Emphasis on the serviceability of the safety valve throughout the operation and Regular and periodic inspection of pressure relief valves. The "low pressure" deviation would be caused by Pilot failure or spring force in the regulator and Pilot insensitivity to downstream pressure which, in turn, Reduce gas pressure for the consumer. For this reason, as a safeguard, it is advisable that Fast telephone connection with gas pressure boosting station to increase inlet gas pressure, Operator supervision on the pressure gauge, Implement filter maintenance instruction, Regular and periodic filter replacement. Other studies have noted that the causes of more pressure are pressure safety valve failure and pump backflow. It proposes using an alarm, a controller and a pressure indicator [10, 29]. Marhavilas [19] pointed out as causes of more pressure, failure of the pressure indicator, blocked line and leakage of raw steam. As a consequence, the fracture of the line, oil spill, risk of fire and release of H2S. It is suggested to install a pressure control valve, installation of pressure alarms, periodic inspections and maintenance of valves and sensors [30-31].

- **Flow Rate:**

It was assumed that it could be increased or reduced; "high flow" when the flow valves are fully open or "low flow", "no flow" when Gas transmission are stopped, or Defects in flow control valves, Causing fleas and clogged pipes, Existence of moisture and high concentration of sulfur compounds. Consequently, Noise and vibration, Dirty gas and Customer dissatisfaction were observed. On the other hand, to solve the problems, periodic inspection of valves and equipment, use of flow alarms, Installation of the limiting orifice before the regulator, Installation of ultrasonic meter to measure current and verification of lines and systems are recommended. Other studies have pointed out that fully open flow valves, faulty flow regulating mechanism, out-of-calibrated controller and pump failure are causes of too much flow. Consequently, the pressure increases rapidly in the pipeline; therefore, the likelihood of leakage and explosion increases [29, 32]. The causes of less flow are the partial opening of the outlet valve, rupture of the flow inlet pipe to the vessel due to mechanical damage and minimal leakage in the pipe [33]. Other studies have showed leaving the flow valve fully open, temperature increase and flow valve failure are causes of more flow [10, 19, 34].

- **Temperature:**

The temperature may also be low or high. The reasons underlying these deviations may be Heater flame is not adjusted, Excessive increase of gas heater capacity, Chimney outlet valve is not adjusted. It was recommended to install alarm system in case of increased heater flame, adjust the gas supply to the heater, adjust the heater flame, regularly check and maintain the flow lines and valves and frequently check the tubes of the heat exchangers. Other studies have shown that the causes of the "high temperature" deviation might be due to more steam entering the heat exchanger system, which will heat the vessel due to a failure in the temperature indicator [24, 31, 32]. Benedetti-Marquez [10] also observed that the deviation would cause uncontrolled heating of the hydrocarbon in the vessel, consequent decomposition and risk of explosion. As mitigation, it is recommended to inspect the tank and calibrate the sensors periodically. Studies noted that the causes of the deviation of "low temperature" can be due to the shutdown of the steam that feeds the heat exchanger, which, in turn, is due to the failure of the refrigerant temperature meter and failure of the supply of steam to the line tracing [24,32]. The low-temperature deviation would result in the crystallization of hydrocarbons and clogging of the lines and loss of production. The recommendation is to install a temperature transmitter in the recirculation line of the storage tank with an alarm. In addition, a low steam flow alarm is recommended.

- **Level:**

In the Odorize system, increased Injection of deodorant due improper operation of the injection pump and Injection device is not adjusted, that lead Toxic and harmful gas leakage for the consumer and Losing your mercaptan. Decrease Injection of deodorant due Increase consumption by the consumer, improper operation of the injection pump and Injection device is not adjusted, that lead Possibility of not detecting gas leakage and Possibility of fire and explosion. Other studies have shown that vessel without supervision or inspection, failure of the level indicator, wrong valve opening and alarm that does not work correctly are causes of more level in the vessel [10, 29]. Also, cracking or corrosion of the vessel, damage to the vessel body seal, weak joints between the ceiling and the vessel structure and damage to the valves and flanges are as causes of the lower level [29].

