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Case Study

Application of Hazard and Operability Analysis (HAZOP) Method for Risk Analysis in CGS Station

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ABSTRACT

Background: The hazard and operability study (HAZOP) method is a risk assessment method based on engineering systems used for qualitative analysis or quantitative evaluation. It is mainly used to discover potential hazards and operational difficulties in the design and qualitative stages of chemical systems. The study aims to apply the HAZOP method in process and safety operations at gas depressurization station. **Methods:** This descriptive study was performed at CGS station. The station was divided into four principal nodes including: filter, heater, regulator, and odorize part. Required information for HAZOP worksheets were gathered by operational procedures, daily reports and interviews with engineers and operators working at the station. To determine the severity of consequences and probability of occurrence of scenarios that were predicted based on the risk matrix, the amount of risk was specified and the necessary suggestions were made in this regard. **Results:** According to this study, the operational indicators in the pressure reducing station process included pressure, flow, level and temperature. 22 main deviations and 50 causes of failures were identified. 5 deviations (23%) were in the low risk range (green area) and 17 (77%) were in the medium risk range (yellow area). **Conclusions:** 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.

Key words: HAZOP analysis; Hazard identification; Natural gas

Introduction

The growth of industries and populations has increased potential risks, financial losses, and casualties more than ever. Accidents can cause various types of damage and irreparable injuries. [1] Many serious accidents occur because of the lack of ideal equipment to precisely analyze knowledge. [2-3] The size and complexity of industrial plants require studying, analysis and control of existing risks in every industrial process.[4] Systemic safety assessment must be performed in chemical units to ensure production safety. This is because process and chemical units are usually toxic, explosive and flammable.[5]

Identifying hazards is fundamental for ensuring

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the safe design and operation of a system in process units and other facilities. Many techniques are available to identify hazardous situations. Nowadays, the most known techniques, according to the ISO 31010, include: PHA (preliminary hazard analysis), HAZOP (hazard and operability study), what if analysis, FMEA (failure modes and effects analysis), FMECA (failure modes and effects critical analysis), ETA (even tree analysis), FTA (fault tree analysis), BTA (bow tie analysis), Bayesian network, HAZID (hazard identification), and LOPA (layers of protection analysis) already known in literature. [6-9]

HAZOP method is used worldwide to process hazard analyses for processing units. [10-11] it is considered an appropriate, organized, and critical examination used to assess the potential hazards obtained for malfunctioning tool and property in terms of the resultant impacts of process facilities. [10, 12]

HAZOP method was in studies on chemical process facilities and related units. Compared to the other risk analysis methods, such as FMEA, FRR (facilities risk review), FTA and QRA (quantitative risk analysis), HAZOP methodology is identifying and estimating risks, like most cases, also it is an excellent method for recommendations. [2, 6, 13, 14] HAZOP method is the most studied PHA (preliminary hazard analysis) 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 method 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 method, analyzed 53 reactor start-up instructions and determined 74 possible procedural deviations. [15] Although HAZOP method is an efficient and well-organized method, it has its limitations. Trujillo explains that HAZOP 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 performance of HAZOP needs to be optimized to maximize its value. [16] HAZOP analysis shows that loading and unloading areas are the most sensitive areas of the plant and where the most significant danger is fuel spill. [6, 17] less experienced individuals do not have the necessary and sufficient knowledge to perceive 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 HAZOP process and DMRA (decision-matrix risk assessment) in association with SCM (safety-color mapping).

This paper is a critical analysis of HAZOP method used to describe a case study of CGS (city gate station). The stations are very important facilities in the gas transportation system at the point of consumption of major industries, factories, industrial towns, and cities. Despite the classic HAZOP being questioned by various researchers, it still remains an effective method for detection, analysis and mitigation of risks. HAZOP also aided the decision-making 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 in a real case of CGS to identify potential hazards that may result from operational problems. This method was the first test carried out after establishment of the unit's operation.

Methods

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

- Station description

CGS stations are typically installed outside the limits of the city entrance. These stations are composed of a complex array from pipes, valves, and

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devices of gas measurement, pressure regulation and reduction to that of distribution system. It supplies gas to the city consumers and industries at the required pressure. For most distribution systems, natural gas is received from transmission pipelines and fed through CGSs. 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, 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
- Heater system
- Regulator
- Safety valve
- Shut off valve
- Counter
- Odorize part

In the following, the simplified process flow diagram of gas depressurization process has been shown (Figure 1).

