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Study and Analysis of Storage Tank Hazards and its Mitigation Measures Using Bow Tie Diagram

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ABSTRACT

Petroleum and petrochemical industry may lead to hazard condition by means of fire, explosion, explosive chemical noise, electrical shock and etc. which result in health, environment and economic loss. These hazards can be a result of the presence of cleaning chemicals, hazardous gases, improper or insufficient lockout-tag out, vapors, fumes, dusts, or excessive heat or cold. Atmospheric storage tank fire very common in industrial facilities. In this work various accidents of storage tanks that taken place in Industrial facilities in Asia over last 40 years. Bowtie Diagram is applied to depict causes and factors responsible which led to various types of storage tank fires. Prevention and mitigation measures are also provided to help operating engineers handling similar types of situations in the future. The results show that 70% of accidents occurred in oil terminals or storage, petroleum refineries and Fire and explosion account for 90% of the accidents. There were accidents caused by lightning, by human errors, including poor operations and maintenance. Other causes were equipment failure, static electricity, sabotage, crack and rupture, leak and line rupture, open flames, etc. Most of these accidents would have been avoided if proper safety management programs, good engineering practices implemented.

INTRODUCTION

Flammable and combustible liquid storage tanks are found in refineries, petrochemical plants, bulk storage of petroleum products and marine terminals. Airports, local fuel companies, power plants and large manufacturing facilities such as automobiles and steel plants may also have bulk storage of flammable and combustible liquids [1].

Storage tanks store flammable and combustible liquids in various ways, depending on the facilities. These tanks can vary from 5 meters to 150 meters in diameter and can have an average height of 15 meters. These flammable liquids such as heavy oil, petrol, diesel, kerosene, ATF, etc. are stored in tanks at atmospheric temperature or under low pressure of 0.5 bar [2]. If they found sufficient amount of energy, they may get ignite and can lead to fire or explosion. If an explosion occurs it may have a devastating effect with waves or overpressure created during explosion, which affects nearby tank also and can be a catastrophic situation. Such tanks can store huge volume of crude and other petroleum products of flammable and combustible liquids. Larger industrial facilities may own more than 300 Tanks of varying sizes which contain various products. These tanks may be placed very near to each other and have serval other thanks within a common dyke.

The storage tank is covered by the peripheral boundary called dykes which acts as barriers to prevent the spilled liquid due to overflow or structural failure of the tank. Every tank is separated and segregated according to their classification. They are usually made of compacted dirt or concrete similar type materials. The dyke of height is considered 2 m. It can be extended on the special recommendation to prevent overflow of flammable liquids. Dykes are made consideration of the total capacity of the tank and additional certain percentage above this as a safety margin. If there is more than one tank in one dyke, the dyke capacity should be at least the volume of the largest tank in consideration a safety margin [3].

THE TYPES OF TANKS

- Fixed roof tanks

- Internal floating roof
- Open top floating roof tanks

FIXED ROOF TANKS

Tanks with fixed roofs include cone roof tanks, dome roof tanks, and column supported roof tanks, all of which are of either welded, riveted (other types), or bolted (other types) construction. Fixed roof tanks are typically used to store a range of refined products, from volatile materials to heavy fuel oils.

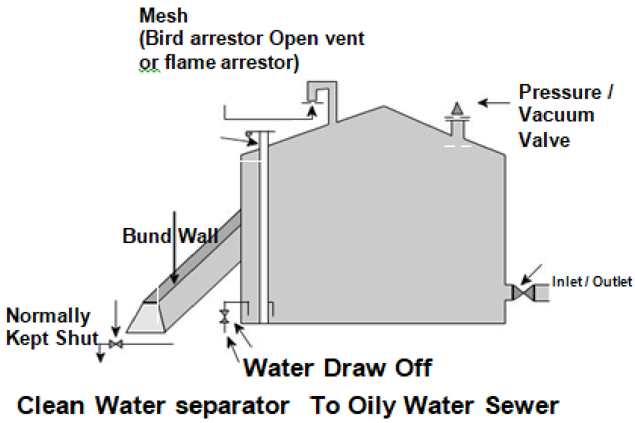

Figure 1. Fixed roof tank.

Fixed roof tanks are welded to the curb at the top of the shell and covered from top section and shell is formed in such a way that the forces are resisting downwards, such as dome roof and conical shape **(Figure 1)**. The tanks have one or more structural section called wind girders which are placed around the tank from the top for resisting bulking and wind loads. The minimum thickness of the roof plating is 5 mm on the new tank. The minimum thickness of the roof plating is 5 mm of a new tank. To support the roof plating in tanks up to about 30 meters diameter [4].

