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Risk Assessment of Tobruck Seawater Desalination Plant Based on Hazard and Operability Study Approach: A Case Study

Mohammed Abdurabbah Ali[1*], Abdulhakim Alamaria[2]
[1]School of Engineering and Applied Sciences, The Libyan Academy - Ajdabiya Branch, Libya.
[2]Department of Chemical Engineering, Faculty of Engineering, Bright Star University, Albriqa, Libya

تقييم المخاطر لمحطة تحلية مياه البحر في طبرق بناءً على نهج دراسة المخاطر وقابلية التشغيل: دراسة حالة

محمد عبد ربه علي[1*]، عبدالحكيم العمارية[2]
[1]كلية الهندسة والعلوم التطبيقية، الأكاديمية الليبية - فرع اجدابيا، ليبيا
[2]قسم الهندسة الكيميائية، كلية الهندسة التقنية، جامعة النجم الساطع البريقة، ليبيا

*Corresponding author: MohamedAltaief@gmail.com

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Abstract:
Operation processes in desalination plants are full of several risks that are difficult to predict, which may cause their failure or poor performance, for this reason become obliged to manage these risks with scientific methodology to detect the risks. This study aims to assess the operational risks of the Evaporator and its accessories in the General Company for Desalination-Tobruck- by using HAZOP technology to examine the process and review the design. The risks were identified by the basic elements of the operation process using guiding words as well as setting the probability and consequences for each deviation with the use of the risk matrix to evaluate the risks. The results showed that many high risks, most notably the risk of high pressure, temperature, increasing of scales in the evaporators and boilers, also increasing noising in the evaporators unit, and clarify the appropriate ways to control or reduce their severity. In this study, two experts from the Tobruck desalination plant and five operators were used to collect data and identify risks.

Keywords: HAZOP, Risk assessment, Desalination plant, Cells unit, Boiler unit, Process safety.

الملخص
عمليات التشغيل في محطات تحلية المياه مليئة بعدة مخاطر يصعب التنبؤ بها، والتي قد تؤدي إلى فشلها أو ضعف أدائها. لهذا السبب، يصبح من الضروري إدارة هذه المخاطر بطريقة علمية للكشف عنها. تهدف هذه الدراسة إلى تقييم المخاطر التشغيلية لمبخر المياه وملحقاته في الشركة العامة لتحلية المياه – طبرق -باستخدام تقنية HAZOP لفحص العملية ومراجعة التصميم. تم تحديد المخاطر من خلال العناصر الأساسية لعملية التشغيل باستخدام الكلمات الإرشادية، بالإضافة إلى تحديد الاحتمالية والعواقب لكل انحراف مع استخدام مصفوفة المخاطر لتقييمها. أظهرت النتائج وجود العديد من المخاطر العالية، وأبرزها خطر الضغط العالي ودرجة الحرارة، وزيادة تراكم الرواسب في المبخرات والغلايات، وكذلك زيادة الضجيج في

وحدة المبخرات، وتوضيح الطرق المناسبة للتحكم في هذه المخاطر أو تقليل شدتها. في هذه الدراسة، تم الاستعانة بخبيرين من محطة تحلية طبرق وخمسة مشغلين لجمع البيانات وتحديد المخاطر.

الكلمات المفتاحية: تقييم المخاطر، محطة تحلية المياه، وحدة الخلايا، وحدة الغلايات، وأمان العمليات.

Introduction

The installation and operation of plants without adequate accident prevention measures pose significant risks. Numerous industrial hazards, particularly in the chemical sector, have been reported globally, with many accidents attributed to human error. For example, the 1974 Flixborough disaster, caused by a reactor leak, resulted in 28 fatalities, 36 injuries, and widespread property damage [2]. Similarly, the 1976 Seveso disaster led to extensive environmental contamination, not due to a lack of knowledge, but the absence of effective risk analysis tools. In 1984, the Bhopal disaster, which resulted in thousands of deaths and significant property loss, was another tragic example of human error [3]. The Bunce field explosion in 2005 and the 2010 BPL refinery disaster further highlighted the severe consequences of inadequate safety measures, including billions in property damage and environmental pollution [4]. These accidents have spurred a global shift toward enhanced safety protocols in chemical plants, leading to a decline in major accidents between 1956 and 1998. This reduction is likely linked to increased research in accident prediction and loss prevention [5][6]. Given the inherent risks—such as flammability, exclusivity, and toxicity—associated with chemical and processing plants, operational decisions to maximize efficiency can exacerbate these hazards. Identifying these risks is essential for the safe design and operation of such facilities [7]. As a result, ongoing research aims to refine safety assessment tools. From the Industrial Revolution onward, numerous accident prevention techniques have been developed, including methods recognized by the ISO 31010 standard, such as PHA, HAZOP, FMEA, FMECA, ETA, FTA, BOWTIE, BAYESIAN NETWORK, HAZID, and LOPA [8]. Among these, Hazard and Operability Studies (HAZOP) are widely used to assess process risks in industrial plants, providing a structured approach to identify potential risks from equipment malfunctions and operational failures, whether in new or existing systems [9].