- HAZOP methodology

One of the analysis methods used is HAZOP to identify hazards and hazardous events. From this method, functional safety requirements are developed to mitigate the identified hazards and hazardous events. HAZOP can be performed at any level of abstraction (system to item level) and at any point in the safety engineering process as the design gets more defined and detailed [6,20]

HAZOP study has specified all possible deviations in parameters regarding design intent (level, flow, and pressure). This 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: This is the step where HAZOP team sets the scope and objectives of the analysis, establishes responsibilities, and selects the team members.

2-Preparation: In this step, the team planned the study, agreed on the style of recording, collected the essential data, estimated the time and ordered the schedule.

3-Examination: This step involves dividing the system into sections, selecting a section and its defining and explaining, 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 the final output.

For authentic HAZOP study, a whole process design was conducted on the basis of PFD (process flow diagram), PID (piping and instrumentation diagram) and standard guidewords. [24]

In the preparation phase of HAZOP study, the team leader must propose a list of guidewords (Table 1) for examining the facilities. The choice of words must be made carefully, as a poorly chosen guideword can significantly limit or generalize the study's focus. The following table, presents some examples of guidewords and the associated deviations frequently used in the process [6, 21, 23, 25-28]:

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

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Table 1. List 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	The opposite of what one expects occurs	Reverse flow
Other	Full replacement	Liquids in a gas pipe

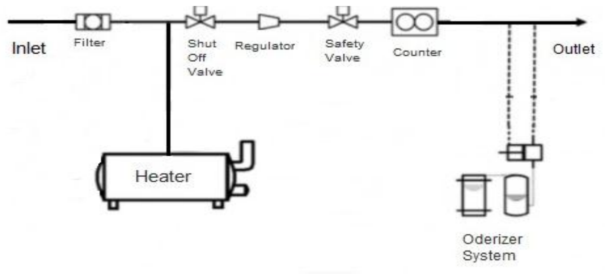

Figure 1. Simplified process flow diagram of gas depressurization process

Case study: HAZOP analysis of a CGS station

Engineers from the operating company (safety, occupational health, production, and maintenance and facility engineers) also participated in the study. Complete examination of facilities took two weeks, with an average duration of 4 hours of analysis per day. In the first session, PIDs and PFDs of the CGS station were exposed. The main equipment operating in that station and the entry and exit lines, as well as the devices attached to them, were identified. Nodes or the 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's control point known as "nodes". It is a separation system to be studied in small sections susceptible to malfunction and defect and ensures that all equipment and lines are analyzed. The nodes were defined according to the function and operation of the equipment and accessories in their neighborhood. The results of four nodes are presented and analyzed in this paper. Table 2 describes station nodes, node components and indicators /parameters which are studied briefly.

2-Choice of guidewords and process limits: These are the words that describe the unit's process parameters (pressure, temperature, flow, level, corrosion…). They are associated with the words that indicate deviations in the normal operation of the unit called guidewords (high, low, none and other). Combinations of these words used throughout the analysis/study assigned indicators of the equipment functioning (nodes).This shows whether they would be operating inside/outside the standard (deviations) of operation, allowing the identification of hazards—for example, high pressure, low temperature, or non-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 authors carried out risk analysis by testing the hypothesis of improper functioning of the equipment. Based on the probable trends of deviations observed, researchers 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 estimated later.

Table 2. Station nodes, node components and indicators

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	Flow, temperature, corrosion, abrasion and leakage
Regulator	Pipeline, ball valve, shut off valve, safety valve, regulator, counter	Pressure, flow, corrosion, abrasion , leakage, vibration
odorize part	Pipeline, plug valve, tank, metering pump	Odor, pressure, flow, level, corrosion, abrasion , leakage

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Table 3. Risk matrix [6]

Risk Classification Matrix		Unlikely (A)	Remote (B)	Frequencies Casual (C)	Likely (D)	Frequent (E)
Severities	Catastrophic (V)	Moderate (M)	Moderate (M)	High (H)	High (H)	High (H)
	Critical (IV)	Moderate (M)	Moderate (M)	Moderate (M)	High (H)	High (H)
	Average (III)	Low (L)	Moderate (M)	Moderate (M)	Moderate (M)	High (H)
	Moderate (II)	Low (L)	Low (L)	Moderate (M)	Moderate (M)	Moderate
	Low (I)	Low (L)	Low (L)	Low (L)	Moderate (M)	Moderate

4-Risk frequency analysis: 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 of consequences: The analysis of 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.