Roof trusses often extend downwards below the curb and therefore may lead to a reduction in storage capacity if, at a later stage. The fixed roof tank is made to hold an internal floating roof cover. The roof plating is attached to the curb, by welding, and if specified the weld may be minimal to make the joint frangible as a protection against accidental overpressure.

All fixed roof should be vented by open vents or through pressure/vacuum valves. For liquids to get in, air and vapor must be pushed out. The pressure in the tank must be slightly above atmospheric.

For a liquid to get out, air and vapor must be sucked in for this the pressure in the tank must be slightly below atmospheric **(Figure 2)**.

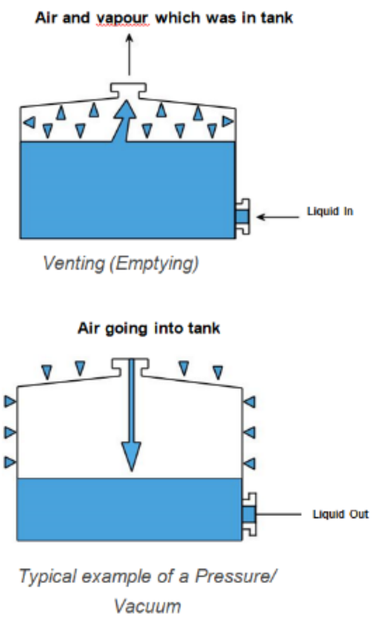

Figure 2. Dome roof tanks.

Dome roof tanks are similar to internal floating roof tanks are designed as a cover over the external floating roof tank. The main purpose of dome rook is to provide protection from fugitive emission to the environment.

INTERNAL FLOATING ROOF TANK

Internal floating roof tank consists of a permanently fixed roof with a floating roof inside the tank. The internal roof floats on pontoons or has a double deck for floatation over the liquid surface **(Figure 3).** These tanks will generally be found in service conditions where high volatility (Low Flash Point) or toxic liquids are stored. In a fixed roof tank without a floating cover, the liquid surface is in direct contact with the airspace above it.

The presence of an internal floating cover reduces these vapor losses by at least 95%, a very important feature where high cost, toxic or flammable materials are concerned. The tank will normally be fitted with open vents around the fixed roof (as Specified in BS 2654 and API 650), but PV vents are often used in practice.

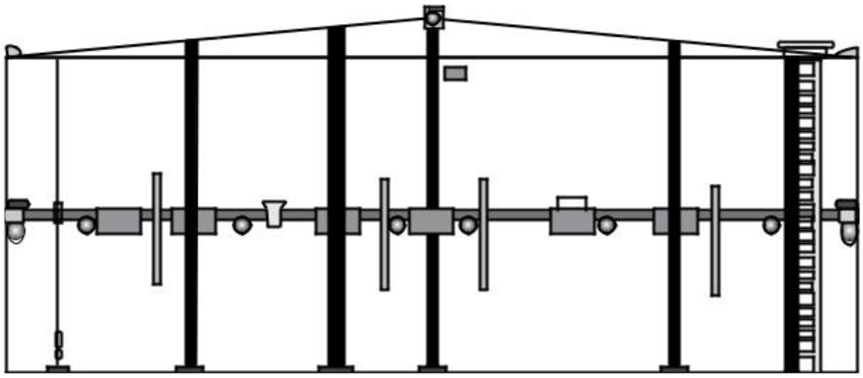

Figure 3. Internal floating roof tank.

EXTERNAL FLOATING ROOF TANK

External floating roof tank consists of a roof which floats on the surface of the liquid, but the roof is exposed to the atmosphere. The roof goes up and down with the change in liquid level. The external floating roof consists of rim seal which prevents the vapors from escaping. Typically, such tanks are used for the storage of crude oil and all volatile (low flash point) products. Crude oil tends to be self-protective where the open tank shell is concerned, while white oils lack this property and the exposed shells become roughened by exposure to the weather **(Figure 4)**.

