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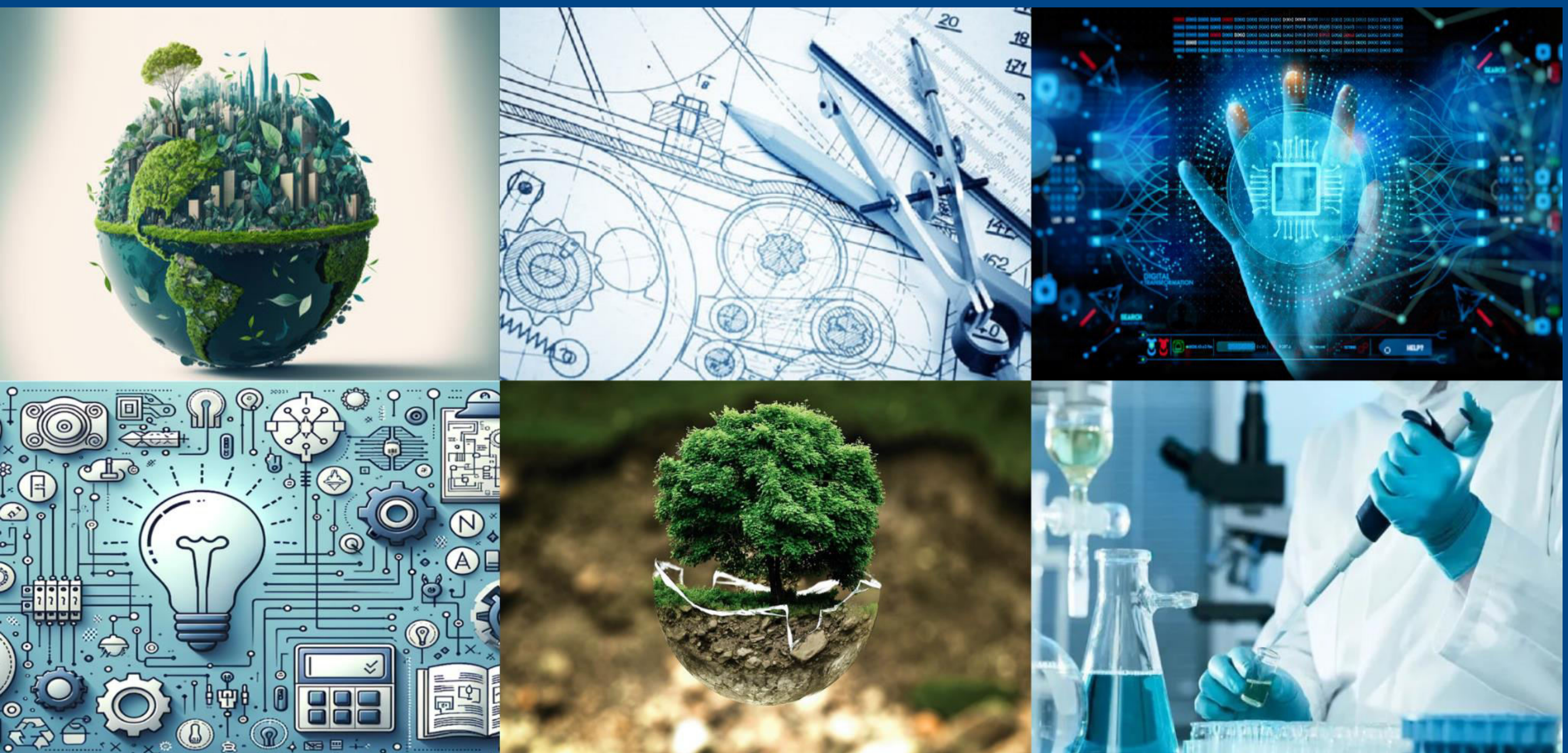

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Review of Liquefied Petroleum Gas Disasters; Causes, Effects and Management

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ABSTRACT: Liquefied Petroleum Gas (LPG) is widely used as a fuel in various sectors, including domestic, commercial, and industrial applications, due to its efficiency and cost-effectiveness. However, its highly flammable nature poses significant risks, which can lead to devastating disasters when safety measures are inadequate. The study relied on information from secondary sources. Explosions at liquefied petroleum gas stations have grown commonplace, resulting in significant economic and societal losses globally and raising concerns about public safety. These incidents cause a significant number of immediate casualties as well as long-term health impacts. The data suggest that; the principal causes originate from Boiling Liquid Expanding Vapor Explosions, Vapor Cloud Explosion, toxic releases and different forms of fires from natural, environmental, operational, equipment and design failures amongst others. Risk reduction strategies should be developed from the design phase, followed by regular maintenance and monitoring, making sure that equipment is in good condition, developing and adhering to standard operational and management procedures, and ensuring preparedness to build resilience in order to effectively and efficiently prevent and mitigate disasters caused by chemical hazards, particularly Liquefied Petroleum Gas.