Results

According to this study, operational indicators in the process of pressure reducing station included pressure, flow, level and temperature. Other deviations determined by the team with the keyword "other conditions" were the indicators of corrosion, abrasion, leakage, vibration and odor. 22 main deviations and 50 causes of failures were identified. 5 deviations (23%) were in the low risk range (green area) and 17 (77%) were in the medium risk range (yellow area).

According to table 4 regarding the filter study node, deviations such as those reported in this node include high flow rate, low pressure, no gas flow and low ambient temperature. 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 table 5 regarding the heater study node, operational indicators in the process of pressure reducing station included flow rate and temperature. Measures to prevent these effects include regular and periodic inspection of flow control valves, adjusting and troubleshooting the flow control valve, separating liquids in filters, descaling of flow pipes inside the heater, installing alarm system in case of increased heater flame, adjusting the gas supply to the heater and adjusting the heater flame.

According to table 6 concerning the regulator study node, deviations such as those reported in this node include high pressure, high flow rate, low pressure and high vibration. Measures to prevent these effects are regular and periodic inspection of the regulator, proper and timely repairs and maintenance of equipment, installing a gas pressure warning sensor before operating the safety valves and disconnecting, periodic analysis of incoming gas, installation of limiting orifice before the regulator, installation of ultrasonic meter to measure current, regular and periodic inspection of the regulator, pilot replacement or diagram, 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.

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Table 4. HAZOP analysis in the filter study node

Deviation	Possible Cause	Consequences	Risk Matrix S	F	R	Recommendation
High flow rate	-Increasing consumption	-Disruption of gas filtration -Decreased filter function -Noise and vibration in the system - Dirty gas	II	C	M	- Fast telephone connection with gas pressure Boosting station to reduce the amount of incoming gas flow
Low Pressure	- Reducing gas Pressure before the filter unit	- Gas pressure drop - Filter element rupture -Damage to equipment and gas cut-off	III	C	M	- Fast telephone connection - Operator monitoring of the pressure gauge - Execute filter maintenance instructions - Regular and periodic filter replacement
No gas flow	- No sending of gas - Inlet valve defect - Blockage of the main pipeline	- No gas at the station and the possibility of stopping gas supply	II	B	L	- Fast telephone connection - Transmission pipeline inspection
low ambient temperature	-Decreasing the temperature, especially in winter	Possibility of freezing in the filter section	III	B	M	- Controlling the ambient temperature and taking timely measures in case of a large decrease in ambient temperature

Table 5. HAZOP analysis in the heater study node

Deviation	Possible Cause	Consequences	Risk matrix S	F	R	Recommendation
low flow rate	- Faults in the flow control valves - Two gas phases -Causing fleas and clogged pipes -Existence of moisture	- Reduce gas flow - Gas leakage	II	B	L	-Regular and periodic inspection of flow control valves -Adjustment and troubleshooting in flow control valves -Separation of liquids in filters -Descaling of flow pipes inside the heater
High heater temperature	-Heater flame is not adjusted -Excessive increase of gas heater capacity	-Increasing the exhaust gas temperature -Boiling stainless steel heater liquid	III	C	M	- Install alarm system in case of increased heater flame - Adjust gas supply to the heater - Adjust the heater flame

Table 6. HAZOP analysis in the regulator study node

Deviation	Possible Cause	Consequences	Risk matrix S	F	R	Recommendation
High pressure	- Improper operation of filters and impurities -Erosion and corrosion in equipment inside regulators and pipes - Regulator malfunction -Collapse malfunction (pacifier)	-Ensuring high pressure gas passage and gas waste through the valve -Disconnecting gas through the pressure shut-off valve -Damage to station equipment - Gas leak	III	B	M	-Regular and periodic inspection of the regulator -Proper and timely repairs and maintenance of equipment -Install the gas pressure warning sensor before operating the safety valves and disconnect -Periodic analysis of incoming gas
High flow rate	-High consumption downstream -Increasing the wear rate	-Noise and vibration - Dirty gas - Customer dissatisfaction	II	C	M	-Installation of the limiting orifice before the regulator -Installation of ultrasonic meter to measure the current
Low pressure	-Pilot failure or spring force in the regulator -Pilot insensitivity to downstream pressure	-Reducing gas pressure for the consumer	III	C	M	-Regular and periodic inspection of the regulator -Pilot replacement or diagram
High vibration	- Unregulated consumption of lines -Burnout of parts -Lack of proper inhibition of piping and sensing -Lack of proper foundation	-Equipment breakdown Reducing the station life -Gas leakage	II	B	L	-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 -Periodic and specialized visits to the status of the foundation

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According to table 7 regarding the odorize system study node, deviations such as those reported in this node include low and high injection of deodorant , high tank capacity, high flow rate, low and high outlet pressure of the pump, high gas velocity, low gas velocity and high odor.