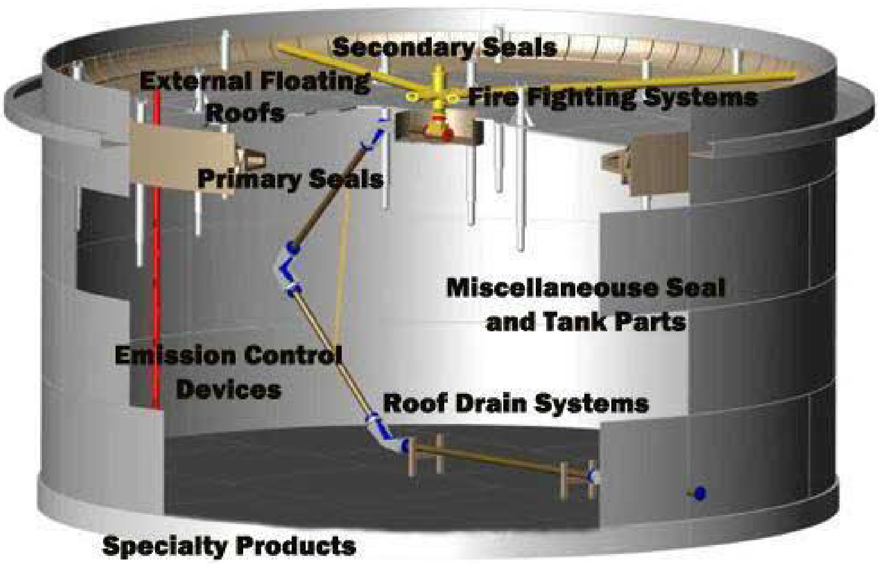

Figure 4. External floating roof tank.

CAUSES OF ACCIDENTS

Lightning

Lightning is one of the most common sources of ignition that may lead to a fire on atmospheric floating roof tanks. In a survey

95% of fire events taken place with the lightning-ignited rim seal fires [5]. It is not necessary that lightning should directly strike on a tank for ignition to occur, a strike in the immediate nearby can generate that certain amount of static charge between the tank shell and floating roof tank that may lead to a fire. The Recent fire which took place on Diesel tank, due to thunder stormed noticed on Butcher Island off Mumbai in Oct 2017 since no fatality was noticed but it took four hours for fuel to completely burn off. This incident costs a nearly financial loss of at least 60-70 crore. Another fire which took place on crude oil tank at HPCL in July 2017 due to the lightning strike at Vishakhapatnam [6].

Maintenance Error

Welding, Grinding during maintenance work is responsible for some catastrophic failures of storage tank vapor explode. Electric sparks and shocks can ignite flammable liquids or vapors lead to fire or explosion also. An incident caused at Lanjou, china refinery due to electric shock generated from electric motors and an incident in 1984 at Kaohsiung, Taiwan has resulted in the same cause [7]. A chemical plant at Chaiyi, an accident caused by sparks generated from the electric soldering machine. To minimize electric hazards, each section, rooms, and areas must be taken into account in determining its classification defined in NFPA 70, National Electrical Code, Article 500, and Hazards (Classified) Locations [8].

Operational Error

Overfilling of tanks is about the frequent cause of this category. Products came out releasing large volumes of vapors into the atmosphere and finding some ignition source lead to fire or explosion. If the tank is filled with flammable liquid and if it overfills, fire or explosion is almost non avoidable. In 2001, Wuyi, Zhejiang, China, 50 Kg of Benzene leaked due to overfilling of tank leads to 46 Children and 2 villagers hospitalized [9].

Eight out of Ten accidents take place in leakage due to Operational Error. In 2009, Jaipur fire at Indian Oil Corporation, Terminal, is caused due non availability of Standard procedure and Absence of Leakage stop device from a remote location i.e., remote operated valve [10].

Sabotage

Sabotage is the fourth cause which can have an impact on any incident on the storage tank. Any terrorist activity or theft operation can lead to major emergencies. The Serval tank farm was put on fire during the Iraqi occupation of Kuwait in 1991. Few burnt tanks were fought for Extinguishment; the rest was left for complete burnout due to the war situation [11].

Equipment Failure

An external floating roof tank of the tank consists of roof drain, breather Valve, and emergency roof drain. There were cases where roof drain found chocked and water gets accumulated on the surface of roof resulting in rook sunken case. Sometimes the excess pressure develops inside the, to relive breather valve is provided; it is found that valve failure leads to buckling of the tank. There is a seal, which is provided on the perimeter of the tank which slides up and down with the tank roof and protects the vapor from escaping out. Failure of seal or material integrity loss leads to Serval incidents of vapor escape [12].

Static Electricity

Taking samples of storage tanks containing flammable liquids in open area results in static electricity. An accident in Japan in 1992 used metal devices or container for taking sample connected with conductive threads [9]. To minimize the hazard, avoid taking a sample in open access. If the open access sample is unavoidable, better use nonconductive materials sampling gauges. Avoid using any device made of metal. The maximum static charge is developed during transferring of material. Bonding of containers should be done to make potential equal.