Risk Acceptance Criteria

The Health and Safety Executive (HSE) in England defines "tolerable risk" as accepting a controlled level of risk to gain specific benefits, rather than ignoring it. This approach focuses on managing and mitigating risk thoughtfully to maximize benefits while minimizing harm [10]. In hazardous industries, especially in developing countries, the benefits often outweigh the risks, making it a justifiable choice. In contrast, developed countries may impose stricter regulations, which can be seen as a challenge to cost-efficiency and competitiveness [11]. Risk assessment is crucial in industries like chemicals, helping identify, evaluate, and manage risks while integrating safety into operations. This process involves several stages, as shown in Figure 1, and ensures safety is balanced with the need for growth and efficiency [12]. Risk assessment involves the process of hazard identification, loss assessment and risk characterization. The first stage of risk assessment deals with the identification of potential hazards and accidents in the process. Hazards should be identified practically at all stages of design, implementation, normal operation and maintenance and in all circumstances where the process may deviate from its normal performance to mitigate potential risks. Among the various methods and techniques developed for process hazard identification, HAZOP is one of the most recognized methods and techniques where risks are assessed qualitatively [13].

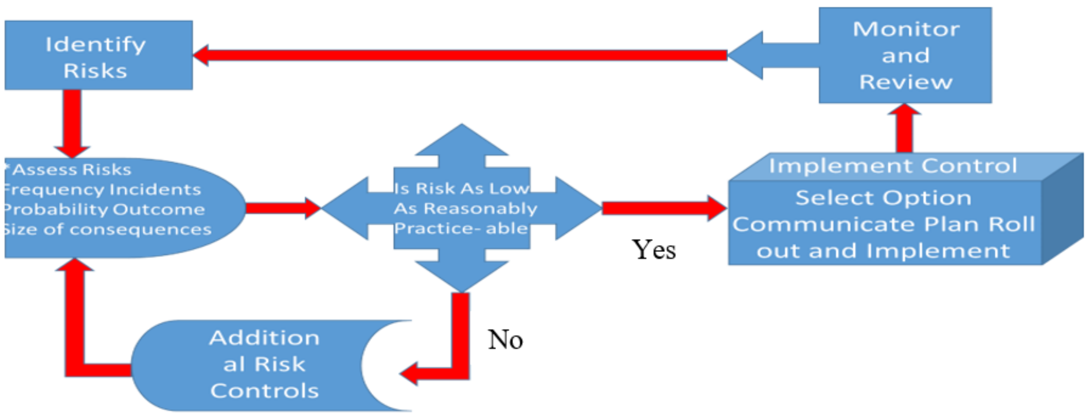

Figure 1: Different stages of risk assessment.

Risk Matrix

A Risk Matrix is used to evaluate risk by assessing both the likelihood and severity of an undesirable event. Severity can include factors like injury, environmental damage, repair costs, or reputational harm [14]. The matrix, shown in Table 2, plots probability [15] against severity [16]. Each axis is assigned values to represent the likelihood and impact of the risk. The resulting risk level is determined by the combination of these ratings [17], helping to prioritize risks and inform decision-making.

Table 1: Risk matrix.

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

Hazard and Operability Studies (HAZOP)

Hazard and Operability Studies (HAZOP) is a methodical approach aimed at identifying potential hazards and operability issues in a process system. It systematically examines the design and operational objectives to detect inefficiencies or errors, while evaluating their consequences on the entire plant. The primary goal of HAZOP is not only to identify deviations from the norm but also to assess them sequentially and propose appropriate solutions to enhance safety. [18] In this approach, a system is considered safe only when all operating parameters—such as pressure, temperature, flow rates, liquid levels, corrosion, pipe integrity, and potential failures—are within the normal range. Although HAZOP can be conducted throughout a plant's lifecycle, performing it during the design phase is particularly valuable, with periodic reassessments every five years helping to prevent accidents in chemical plants. In the study described, the system was divided into smaller sections, or study nodes, to facilitate the identification of potential deviations. Figure 2 demonstrates how changes in process parameters affect each of these nodes [19].