According to the table 8 in all nodes studied, the indicators of corrosion, abrasion, and leakage were examined. Corrosion occurs due to increase of 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 to defects in pipelines, valves and fittings leads to leakage of gas into the environment, possibility of fire and explosion and customer gas cut-off.

Table 7. HAZOP analysis regarding the odorize part study node

Deviation	Possible Cause	Consequences	Risk matrix S	F	R	Recommendation
High injection of deodorant	-Improper operation of the injection pump - Failure to adjust the injection device	- Toxic and harmful gas leakage - Losing your mercaptan	III	C	M	-Periodic survey - Check the liquid level of the odor tank
Less injecting deodorant	-Increase consumption -Improper operation of the injection pump - Failure to adjust the injection device	-Possibility of not detecting gas leakage -Possibility of fire and explosion	III	B	M	-Periodic survey - Check the liquid level of the odor tank -Education
High tank capacity	-Equipment breakdown -Human errors	-Possibility of toxic material leakage into the environment	II	C	M	-Check the tank's liquid level -Check the pressure gauge of the gas inlet path to the tank -Supervise the correct implementation of the transfer instructions and fill the odor tank -Education
High flow rate	-High consumption by the consumer	-Low injection of deodorant	II	C	M	-Check the amount of flow on the gas path Periodic and regular inspections and monitoring
Low outlet pressure of the pump	-Lack of sufficient liquid in the tank -Clogging of the deodorizer path	- Possibility of fire and explosion	III	B	M	-Periodic inspection of the amount of liquid in the tank -Existence of pump output gauge - Periodic and regular inspections and monitoring
High pump outlet pressure	-Malfunction regulator at the input of the storage tank	-Damage to the tank -Possibility of bursting	III	B	M	-Existence of pressure relief valve -Pressure gauge control
High gas velocity	-Inadequate diameter of the orifice	-Possibility of orifice abrasion -Less injections of Advent -Possibility of pipe abrasion -Fire and explosion	III	B	M	-Periodic survey -Periodic and seasonal replacement of orifice
Low gas velocity	-Inadequate diameter of the orifice -orifice closure	-Reduction of adventitious injections - No smell of gas Consumer gas cut-off	II	B	L	-Periodic survey -Periodic and seasonal replacement of orifice
High odor	- Problems in connections -No sealing -Existence of tanks at the station	-Environmental problems -Injury to people	II	C	M	-Periodic survey -Use of appropriate personal protective equipment

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Table 8. HAZOP analysis of the corrosion, abrasion and leakage indices in all nodes

Deviation	Possible Cause	Consequences	Risk Matrix S	F	R	Recommendation
Corrosion	- the increase of humidity and oxygen in the air	Reducing the thickness of the pipes, valves and fittings.	III	B	M	-Inspection of colored coatings on pipes and equipment -Pay attention to local blisters and body tears -Develop a schedule for inspecting pipelines and equipment for corrosion
Abrasion	-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 -improper diameter of the pipe	-Creating abrasion the inner body of pipes and equipment -reduce equipment and station life	II	B	L	-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 -Minimize the increase and decrease of pipe diameters
Leakage	-Defects in pipelines, valves and fittings	-Gas leakage into the environment - Possibility of fire and explosion -Customer gas cut-off	IV	C	M	-Perform periodic sub-tests /leak detector program -F&G system installation study -Study to install the shut-off valve system -Observance of IGS standards in the station building

Discussion

According to this study, the operational indicators in the process of pressure reducing station included pressure, flow rate and temperature. Other deviations determined by the team with the keyword "other conditions" were 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 failure of 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. Deviation also occurs because of 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, the following is advised: Fast telephone connection with gas pressure boosting station, preventive repairs and scheduling of valves, installing 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, reduces gas pressure for the consumer. For this reason, as a safeguard, fast telephone connection with gas pressure boosting station is advised to increase inlet gas pressure, operator supervision on the pressure gauge, implement filter maintenance instruction, and replace the filter regularly and periodically. Other studies have noted that the causes of more pressure are pressure safety valve failure and pump backflow. Using an alarm, a controller and a pressure indicator is proposed. [10, 29] Marhavilas [19] pointed out as causes of high pressure, pressure gauge failure, tube blockage and steam leak. As a consequence, there was fracture of the line, oil spill, risk of fire, and release of