Leak and Line Rupture

The incident took place in 1977, there is LPG leaked at Vishakhapatnam for without detected for Serval hours and after tanker ship pumped at the shore of Vishakhapatnam, resulting in a thick blanket of smokes which overwhelming the entire port city resulting in 37 deaths and 100 injuries [13].

Open Flames

Open Flames resulting from cigarette smoking, ground fires, and hot particles also ignite flammable vapors around storage tanks.

Natural Disasters

Due to Impact of seismic motions in earthquake phenomenon on the structure of storage tank leads to cracking of its structure which leads to leakage of flammable liquid due to a disturbance in equilibrium. As Asia comes in an earthquake-prone area, there is always a fear of some catastrophic failure of a tank. Fortunately, there are only a few cases which result from an earthquake. The fire involved in Japan Refinery in 1964 in Niigata, resulted from sparks ignited hydrocarbon vapors released due to an earthquake [14].

Runaway Reactions

Runaway reaction may take place when impurities mixed with material stored in tanks resulting in an exothermic reaction. One of biggest disaster that took place in India, Bhopal gas Tragedy, 1984, caused due to water got mixed with methyl isocyanate stored in underground storage tank releasing huge volume of toxic gas killing hundreds of people [15].

TYPES OF INCIDENT SCENARIOS

Boil Over

Boil over is a phenomenon which occurs in storage tank fire consist of heavy hydrocarbon or a blend of hydrocarbon liquids e.g. Crude is released in explosive form when burning oil comes in contact with water, which settled at bottom of the tank. The heat is dissipated downwards and converts water into steam which expands 1500 times and carries burning crude with it. A boil over in tank covers an area of approximately 10D of the tank in downwind direction and 5D of the tank in crosswind directions [16].

Slopover

Slopover is a phenomenon which occurs when water is applied to full surface fire tank and the water gets accumulated downwards results in overfill of product from the tank.

Vent Fire

Vent fire takes place in the fixed roof tank when one or more of vents get ignited due to vapor flammable vapor released. The presence of flammable vapors has been always there either due to tank filling operation or tank's daily breathing cycle. More of vent fire found due to lightning strikes or found some ignition source nearby.

Full Surface Fire (Fixed Roof Tank)

A full surface of the fixed roof can occur due to vent fire escalation. A vapor cloud explosion can occur is flammable vapor is found within flammable range during the flame flashback, mainly if flame arrestors/PV is not in working condition. If a tank is constructed as per API 650, it should separate from weal seam. Depending on the vapor space explosion force, the roof may remove partially ("Fish's mouth" opening) or fully removed.

Full Surface Fire (Open Floating Roof Tank)

Full surface fire is one where the tank roof has lost its buoyancy and some or the entire liquid surface has been exposed and involved in fire.

Rim Seal Fire

A rim seal fire takes place where the seal between the tank shell and roof has lost its integrity and released vapors exposed to an ignition source and involved in fire.

Bund Fire

A fire in the band is a type that occurs outside the tank shell within the containment area. These types of fire involved small spillage fill up to fire covering whole bund area.

METHODOLOGY

The major tank accidents that had been occurring in Asia in last few decades have been reviewed in this paperwork. The data are collected from various published reports. It has been found the major accidents have taken place in Oil & Gas sector as compared to a petrochemical plant, storage terminals and other facilities like gas plants, power plants, and fertilizer industry. This work explains with the help of a Bow Tie diagram **(Figure 5)** using BowTie XP Software for different causes of events that is explained above which was responsible for incidents happened that lead to the different fire scenarios as worse case which can be prevented if proper mitigation measures have been taken into account or proper SOPs and SMPs is followed Various Preventive barriers have been taken into account with different threats and proactive/recovery barriers or mitigation measures with consequences with escalation factors for both threats and consequences.