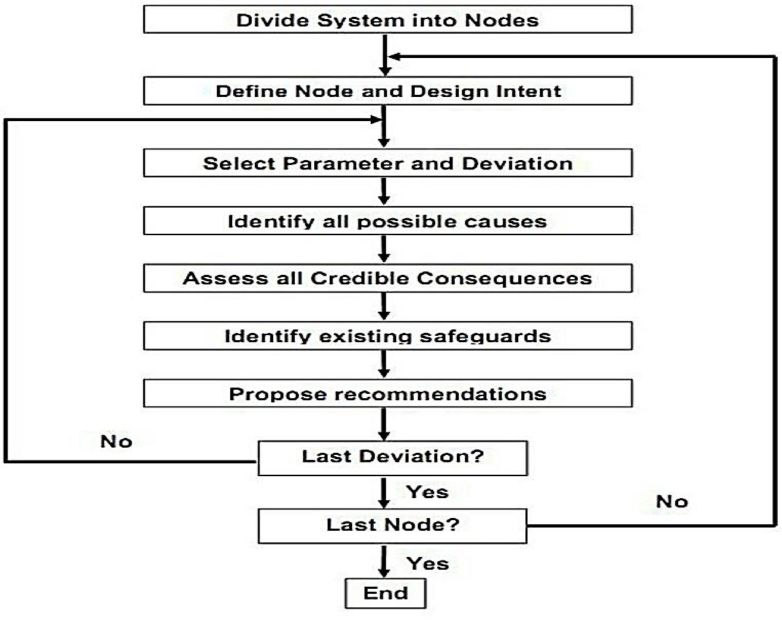

Figure 2: HAZOP methodology

Results

Figure 3 shows the P & ID of the stabilization system of the desalination plant under study. The plant has 4 evaporators, the evaporator has the number " 6 " cells, and 3 boilers, two works and one stand by. The HAZOP analysis for the Evaporators (Node 1) and Boilers (Node 2) units identified key risks and recommended mitigation strategies for the operation and maintenance teams. The analysis focused on several elements: Chemical Injection: Anti-scaling and anti-foam agents in the evaporators, and Trisodium phosphate in the boilers. Pressure: Assessed for both units. Flow: Analyzed under five scenarios: low/high flow in the evaporators and boilers, and at the Economizer Inlet. Level: In the evaporators, level issues were caused by valve and pump failures; in the boilers, fuel tank level readings were problematic. Corrosion: Analyzed for causes, effects, and mitigation. Conductivity: Evaluated for both units. Noise: Distillation unit noise exceeded safe exposure limits. Temperature Variations: Both temperatures rise and fall impacts were studied, along with vacuum issues in the evaporators. Fire and Explosion Risks: Assessed for both nodes.