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H2S. It is suggested to install a pressure control valve, pressure alarms, periodic inspections and maintenance of valves and sensors. [30-31]

- Flow Rate

It was assumed that flow rate could be increased or reduced: "High flow" is when the flow valves are fully open or "low flow", "no flow" is when gas transmission is stopped, or there are defects in flow control valves. It causes 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 low flow are 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 shown that leaving the flow valve fully open, temperature increase and flow valve failure are causes of more flow. [10, 19, 34]

- Temperature

Temperature may also be low or high. The reasons underlying these deviations may be that heater flame is not adjusted, gas heater capacity is excessively increase, and 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 indicated that the causes of "high temperature" deviation might be due to entering of more steam into 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 deviation would cause uncontrolled heating of the hydrocarbon in the vessel, consequent decomposition and risk of explosion. Regarding mitigation, authors recommend to inspect the tank and calibrate the sensors periodically. Studies noted that the causes of deviation of "low temperature" can be due to shutdown of the steam that feeds the heat exchanger. This, in turn, is due to the failure of the refrigerant temperature meter and non-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 suggested.

- Level

In the odorize part, increased injection of deodorant is due to improper operation of the injection pump and not adjusting injection device. This leads to toxic and harmful gas leakage for the consumer and loss of mercaptan. Decreased injection of deodorant due increased consumption by the consumer, improper operation of the injection pump and not adjusting the injection device may lead to non-detection of gas leakage and possibility of fire and explosion. Other studies have demonstrated that non-supervision or inspection of vessel, failure of the level indicator, wrong valve opening and alarm that does not work correctly are causes of higher level in the vessel .[10, 29] Moreover, cracking or corrosion of the vessel, damage to the vessel body seal, weak joints between the ceiling and vessel structure and damage to the valves and flanges are causes of the lower level. [29]

Other conditions

- Corrosion/abrasion

The corrosion due to the increase of humidity and

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oxygen in the air reduces thickness of the pipes. It is recommended to inspect 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. Abrasion in the system is caused for reasons such as high amount of solid particles in the gas, increased 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. They cause abrasion in the inner body of the 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, create gas flow in a calm state, use appropriate coatings and minimize the increase and decrease of pipe diameters. Singh [35] also observed that the erosion-corrosion process causes the reduction of wall thickness in the horizontal pipeline. However, properties of sand, namely, size, shape and static settled concentration of particles play a key role in the erosion wear of the pipeline. 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 result 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. Qin [37] demonstrated that, generally, the mechanic-electrochemical effect at corrosion defect causes an increased stress concentration and anodic current density (i.e., corrosion rate), decreasing the failure pressure of the pipeline. Both the stress and anodic current density regarding corrosion defect were dependent on the defect geometry, especially the defect depth.

- Leakage

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

- Vibration

High vibration deviation is caused by unregulated consumption of lines, burnout of parts, lack of proper inhibition of piping and sensing and lack of proper foundation. This leads to equipment breakdown, reduction of station life and leakage of gas. 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 are suggested. Zhu [41] illustrated that the buried corroded cast iron gas pipeline is more likely to be damaged by engineering blasting vibration. Results revealed that corrosion reduces the anti-vibration characteristic of the pipeline, and the peak particle velocity. 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 that vibration propagation characteristic is investigated for a periodic composite

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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 stability design of periodic pipeline structures.

Conclusions

Main contribution of this study is demonstrating the efficacy of HAZOP method. This is 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, level, temperature, corrosion, wear, leakage, vibration, etc. were examined according to the node conditions and the causes of deviations from normal in the process. As a result, pressure reduction stations were identified. According to the findings, 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, measures to solve the problem were based on recommendations regarding installation of sensors and security alarms, as well as periodic maintenance of the installation.

Although benefits of operational HAZOP analysis of CGS are satisfactory, the model does not consider human factors. There were, however, some limitations. The experience of HAZOP team influences the efficiency of 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 to present all aspects of HAZOP analysis, focusing only on the analysis of process and operations risks. It leaves 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.

Conflict of Interest

The authors have no conflict of interest to declare.

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Authors Contribution

Both authors contributed equally to the study.

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