KEYWORDS: LPG (Liquefied Petroleum Gas), Gas Leak, Explosion, Disaster Prevention, Risk Management.

I. INTRODUCTION

The need for energy has resulted in a constant rise in the use and consumption of petroleum products, including coal, biomass, liquefied petroleum gas (LPG), diesel, gasoline, and natural gas (NG), which includes compressed natural gas (CNG) and liquefied natural gas (LNG). Petroleum products, natural gas, and coal are the primary energy sources used by Nigeria and the majority of developing nations to meet their energy needs. Propane and butane are examples of the liquid, flammable mixture of hydrocarbon gases known as liquid Petroleum Gas (LPG). Due to its relative price, efficiency, and environmental friendliness, LPG is quickly replacing other fuels as the preferred option in most regions of the world, including Nigeria (Asamoah et al., 2012). Households account for 49% of global LPG consumption, followed by the petrochemical industry (21.6%), other industrial uses (11.8%), direct consumption in refineries and the agricultural sector (2%), and other sectors (such as autogas) that contribute to a total of 9.3% of consumption (Anon, 2022d). LPG emits very little sulfur and burns comparatively cleanly, producing little to no soot. According to Kwaw (2014) and Beheshti et al. (2018), its mixes containing air in percentages between 2% Lower Explosive Limit (LEL) and 10% Upper Explosive Limit (UEL) have the potential to ignite and explode, resulting in injuries, fatalities, and property destruction.

The liquefied petroleum gas (LPG) hazard might be made up of butane, propane, or a combination of the two. It is often supplied in pressurized steel cylinders and kept in gas stations. It is a colorless volatile liquid that is produced by pressurizing cooling liquefaction of natural gas or oil in a refinery (Sanjay 2018). Even while LPG is generally safe when used properly, handling, storing, or transporting it incorrectly can result in serious accidents. Leakage from storage tanks, improper installation or maintenance, human error, natural calamities, malfunctioning gas cylinders, and overfilling or overpressurization are some of the causes of LPG accidents. The impacts of LPG disasters, however, can range from explosions and flames, resulting in extensive loss of life, destruction of property, harm to the environment, financial

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losses, and psychological distress. These rely on the substance discharged, the release mechanism, the substance's temperature and pressure, and the ignition point.

The probability of LPG catastrophes can be reduced in large part by taking preventative action. Safety guidelines for the handling, transportation, and storage of LPG have been established by governments and industry agencies (Anon, 2022a; Velmurugan et al., 2019). The installation of pressure release valves and leak detection systems, regular inspections of cylinders and storage tanks, making sure that LPG storage areas are well-ventilated and away from sources of ignition, and requiring the use of safety features like gas shut-off valves in household and commercial appliances are some examples of these standards. Regular audits and inspections are used to enforce compliance with LPG safety rules in several nations.

LPG catastrophes can have catastrophic effects on economy, the environment, and human life. These catastrophes have a variety of origins, including natural calamities, human error, and mechanical failure. The long-term repercussions can be even more severe than the terrible immediate ones, which include property destruction and fatalities. Effective management, on the other hand, can greatly reduce these hazards and guarantee the safe use of LPG. This includes regulation, safety procedures, public education, and emergency readiness. The purpose of this article is to review the causes, consequences, and management of liquefied petroleum gas (LPG) disasters.

Several author's have researched on LPG disasters. The Feyzin disaster of 1966 is of note as simple disregard for procedures may result in a catastrophic event. Although freezing in the pipeline has been cited as the accident's cause, this is actually a result rather than a cause. The catastrophe was primarily caused by a number of malfunctions at various levels, which ultimately resulted in human mistake (Fig. 1). Preventing storage tank accidents, particularly those with similar origins, can be greatly aided by identifying the causes of these incidents and drawing lessons from them. Comprehensive investigations on tank fires have been carried out by numerous researchers. Chang et al. (2006) investigated 242 storage tank mishaps. According to this report, fire and explosion are the two main risks connected to storage tanks.

Zheng et al. (2011) looked into 50 Chinese storage tank mishaps. The findings indicated that operator mistake was the primary cause of accidents. According to research by Ahmadi et al. (2020), which looked at 104 mishaps involving atmospheric storage tanks, the average cost of domino accidents was $205 million, whereas the average cost of non-domino accidents was $24 million. According to the study's findings, environmental variables accounted for 38% of accidents, followed by equipment issues (20%), operational factors (15%), domino effects (13%), maintenance (10%), and sabotage and terrorism (4%). An event that begins with one object and spreads to neighboring items through thermal, blast, or fragment impact is known as a "domino effect" (CCPS, 2000). According to a different study of 225 accidents involving the transport of hazardous chemicals and the domino effect in process industries, 89% of the accidents involved combustible materials, with liquefied petroleum gas being the most frequently implicated (Darbra et al., 2010).