Other conditions

- **Corrosion/Abrasion:**

The corrosion due to the increase of carbon disulfide, carbon dioxide, humidity and oxygen in the air, that cause to reduce the thickness of the pipes. It is recommended to - Inspection of colored coatings on pipes and equipment, Pay attention to local blisters and body tears and develop a schedule for inspecting pipelines and equipment for corrosion. The abrasion, which is caused in the system for reasons like high amount of solid particles in the gas, Increase the speed of gas flow, Turbulent gas flow, Existence of elbows, transformations, tees, large distance of parts from each other, Inadequate pipe material and improper diameter of the pipe, That cause to Create abrasion the inner body of pipes and equipment and reduce equipment and station life. It is recommended to review the station design regarding elbows, turns, pipe material and pipe diameter,, adjust the amount of solid particles in the gas, adjust the gas flow rate, creating a gas flow in a calm state, use of appropriate coatings and minimize the increase and decrease of pipe diameters. Singh [35] also observed that the erosion-corrosion process causes the wall thickness reduction of the horizontal pipeline. However, the properties of sand namely size, shape and static settled concentration of particles play a key role in the erosion wear of the pipeline. The solid particles of the sand eroded the pipeline material, which results in pits, craters, and cutting wear mechanisms on the pipeline surface. It can be said that the use of pipelines having an uneven hardness and lack of established inspection norms results in unexpected failures. Oh [36] observed that Flow accelerated corrosion is a type of pipe corrosion in which the pipe thickness decreases depending on the fluid flow conditions. Results Qin [37] demonstrated that, generally, the mechanic-electrochemical effect at corrosion defect caused an increased stress concentration and anodic current density (i.e., corrosion rate), decreasing the failure pressure of the pipeline. Both the stress and the anodic current density at the corrosion defect were dependent on the defect geometry, especially the defect depth.

- **leakage:**

The leakage due Defects in pipelines, valves and fittings, that lead Gas leakage into the environment, Possibility of fire and explosion and Customer gas cut-off. It is recommended perform periodic sub-tests / leak detector program, F&G system installation study, study to install the shut-off valve system and observance of IGS standards in the station building. Wang [38] Stated gas pipe leakage is a common and significant problem around the word. To detect the leakages, an in-pipe detector mounted on an acoustic inspection module is a direct and reliable solution. Kim [39] proposed a flowchart for leak detection in the gas pipeline. The proposed procedure can be applied to various pipelines and support more efficient operation by detecting leaks in real-time. Pérez-Pérez [40] Stated Leakages in pipelines affect the reliability of fluid transport systems causing environmental damages, economic losses, and pressure reduction at the delivery points.

- **Vibration:**

High vibration deviation would be caused by unregulated consumption of lines, Burnout of parts, Lack of proper inhibition of piping and sensing and Lack of proper foundation, that lead Equipment breakdown, Reduce station life and Gas leak. It is recommended Installation of appropriate support, Periodic station vibration measurement, Preparation of instructions for installing the appropriate support and fasteners on the equipment as needed in the lines and Periodic and specialized visits to the status of the foundation. Zhu [41] stated the buried corroded cast iron gas pipeline is more likely to be damaged by engineering blasting vibration. The results show that the corrosion reduces the anti-vibration characteristic of the pipeline, and the peak particle velocity and effective stress of the pipeline will increase with the increase of the corrosion depth and the operating pressure. The peak effective stress, vibration velocity, corrosion depth and operating pressure have a mathematical-statistical relationship.

Wang [42] showed the vibration propagation characteristic is investigated for periodic composite pipeline with crack damage. This study enriches the theoretical modified transfer matrix method (TMM) for pipeline systems vibration with crack damage, and provides some reference for the stability design of periodic pipeline structures.

Conclusions

The main contribution of this study was to demonstrate the efficacies of HAZOP methodology to identify potential hazards that may result from operational issues in a CGS station as a useful method to provide essential knowledge for the company's leaders, decision-makers and operations managers.

In the study conducted at the gas pressure reducing station, some operational indicators including pressure, flow, temperature, corrosion, wear, leakage, vibration, etc. were examined according to the node conditions and the causes of deviations from normal in the process. Pressure reduction stations were identified. According to the results, the risks of the process were higher than expected and corrective measures are necessary to prevent and control them.

Among the main causes of deviation, there were safety flaws in the installation, followed by equipment failures. Furthermore, the measures to solve the problem were based on recommendations to the installation of sensors and security alarms, as well as the periodic maintenance of the installation.

Although the benefits of operational HAZOP analysis of CGS are satisfactory, the model does not contemplate human factors. Some limitations were noted: the experience of the HAZOP team influences the efficiency of the results, and the analysis time was not enough. The methodology should be reinforced with the same quantitative tools or support decision tools. This paper fails in not presenting all aspects of HAZOP analysis, focusing only on the analysis of process and operations risks, leaving aside the risks resulting from human decisions—Human HAZOP and Procedure HAZOP—as well environmental risk scenarios. In fact, the risk of accidents is never reduced to zero, only reduced to a tolerable margin, as proven by the study. Once the recommendations are followed, a new study should be scheduled to prevent future risks.