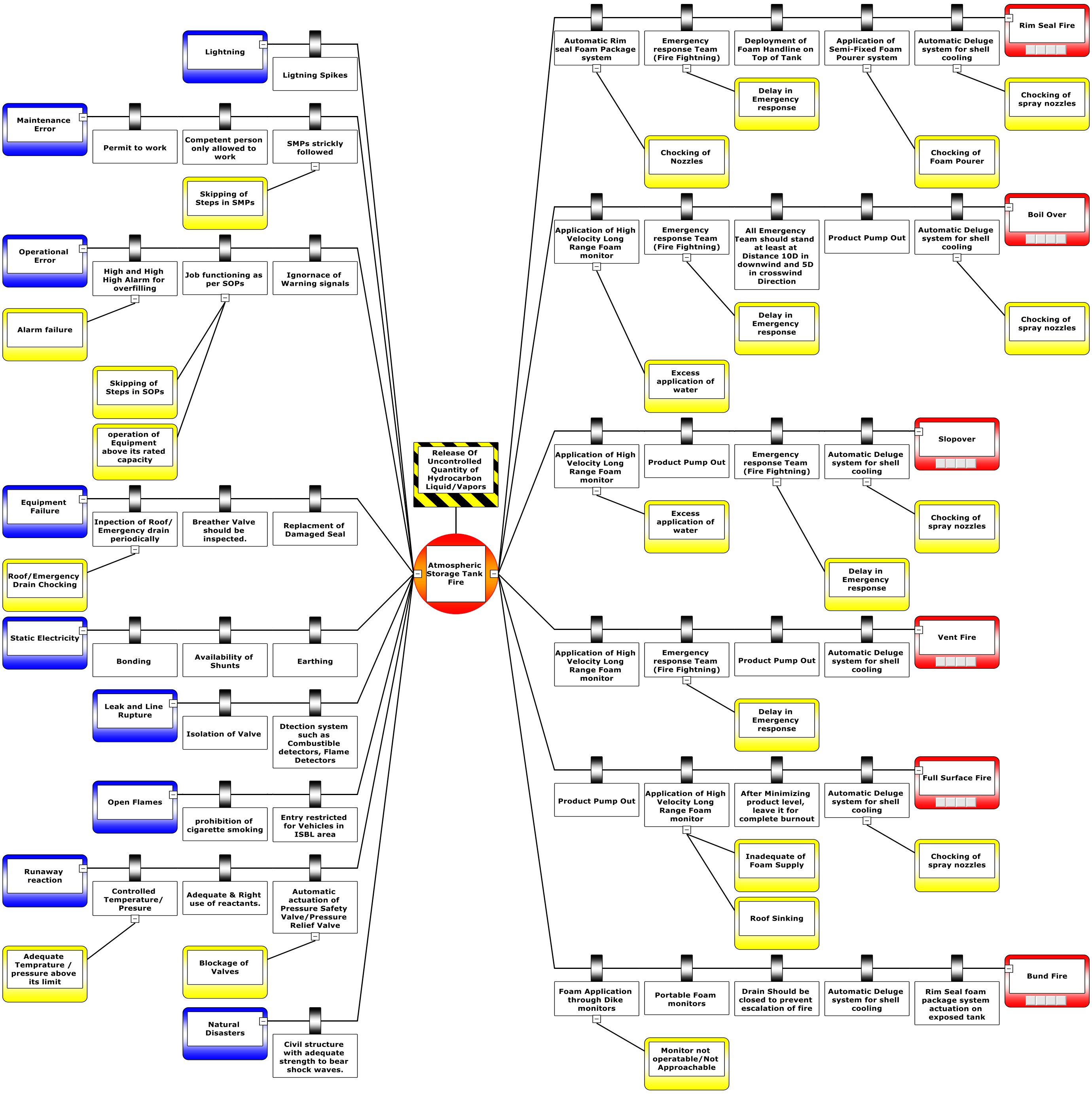

Figure 5. Bowtie diagram.

RESULTS AND DISCUSSION

This section covers Causes and consequences of storage tank hazards with their mitigation measures. Various preventive barriers which related to the particular threat through bow tie diagram has been identified and expressed which also includes its escalation factors that have acted as an additive to hazards. After identifying all types of threats such as equipment failure, lightning, operational factors, etc., the consequence has been described with their mitigation measures such Automatic deluge system, Portable foam monitors application, Product pump out etc. which have decreased the effect of consequence that has taken place.

As there is mitigation measure which act as proactive /recovery barriers also have an escalation factor of consequence that have put a stop or act as a hurdle in extinguishment or reducing the consequence, such as inadequate supply of foam which is a hurdle for application of foam monitors or chocking of nozzle for automatic deluge system etc. It has been found that if proper maintenance of these equipment's, better and efficient equipment is used this can prevent the escalation factors for consequences.

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CONCLUSION

In this paperwork accident taken place in industrial facilities on various tanks has been reviewed. The Cause and factor responsible that led to catastrophic consequences were expressed with the help of a Bowtie diagram in a systematic way. Most of the accidents would have avoided if maintenance and operation, good engineering in design, construction has been practiced and proper safety management programs, SOPs, SMPs implemented and executed.

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