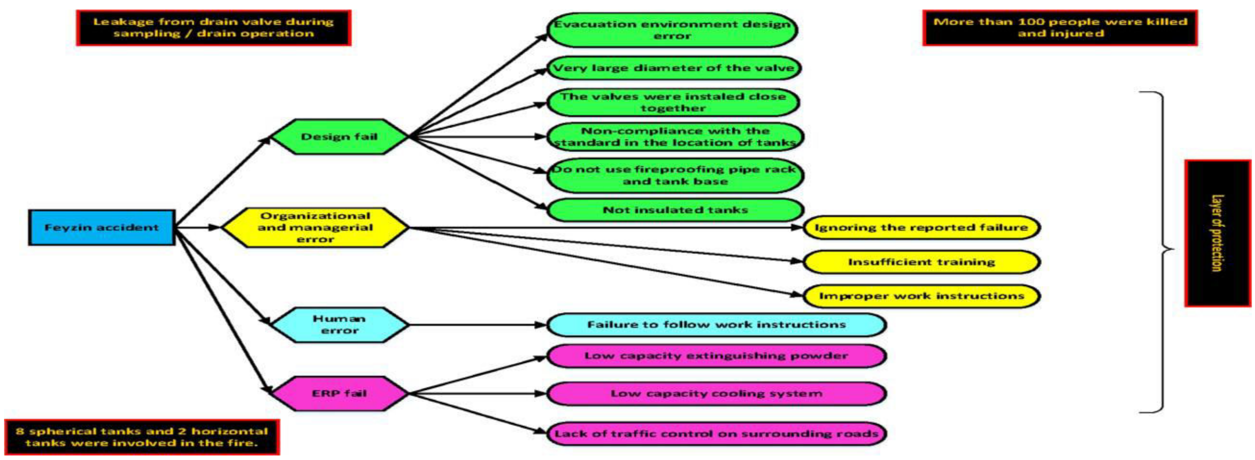

Fig. 1 Feyzin accident, 1964

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Hazardous Properties of Liquefied Petroleum Gas

The components of liquefied petroleum gas (LPG) include butane, propane, or a combination of the two. LPG contains a higher percentage of butane at higher average temperatures and a higher percentage of propane at lower average temperatures. The boiling points of the two gases account for this discrepancy (Rodriguez, Diaz, Santos, & Aguirre, 2017). It is often supplied in pressurized steel cylinders and kept in gas stations. It is a colorless volatile liquid that is produced by pressurizing cooling liquefaction of natural gas or oil in a refinery (Sanjay 2018). Additionally, it has no smell, but the addition of Mercaptans gives it a distinct smell (Rodriguez, Diaz, Santos, & Aguirre, 2017). The main characteristics of butane, propane, and liquefied petroleum gas (LPG) are given in Table 2. Fires and explosions are the two main risks associated with LPG. The main risks associated with liquefied petroleum gas are its high density compared to air, high coefficient of expansion, high flammability, pressure, and storage temperature over the boiling point. The key characteristics of liquefied gas that make it a dangerous material are displayed in Figure 2 and Table 1 (ARIA, 2004).