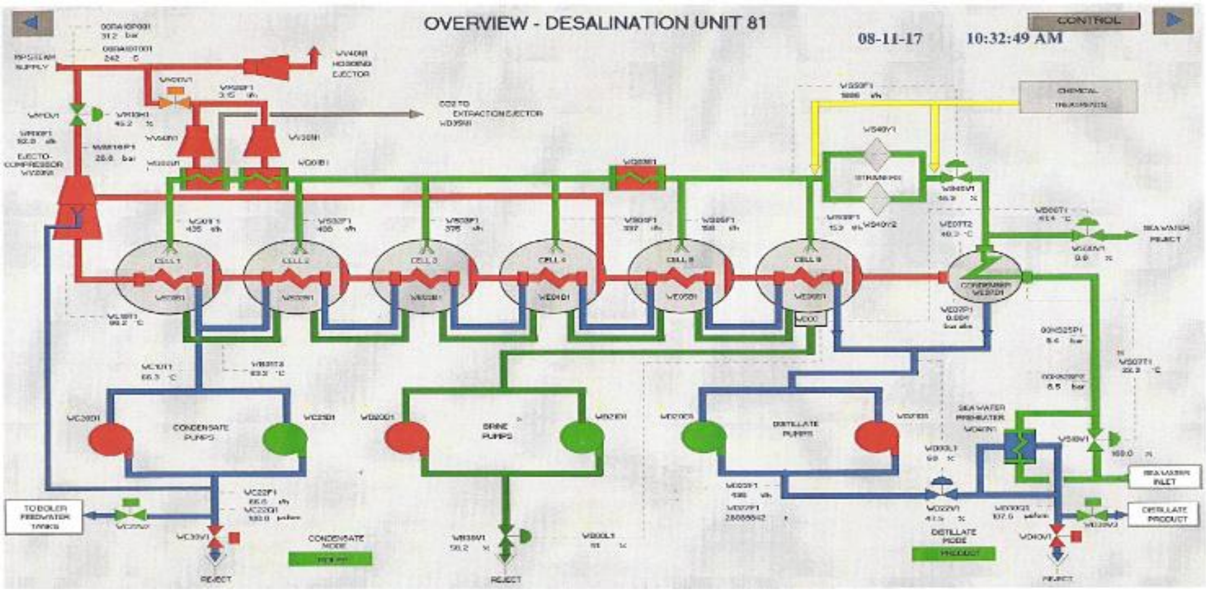

Figure 3. Process Instrumental Diagram (P&ID) of desalination plant.

Discussion

This project has provided valuable insights into safety, operations, and environmental impact. The recommendations aim to enhance safety, productivity, cost efficiency, plant availability, and capacity. The HAZOP team analyzed 34 operational deviations, 90 causes, and 48 consequences, identifying 15% of deviations as high-risk and 54% as medium-risk. Key recommendations for improving plant safety and operations are summarized in Tables 2-3. The HAZOP study of the Stabilization Unit at the Tobruck Desalination Plant successfully identified failure causes and consequences, leading to recommended preventive actions and process modifications to prevent accidents includes:

- Chemical Injection Issues: Poor chemical injection in the evaporator and boiler can lead to increased salt deposition, a major hazard in desalination processes. Salt buildup can block brine pipes, reduce flow rates, and increase pump pressure and energy consumption. It also decreases heat transfer efficiency, reducing plant productivity and efficiency. Monitoring and improving chemical injection are critical to maintaining optimal flow, reducing energy consumption, and improving desalination efficiency.
- Low Pressure in Lines: Low pressure in the system can indicate reduced flow, which could lead to plant failure and decreased production. Pressure drops in the boiler and evaporator may disrupt desalination. To prevent this, regular checks on pressure safety valves, control indicators, and ejectors, along with periodic maintenance, are essential to avoid pressure-related issues.
- High Noise Levels: The high noise level in the evaporator unit, measured at 115 decibels, exceeds international safety limits and poses long-term health risks to workers, including mental health effects. Operators often neglect to wear ear protection, and the plant does not provide it. Addressing this issue is crucial for protecting worker health, and all recommended noise control measures should be implemented.
- Fuel Tank Level in Boiler: It is recommended to maintain the fuel tank below the required level to prevent leaks and environmental pollution.

Table 2. Risk assessment of sea water desalination for the evaporator's unit-Tobruck desalination plant.