References

1. Abbasi, S.; Bakhtom, S.; Ziaei, M.; Arghami, S. Comparison of Risk Assessment Using HAZOP and ETBA Techniques: Case Study of a Gasoline Refinery Unit in Iran. *J. Human Environ. Health Promot.* 2015, *1*, 19–27.
2. Dunjó, J.; Fthenakis, V.; Vílchez, J.A.; Arnaldos, J. Hazard and Operability (HAZOP) analysis. A literature review. *J. Hazard. Mater.* 2010, *173*, 19–32.
3. Di Nardo, M.; Madonna, M.; Gallo, M.; Murino, T. A Risk Assessment Proposal through System Dynamics. *J. Southwest Jiaotong Univ.* 2020, *55*
4. Fuentes-Bargues JL, González-Gaya C, González-Cruz MC, Cabrelles-Ramírez V. Risk assessment of a compound feed process based on HAZOP analysis and linguistic terms. Journal of Loss Prevention in the Process Industries. 2016 Nov 1; 44:44-52.
5. Kang, J.; Guo, L.; Wang, N. A Simplified HAZOP Analysis based on Fuzzy Evaluation of Node Criticality for Chemical Plants. *Int. J. Simul.-Syst. Sci. Technol.* 2016, *17*, 1–6.
6. Penelas AD, Pires J. HAZOP Analysis in Terms of Safety Operations Processes for Oil Production Units: A Case Study. Applied Sciences. 2021 Jan; 11(21):10210.
7. Bahrami, M., Bazzaz, D.H., and Sajadi, S.M. (2012) Innovation and Improvements in Project Implementation and Management; Using FMEA Technique. Procedia-Social and Behavioral Sciences, 41, pp. 418-425
8. Gallo, M., Dinardo, M., and Santillo, L.C. (2013) A simulation based approach to support risk assessment. Recent Advances in Automatic Control, Modelling and Simulation, pp. 86-92.
9. WILLEY, R.J. (2014) Layer of Protection Analysis. Procardia Engineering, 84, pp. 12-22
10. Benedetti-Marquez, E.B.; Sanchez-Forero, D.I.; Suarez-Urbina, A.J.; Rodrigues-Urbina, D.P.; Gracia-Rojas, J.; Puello-Mendez, J. Analysis of Operational Risks in the Storage of Liquid Ammonium Nitrate in a Petrochemical Plant, through the HAZOP Methodology. *Chem. Eng.* 2018, *67*, 883–888
11. BYUN YS. A Study on Safety Improvement for Mobile Hydrogen Refueling Station by HAZOP Analysis. Transactions of the Korean hydrogen and new energy society. 2021; 32(5):299-307.
12. Baybutt, P. A critique of the Hazard and Operability (HAZOP) study. J. Loss Prev. Process. Ind. 2015, 33, 52–58
13. Dunjó Denti, J. New Trends for Conducting Hazard & Operability (HAZOP) Studies in Continuos Chemical Processes. Ph.D. Thesis, Universitat Politècnica de Catalunya, Catalunya, Spain, 2010.
14. Dunjó J, Fthenakis VM, Darbra RM, Vílchez JA, Arnaldos J. Conducting HAZOPs in continuous chemical processes: Part I. Criteria, tools and guidelines for selecting nodes. Process safety and environmental protection. 2011 Jul 1; 89(4):214-23.
15. Sauer ME, Oliveira JM. Analysis of the IEA-R1 reactor startup procedures: an application of the HAZOP method.2005.
16. Trujillo A, Kessler WS, Gaither R. Common mistakes when conducting a HAZOP and how to avoid them. Chemical engineering. 2015 Dec 1; 122(12):54-8.
17. Fuentes-Bargues, J.L.; Gonzáles-Cruz, M.; Gonzáles-Gaya, C.; Baixauli-Pérez, M. Risk analysis of a fuel storage terminal using HAZOP and FTA. *Int. J. Environ. Res. Public Health* 2017, *14*, 705.
18. Single, J.I.; Schmidt, J.; Denecke, J. Ontology-based computer aid for the automation of HAZOP studies. *J. Loss Prev. Process. Ind.* 2020, *68*, 104321.
19. Marhavilas PK, Filippidis M, Koulinas GK, Koulouriotis DE. Safety Considerations by Synergy of HAZOP/DMRA with Safety Color Maps—Applications on: A Crude-Oil Processing Industry/a Gas Transportation System. Processes. 2021 Aug; 9(8):1299.
20. Aoanan P. *A Systematic Approach to Hazard and Operability Study (HAZOP)* (Doctoral dissertation).2021.
21. Rossing NL, Lind M, Jensen N, Jørgensen SB. A functional HAZOP methodology. Computers & chemical engineering. 2010 Feb 8; 34(2):244-53.
22. Capito L, Redmill KA. Methodology for Hazard Identification and Mitigation Strategies Applied to an Overtaking Assistant ADAS. In2021 IEEE International Intelligent Transportation Systems Conference (ITSC) 2021 Sep 19 (pp. 3972-3977). IEEE.
23. Suzuki T, Izato YI, Miyake A. Identification of accident scenarios caused by internal factors using HAZOP to assess an organic hydride hydrogen refueling station involving methyl cyclohexane. Journal of Loss Prevention in the Process Industries. 2021 Jul 1; 71:104479.
24. Ishtiaque S, Jabeen S, Shoukat S. Hazop Study on Oil Refinery Waste Water Treatment Plant in Karachi. Available at SSRN 2984527. 2017 Jun 11
25. Rausand M, Hoyland,A. HAZOP – Hazard and Operability Study. System Reliability Theory; Models, Statistical Methods and Applications, Second Edi. New York: John Wiley & Sons, 2011.