Fig. 2 Properties of LP gas that make it hazardous

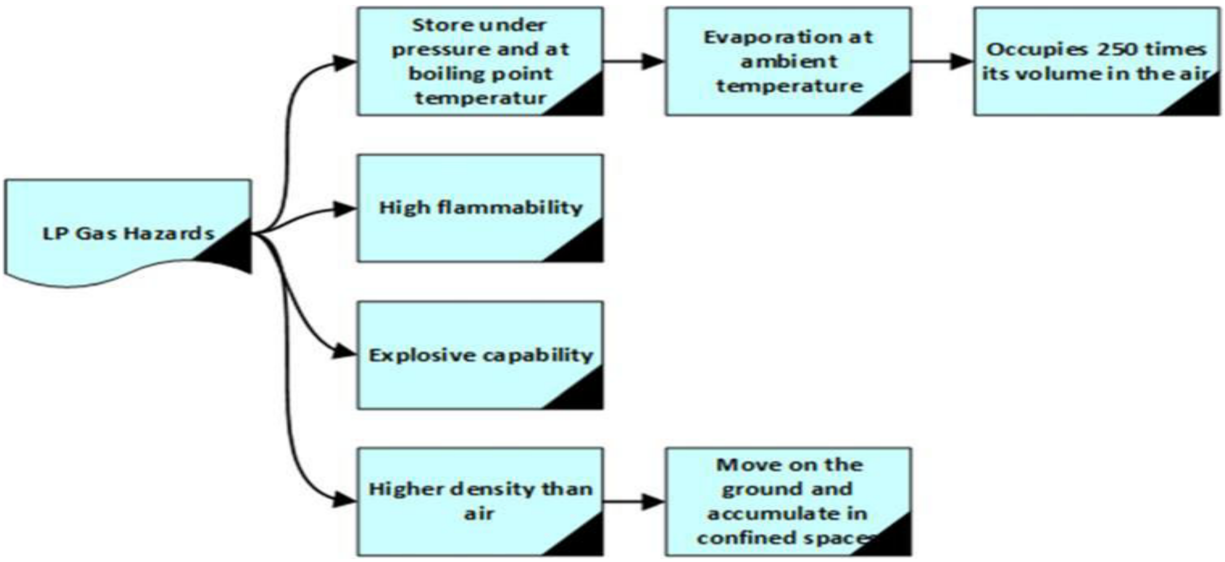

Table 1: Summary of the Properties of Propane, LPG and Butane;

	Designation	Propane	LPG	Butane
Composition (% Vol)				
Propane	%	100.00	60.00	00.00
Butane	%	00.00	40.00	100.00
Physical Properties				
Vapour pressure (at 37.8 ºC)				
Vapour pressure (at 0.0ºC)	psig	208	160	70
Boiling point (at 1 atm)	psig	70	48	15
Liquid:	ºC	-42.1	-25.5	-0.5
Specific weight (at 15ºC) (Water=1)		0.5083	0.5389	0.5847
Density (at 15ºC)	Kg/gal	1.922	2.038	2.211
Vapour				
Relative Density (air=1)		1.5225	1.7162	2.0068
Flammability				

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Lower Explosive Limit (LFL) %Vol Air	%	2.00	1.80	1.50
Upper Explosive Limit (UFL) %Vol Air	%	9.50	9.30	9.00
Combustion				
Vol air / Gas for combustion (ideal)		23.86	26.72	31.02
Calorific Power	BTU/Kg	47.375	47.063	46.596
Calorific Power (Vapour at 15ºC)	BTU/m^3	88.353	98.940	114.54
Calorific Power (Liquid at 60ºF)	BTU/gal	90.823	95.657	102.91

Source: (Rodriguez, Diaz, Santos, & Aguirre, 2017).

Historical Disasters of Liquefied Petroleum Gas Facilities

In the past, liquefied petroleum gas facilities have had a number of catastrophes that have resulted in losses and catastrophes of varying sizes. There were 115 m3 horizontal tanks at the Port Newark (New Jersey, July 7, 1951) facility for receiving propane from ships and delivering it via tank truck or tank rail car. There was an unidentified leak in the plumbering close to one set of tanks. After an instantaneous ignition, operators were able to activate an emergency shut-down station, which activated shut-off valves on every tank, approximately three minutes later. The first of the tanks burst immediately after this move was taken.

A group of 70 tanks burst with varied degrees of violence over the course of the next hours. Tanks in nearby factories were damaged and punctured by some tank fragments that were hurled up to 800 meters. Another set of tanks, 107 meters away, did not burst. Several flange leaks that did happen at the tanks were managed by firefighters. A total of $1,050,000 was lost. Due to the insulating effect of cork insulation material put on the tank cars, several full propane tank cars that were situated on a rail siding next to and significantly exposed by the fire did not burst.

On May 30, 1978, a refinery alkylation unit and other production units were situated next to a tank farm in Texas that was used to store propane, propylene, butane, and butylenes. The tank farm has four 160m3 vertical "bullets," five 160m3 horizontal "bullets," and three 800m3 (210,000 gal) spheres. There was a pipeline delivery filling a sphere. A defective relief valve and instrument malfunction caused one of the spheres to become overfilled and overpressured to the point of bursting. Over the course of the following 20 minutes, all of the remaining tanks and spheres in the tank farm ruptured as a result of the massive fireball and subsequent fire. Tank and sphere fragments flew in all directions, seriously damaging tanks, fire protection facilities, and other operating units. A sphere's main section went 230 meters. One of the "bullets" that were vertical traveled 150 meters. An empty atmospheric oil storage tank was entirely penetrated by the domed end of a horizontal "bullet" that traveled 60 meters. More than $100 million was lost.

A facility for storing butane and propane that was received by pipelines was described in Ixhuatepect (1984). It included two spheres, four 1600 m³ storage tanks, and forty-eight horizontal "bullet" storage tanks of various sizes. The terminal has a total storage capacity of 16,000 square meters. A leak occurred at the site while tanks were being filled from a pipeline, possibly due to overfilling and over-pressure of one or more tanks. A vapor cloud was ignited at a nearby plant, and approximately one minute later, one or possibly two spheres ruptured. The terminal was originally built in 1962 in an open country area; however, since then, nearly 4,000 people have moved into the immediate area, which started just 130m from the LPG storage area. During the next hour and twenty minutes, nine major explosions and numerous smaller ones occurred from vessel BLEVEs, causing burning and unburned gases to enter houses and set everything on fire. The fire killed about 500 people and seriously injured about 7000 others, with the majority of the dead being located within 300 meters of the storage area's center. Additional LPG facility disasters are detailed in table 2 below.