Deviation	Causes	Consequences	Risk Matrix			Safeguards	Actions
			P	C	RR		
Poor Antiscale injection	1- Pump is discharging through the safety valve. 2- suction strainer is clogged. 3- pump is not pumping.	1- Increases the rate of deposition on the steam tubes in evaporators. 2- Reduces the heat exchange process between steam and seawater in evaporators	45 C	80 V	36 H	1- An alarm that causes the unit to shut down and stop working after half an hour if the necessary measures are not taken.	1- Check pump pressure and check injection line, start stand-by pump and adjust safety valve. 2- Change to stand-by pump and clean strainer. 3- Check pump mechanically.
Water makes up pressure low	1- Air entry pump section. 2- Cell 1 water make up pressure switch faulty. 3- Cell 1 water make up pump problem.	This results in a decrease in the required quantity designed for the station, which causes sedimentation	20 A	35 II	7 L	Keep the pressure and mass flow as design for the evaporator.	1- Inform instrument technician for repair. 2- Check pump performance, pressure bearing temperature.
Distillate condenser vapour high pressure	Water floods evaporator and air is not extracted.	1- Increase in heat balance. 2- Decreases in production rate. 3- Formation of sedimentation on the evaporator tubes.	45 C	60 III	24 M	1- Cheek ejectors periodically 2- Keep steam flow pressure as design to return back pressure as design.	1-Open vent valve to start up ejector TWV31AA081. 2-Start brine pump.
Poor anti-foam injection	It generates foam, raising the conductivity of the water. also Reduces water evaporation.	Loss of high-quality water production.	20 A	60 III	12 L	Periodic monitoring of injection rate and preparation rate in tanks.	Maintain the required level of antifoam injection.
More corrosion	1- The salt concentration is high. 2- High tempe- 3- Injection of hydrochloride.	Operators are forced to shut down the unit until the corrosion is addressed.	90 E	90 IV	81 H	1- Injecting DE chlorinator into feed water. 2- Create a cathodic protection.	Turn off the evaporator and treat the affected parts before the problem gets worse.
Distillate conductivity high.	1-Poor vacuum. 2-Foaming. 3-Demister not properly installed.	Loss of high-quality water production.	20 A	50 III	10 L	Sample monitoring and chemical injection into feed water.	1- Refer to case 1. 2- Check anti-foam injection. 3- Check demister in all cells. 4- plug up or replace tube.
More noise	The noise generated around desalination plants is caused by use of high-pressure pumps, and power generations, such as turbines.	Loud noise can cause both physical damages, like ear muscle strain, and psychological effects, such as distraction, difficulty concentrating, and impaired communication.	95 E	90 V	85 H	1- Isolate noisy areas and limit worker exposure. 2- Ensure ear protection is worn near the vaporizer. 3- Provide safety gear and conduct regular health checks for workers. 4- Use quieter, modern equipment.	
Thermocompressor A/B outlet temperature high.	1- Incorrect steam parameters to thermocompressor. 2- faulty DE superheating.	1- increase in heat balance. 2- Sedimentation formation in cell	15 A	80 IV	12 M	Attention to heat based on design.	1- Check from stem generation side and make good. 2- Check open DE superheating valves TWC40AA081, if no remedy, after

							shutdown, open and check nozzles.
Brine cell 1A or 1B temperature high.	1- Cell 5 temperature too high (Set point 65 ºC). 2- Insufficient make up flow. 3- vacuum trouble.	1- Disturbance in the heat balance which causing distribution in the production process. 2- Sedimentation formation.	15	70	10	Keep this temperature as parameter design.	1- adjust with TWS40AA051. 2- Refer case 12. 3- Check steam parameters and adjust to nominal ones.
			A	IV	M		
Seawater makes up flow low	1- Low seawater make- up pressure. 2- Trouble in booster pump. 3- Make up spraying nozzles chocked.	1- Decreases in product rate. 2- increase in the sedimentation if the problem is not resolved as soon as possible.	20	35	7		1- Check and adjust flow. 2- Check pump parameters and send local operator to confirm. 3- Check differential pressure TWX40CP301 less than 500 mbar.
			A	II	L		
Distillate condenser level high or low	1- Incorrect distillate level control set point. 2- Distillate level controller failure.	Leads to shut down if no backup solutions are available	30	10	3		1- Check set point of distillate level controller. 2- Check level controller. 3- isolate steam to thermocompressor.
			B	I	L		
Brine level high or low	1- Make-up flow incorrect. 2- Level control set point incorrect. 3- Level controller failure.	Trip, when the brine level is high.	30	45	12	The only thing is shut down until the problem solved.	1- Adjust make-up flow to design value. 2- check set point of brine level control. 3- check make-up control value is not in locked position. 4- check controller value.
			B	III	M		
Fire/Explosion			10	10	1	Adding a safety valve to the evaporator, in case of high pressure inside the evaporator, it opens automatically and keeps the unit from exploding	
			A	I	L		

Table 3. Risk assessment of sea water desalination for the boiler's unit-Tobruck desalination plant.

Deviation	Causes	Consequences	Risk Matrix			Safeguards	Actions
			P	C	RR		
Poor Trisodium phosphate injection.	1- Pump is discharging through the safety valve. 2- pump is not pumping.	1- Increase the conductivity. 2- Decreasing in the PH. 3- Incorrect chemical dosages can leave metal surfaces susceptible to corrosion.	10	25	2	1- an alert in the control room if the injection pump malfunctions. 2- Regularly test boiler feed water samples using proper analysis methods.	1- Check pump pressure and check injection line. 2- Change to stand-by pump. 3- Check pump mechanically.
			A	II	L		
Fuel Level Low	1- Tank reading is incorrect 2- Tank filling has stopped	Tripping, when the Fuel level is low.	65	85	48		Transferring the fuel of the second and backup boiler to the first boiler, and operating the unit with one boiler.
			D	V	H		
Fuel Level high	Level reading is incorrect	The tank overflows, which in turn causes pollution to the environment.	30	70	21	Tank filling is less than the required level.	Stop filling the tank and clean up the leaked fuel.
			B	IV	M		
Low Pressure Economizer Inlet	1- If the feed water inlet pressure is less than 13740 kPa. 2- Failure of the boiler feed pump.	1- Low generation. 2- Load run back.	5	80	4	Attention to periodic maintenance.	1- Increase the BFP flow 2- Manually stop the pump, check for leaks.
			A	IV	M		