26. Galante E, Bordalo D, Nobrega M. Risk assessment methodology: quantitative HazOp. Journal of Safety Engineering. 2014; 3(2):31-6.
27. Signoret JP, Leroy A. Hazard and Operability Study (HAZOP). In Reliability Assessment of Safety and Production Systems 2021 (pp. 157-164). Springer, Cham
28. Klose A, Kessler F, Pelzer F, Rothhaupt M, Kostiuk D, Kabashi A, Forkel V, Urbas L. Representing Causal Structures in HAZOP Studies. In2021 26th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) 2021 Sep 7 (pp. 1-4). IEEE.
29. Ibrahim, H.A.; Syed, H.S. Hazard Analysis of Crude Oil Storage Tank Farm. *Int. J. ChemTech* Res. 2018, 11, 300–308.
30. Whitty, S.; Foord, T. Is HAZOP worth all the effort it takes? *Inst. Chem. E* 2009, *155*, 143–148
31. Sarsama, J.; Nissilä, M.; Koski, P.; Kaisalo, N.; Tallgren, J. HAZOP report: PEMBeyond Deliverable 6.5. 2017.
32. Jagtap, M. Hazard and operability (HAZOP) analysis: A review of basics. *Clinition's Sci. J.* 2017, *1*, 1–15
33. Choi, J.-Y.; Byeon, S.-H. HAZOP Methodology Based on the Health, Safety, and Environment Engineering. *Int. J. Environ. Res. Public Health* 2020, *17*, 3236
34. Sikandar, S.; Ishtiaque, S.; Soomro, N. Hazard and Operability (HAZOP) study of wastewater treatment unit producing biohydrogen. *Sindh Univ. Res. J. SURJ Sci. Ser.* 2016, *48*, 131–136.
35. Singh J, Singh S, Singh JP. Investigation on wall thickness reduction of hydropower pipeline underwent to erosion-corrosion process. Engineering Failure Analysis. 2021 Sep 1; 127:105504.
36. Oh SB, Kim J, Lee JY, Kim DJ, Kim KM. Analysis of pipe thickness reduction according to pH in FAC facility with In situ ultrasonic measurement real time monitoring. Nuclear Engineering and Technology. 2021 Aug 20.
37. Qin G, Cheng YF. Modeling of mechano-electrochemical interaction at a corrosion defect on a suspended gas pipeline and the failure pressure prediction. Thin-Walled Structures. 2021 Mar 1; 160:107404.
38. Wang W, Mao X, Liang H, Yang D, Zhang J, Liu S. Experimental research on in-pipe leaks detection of acoustic signature in gas pipelines based on the artificial neural network. Measurement. 2021 Oct 1; 183:109875.
39. Kim J, Chae M, Han J, Park S, Lee Y. The development of leak detection model in subsea gas pipeline using machine learning. Journal of Natural Gas Science and Engineering. 2021 Oct 1; 94:104134.
40. Pérez-Pérez EJ, López-Estrada FR, Valencia-Palomo G, Torres L, Puig V, Mina-Antonio JD. Leak diagnosis in pipelines using a combined artificial neural network approach. Control Engineering Practice. 2021 Feb 1; 107:104677.
41. Zhu B, Jiang N, Zhou C, Luo X, Yao Y, Wu T. Dynamic failure behavior of buried cast iron gas pipeline with local external corrosion subjected to blasting vibration. Journal of Natural Gas Science and Engineering. 2021 Apr 1; 88:103803
42. Wang D, Zeng Q, Zang F, Zhang Y. Vibration Propagation Analysis of Periodic Pipeline With Crack Defects. InPressure Vessels and Piping Conference 2021 Jul 13 (Vol. 85321, p. V002T03A042). American Society of Mechanical Engineers.