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Table 2: Disasters from Liquefied Petroleum Gas Facilities

S/N	Location and Date	Cause	Effect
1.	Ohio, USA, 1944	Explosion of gas clouds	Killed 130 people
2.	Feyzin, France 1966	Disregard of SOP	18 people dead, 81 injured
3.	Kingman, Arizona, USA 1973	Tank leakage	12 people died
4.	Oneonta, New York 1974	Train derailment	50 people injured
5.	Mill Woods Area, Canada 1976	Excessive pressure in pipeline	19000 people evacuated
6.	Umm said, Qatar 1977	Tank weld failure	Killed 6 people
7.	Belt Montana 1977	Train derailment, heat radiation	2 people died, 11 injured
8.	Donnellson Iowa, USA 1978	Heat radiation; Pipeline unsealing	2 people died, 3 injured
9.	Nijmegen, Holland 1978	Radiation and overpressure wave	40m diameter, 25m height
10.	Warsaw, Poland 1979	Disregard of fire safety regulations	2 people injured
11.	Vishakhapatnam, India 1983	Tank loading ignition	37 people died, 100 injured
12.	Albert City, USA 1998	Driver carelessness	2 people died, 7 were injured
13.	Accra, Ghana 2016	Human error	7 people died, 132 injured
14.	Warri, Nigeria 2017	Discharge from hose	1 person injured
15.	Accra, Ghana 2017	Offloading petrol tank	5 people died
16.	Magodo, Nigeria 2018	Gas tank leakage	7 people died
17.	Lafia; Nigeria 2018	Leakage during offloading	Over 20 set ablaze
18.	Lynchburg, Virginia, USA 2019	Gas leakage	2 people died, 4 injured
19.	Bangkok, Thailand 2022	Cylinder fire	5 people injured
20.	Magodo, Nigeria 2018	Gas tank leakage	7 people died
21.	Lafia; Nigeria 2018	Leakage during offloading	Over 20 set ablaze
22.	Agbor, Nigeria 2021	Unknown	4 died, 11 persons injured
23.	Rumuodumaya, Nigeria 2021	Leakage during offloading	3 people died
24.	Obirikwerre, Nigeria 2022	Tank leakage	3 people affected
25.	Bucharest, Romania 2023	Unknown	2 dead, 56 injured

Causes of Liquefied Petroleum Gas Stations Accidents

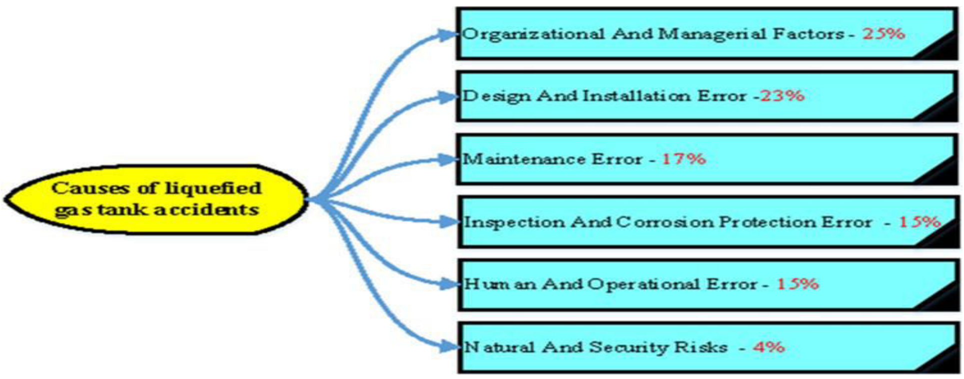

Fig. 4 Causes of accidents in LPG tanks

Design and Installation Failure

Design flaws contributed significantly to the incidence or escalation of the accident in the majority of the examined incidents. Because of the downstream pipe's small diameter and a malfunctioning valve, liquefied gas spilled out in the Albert City, Iowa, propane tank accident. Because there was no emergency shut-off mechanism in place, it was impossible to stop the pipeline's flow in the Sat. Harvey accident. One of the main reasons for the Feyzin disaster was the drain valve's poor design. Several instances of buildings and tanks being arranged incorrectly have caused accidents

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to worsen and resulted in more casualties. Examples of this include the accidents in Ghent, Virginia, and Visakhapatnam, India. Metallographic tests confirmed the poor quality of the gaskets, and the accident at the Khark Petrochemical de-ethanizer tower spread due to the absence of a cooling system, emergency shut-off system, and fireproofing of the tower. In the Valero-McKee refinery accident, the danger of using chlorine near equipment that contains flammable hydrocarbons was not identified. Additional cases that have been identified include an ineffective gas detector, an inadequate extinguishing system, a poorly designed drain valve, a poorly designed drain area, a poorly designed tank body, a terminal design that does not adhere to legal requirements, a lack of a passive fire protection system, non-compliance with the necessary standards, a higher operating set pressure of the safety valve, and the failure to use remote isolation valves (Kazem et al., 2021).