High pressure Economizer Inlet	1- If the inlet pressure of the feed water is more than 13,740 kPa. 2- (BFP) failure.	Can break the baffles in the economizer.	A	II	L	Maintaining the flow of what is required.	1- Reduce the BFP flow. 2- Stop the pump manually, check for leaks and perform maintenance on the pump.
			A	II	L		
Low Flow Economizer Inlet	1- High Pressure Heater failure. 2- Loss of Boiler Feed Pump.	No supply of feed water to the economizer.	7	85	6	Alert in control room, then return flow as designed.	Maintenance of High-Pressure Heater.
			A	IV	M		
High flow Economizer Inlet	1- Two boiler feed pumps operating at 50% of maximum continuous rating (MCR). 2- if the BFP discharge is more than 97 t/h.	A high amount of dissolved oxygen goes to the economizer.	4	70	3	Alert in control room, then return flow as designed.	Stopping one Boiler Feed Pump.
			A	IV	M		
High Temp- Boiler Drum Outlet	1- Excess burning at a particular Load. 2- If inlet temperature of the steam is more than 486 ^{0}C.	Destroys the drum water wall tubes due to overheating of the tubes (down comers and tube risers), and could lead to drum explosion.	3	80	2	Keep this tempera-ture as parameter design.	Install water spray on the Primary and Secondary Superheaters.
			A	V	M		
Low Temp- Boiler Drum Outlet	1- Less number of burners working. 2- Tripping off of burners. 3- If the inlet steam temperature is less than 486 ^{0}C.	Reduce generation steam.	A	V	M	Attention to heat based on design.	Starting more burners to add more heat thereby raising the temperature.
			A	V	M		
More corrosion	1- If the pH level of the boiler feed water is too low or too high, it can promote corrosive conditions 2- Scales and deposits.	Corrosion can lead to equipment damage, leaks, and reduced system reliability.	3	90	3	using water with low conductivity, minimizing corrosion risk in boiler Also Protective coatings and inhibitors are crucial for preventing corrosion.	Boiler shutdown, maintenance must be done to prevent corrosion inside the boiler.
			C	V	H		
Fire/Explosion	1- Increased pressure in the boiler body. 2- Fuel leakage into the furnace.	If a large industrial boiler explodes, and the boiler room collapses, the factory area will also suffer a certain degree of damage, which is a very serious disaster.	5	95	4	1- Routine maintenance of equipment's. 2- Operators should follow manufacturer recommendations and industry best practices.	

Conclusion

The HAZOP study of the Tobruck desalination plant successfully identified potential causes and consequences of process failures. It recommended several preventive actions to reduce future risks:

- Chemical Injection Issues: Inadequate chemical injection in the evaporator and boiler can lead to increased salt deposition, causing pipe blockages, reduced heat transfer, and decreased efficiency. Monitoring and improving chemical injection can help prevent these issues, maintain water flow, and reduce energy consumption.
- Low Pressure Risks: Pressure drops in the boiler and evaporator can disrupt desalination and reduce production. Regular checks on pressure safety valves, control indicators, and ejectors, along with proper maintenance, are essential to prevent pressure-related failures.
- Excessive Noise: High noise levels, measured at 115 decibels, pose a significant health risk to workers, especially mental health. The lack of ear protection and oversight from the General Water Company exacerbates this risk. Implementing noise control measures and providing ear protection are crucial to mitigate this hazard.

The HAZOP study was improved to prevent accidents by taking a comprehensive approach, where all deviations were examined by an experienced team. However, its main limitation is that it only addresses issues supported by process charts and operational data. Additionally, the study is slow and time-consuming. Despite this, HAZOP is just the first step in risk assessment, and it's recommended to follow up with methods that sequentially evaluate the severity of risks in the system

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