Organizational and Managerial Factors

Organizational and managerial considerations have played a significant effect in the incidence of accidents. Despite earlier concerns that the drain valve in the Feyzin accident was faulty, nothing was done to fix the problem. One of the major contributing factors to the Khark petrochemical catastrophe was the poor management of the reform program. Risk analysis was not done for many of the modifications, particularly the reboiler relocation, and the inlet flange did not match the de-ethanizer tower skirt. Other management variables that contributed to this accident's occurrence were a lack of information about comparable accidents, a lack of analysis of prior similar incidents, and a deficiency in organizational memory brought on by a failure to write records and experiences. System safety is significantly influenced by organizational elements like training, safety culture, safety management strategy, and motivation. Lack of resources, low responsibility, disregard for reporting deficiencies, lack of training programs or inappropriate training programs, lack of emergency response plan, poor communication system (both inside and outside the organization), and inappropriate work instructions were other organizational and managerial factors found in this study.

Human and Operational Factor

There is no denying that human error plays a part in accidents. From the start of leakage to evacuation and emergency procedures, human factors have an impact at every stage. A departure from the reference action is referred to as human error. As a result, each action that deviates from the framework is regarded as a human error. Leaving the drain valve open has resulted in tank overflow in a few of the accidents that have been investigated. One such instance is the Rio de Janeiro accident in Brazil. Not reporting all defects, failing to follow work instructions, failing to follow work permits, failing to learn from previous accidents, working without a supervisor, being careless, failing to evacuate after a leak, issuing work permits without verifying the conditions, performing non-routine operations, and failing to inspect the tank prior to a water test are all examples of known human errors in these accidents.

Fig. 5 Causes of accidents in the three phases

Maintenance Failure

Preventive maintenance lowers accident rates and improves equipment safety. Leakage from the input line to the converter occurred in the Khark Petrochemical accident as a result of improper gasket connections. Poorly tightened bolts

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and joints, poor welding, delayed repairs, failure to detect flaws, insufficient training, inexperience, poor inspection, lack of isolation during maintenance, disregard for work instructions, incorrect valve position following maintenance, mistakes made during maintenance, and wear of valve threads are some of the factors that can cause a maintenance program to fail.

Inspection and Corrosion Protection Failure

Metal surface cracking, subsurface cracking, internal and external corrosion, and a general or local decrease in metal thickness should all be monitored using the inspection unit's continuous thickness readings. Failure to monitor corrosion on external joints and foundations, internal corrosion monitoring, corrosion monitoring under insulation, longitudinal and peripheral welds, improper work instructions, noncompliance with instructions, and visual inspection revealing inadequate calibration of monitoring equipment and training are all examples of failure factors for this barrier.

Natural and Security Hazards

Even while process hazards are a major contributor to accidents in the process industry, other hazards like natural disasters and terrorist attacks also have a significant impact. The truck was able to collide with the pipeline in the Albert City disaster because there was no fence or other physical barrier protecting the propane tank and piping system. Five BLEVE were caused by the Tokhuho earthquake in Japan, which also destroyed 17 tanks of the Cosmo oil refinery. Because of the vast region they cover and the severity of the incidents, these dangers inflict significantly more harm to industry. Some of the causes of the mishaps are the lack of a foundation reinforcement program, the site's insufficient security system, the lack of an emergency response strategy, and the failure to contain the reservoirs to prevent them from drifting during floods.

Causes of Liquefied Petroleum Gas Storage Tank Explosions and Accidents

Because of their fragility and susceptibility to damage from overpressure, storage tanks are the piece of equipment in the chemical process industry that is most likely to be involved in accidents, according to Tauseef, Abbasi, Pompapathi, and Abbasi (2018). Approximately 97% of storage tank failures include flammable chemicals, which may be caused by equipment malfunctions like valve jamming, operational mistakes that result in overfilling, tank ruptures and cracks, or adjacent pipelines that inadvertently release flammable liquids. Such leaks could cause flash, jet flames, or vapor cloud explosions (VCEs) if they are not stopped and managed right away. These events could trigger additional fires or explosions, making the first disaster even more severe. Chang and Lin (2006) reviewed 242 storage tank mishaps and found that 74% of disasters were in refineries, terminals, or storage facilities. The most common causes of these incidents were chemical spills and poisonous gas/liquid escapes, which primarily resulted in fire and explosions. Additionally, they believed that lightning and human mistake, such as inadequate management and maintenance, were the primary causes of storage tank disasters (Figure 6). Additional causes included open fires, leaks, sabotage, cracks and ruptures, equipment failures, and static electricity.

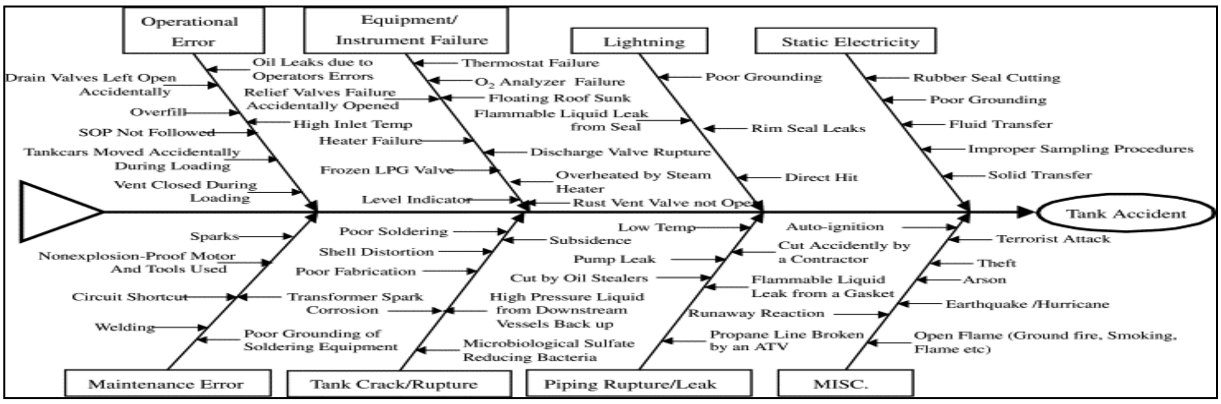

Figure 6: Causes of LPG Leakage and explosion

Source: Chang & Lin, (2006)

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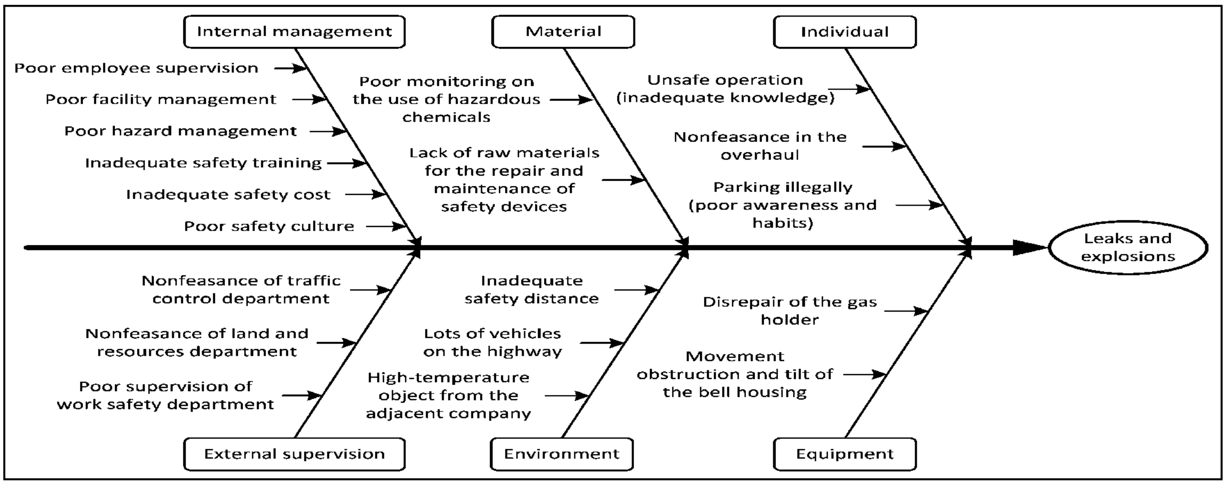


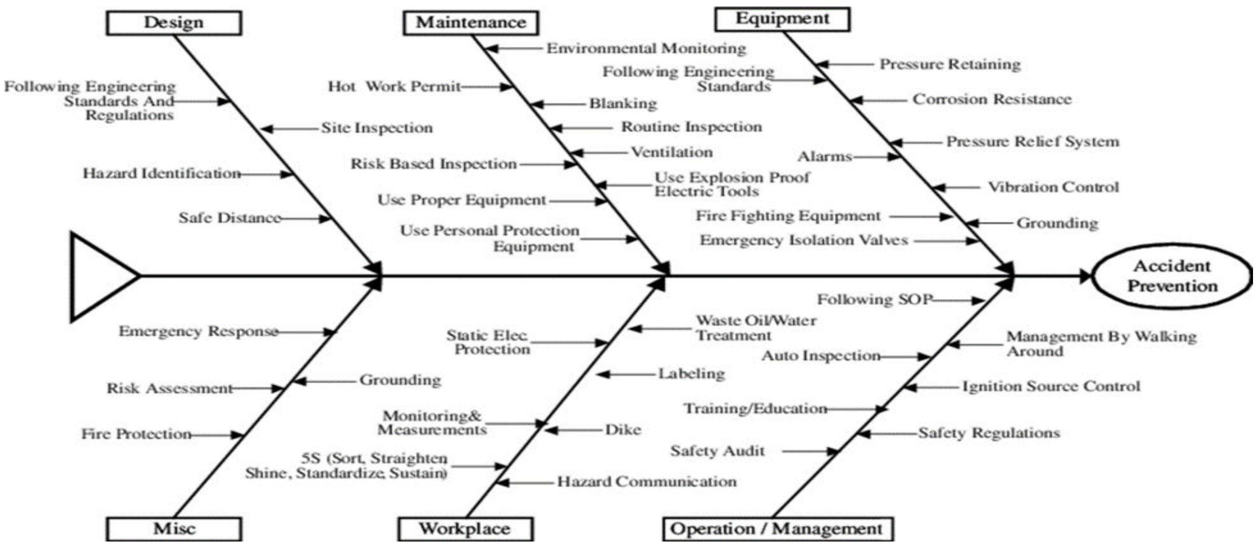
Figure 7: Causes of LPG Leakage.

Source: Wang et al. (2020)

Wang et al. (2020) (Figure 7) based their conclusion on the causes of leaks and explosions on inadequate internal management, material, individual, external supervision, environment, and equipment in order to further reinforce the human error component of Chang & Lin's causes of accidents.

Management

Political and institutional measures must be put in place to limit exposure, improve recovery readiness, and develop resilience in order to manage LPG risk, minimize loss of life and livelihood, and stop future dangers. In order to ensure readiness and workplace safety, the management measures of chemical risks, particularly LPG, might be implemented from the design phase, regular maintenance and monitoring, making sure equipment is in excellent condition, and developing and following operational and management processes (figure 8).



To put it another way, making investments in chemical safety resilience should be a key component of every stage of the development of a hazardous plant, from site selection and planning to design and building, operation and maintenance, and decommissioning, closure, and demolition. This implies that preventing and responding to chemical accidents should be a component of good chemical management in order to protect the environment, prevent harm, save lives, and preserve the viability of emerging economies as well as the financial stability of the involved businesses. Cooperation among a variety of stakeholders, including response teams, medical professionals, the commercial sector, and public and media representatives, is necessary to improve emergency preparedness. On-site planning for chemical accidents is primarily the duty of industry, while off-site planning is primarily the responsibility of public authorities.

The more hazardous materials are produced, stored, and used, the higher the chance of serious industrial mishaps. Workers, communities, towns, enterprises, and the environment are severely harmed by major accidents as well as smaller, frequent chemical incidents. Therefore, it is necessary to control dangerous compounds in a methodical manner. Strengthening the governance structure is essential to this strategy, and this could be accomplished by creating a national program for chemical accidents that is tailored to the unique needs of the nation. In order to reduce the frequency and severity of chemical and industrial accidents, as well as to ensure sustainable business performance, effective governance on process safety is crucial. When it comes to the location of hazardous industrial operations, their modifications, and the planning of land use around existing sites—for instance, for homes, schools, hospitals, and other public services—as well as the development of infrastructure, good governance is especially crucial. This is regarded as management commitment in the majority of industries, particularly private ones. This dedication should transcend the private arena to the public domain in effective governance frameworks, as the commitment of the management in most private enterprises have resulted in a more efficient and effective safety culture hence decreasing loss to lives, properties and livelihoods.

Finally, efficient emergency preparedness needs coordination among multiple stakeholders including, response professionals, health personnel, the private sector and representatives of the public and the media. Industry is primarily responsible for on-site planning for chemical accidents, while public authorities are primarily responsible for off-site planning, which may include conducting preparedness exercises and simulations, reviewing and updating plans on a regular basis, and incorporating lessons learned from previous accidents and emergencies. Increased cooperation between public, business, and governmental players is also crucial, as preparedness initiatives can be financed by a range of national governments and civil society groups.

II. CONCLUSION

The review considered "Liquefied Petroleum Gas Station Disasters: Causes, Effects, and Management".This paper explores the causes, effects, and management strategies of LPG-related disasters. The causes of such disasters are often linked to mishandling, leakage, improper storage, and inadequate safety protocols during transportation and installation. The effects can range from minor injuries to catastrophic explosions resulting in loss of life, environmental damage, and economic costs. Effective management of LPG-related hazards involves the implementation of robust safety regulations, regular inspections, proper training for users, and emergency response preparedness. The paper concludes by emphasizing the need for increased awareness, technological advancements, and governmental oversight to prevent LPG disasters and minimize their impact on society and the environment.

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