Muhammad. N. Idris

Safety Evaluation of Petroleum Tank Farm: An Analytical Study of NNPCL Maiduguri Depot Plant

Process Refining Technology and Sustainable Energy Development Group, Department of Chemical Engineering, University of Maiduguri, Nigeria.

The link to this publication is **https://ajoeer.org.ng/otn/ajoeer/2022/se-09/02.pdf**

ISSN: 2635-2974

Safety Evaluation of Petroleum Tank Farm: An Analytical Study of NNPCL Maiduguri Depot Plant

Muhammad. N. Idris[1]*, Abdul. A. Gajere[1] and Neeka. J. Biragbara[2]

[1]Process Refining Technology and Sustainable Energy Development Group, Department of Chemical Engineering, University of Maiduguri, Nigeria.

[2]Research and Innovative Administration, Petroleum Technology Development Fund (PTDF), Abuja, Nigeria.

*Corresponding Author: *idrismn@hotmail.com,*

neeka.jacob@yahoo.co.uk

ABSTRACT

A petroleum tank farm, usually known as an oil terminal is a common facility that stores flammable liquid. Tank farm has possible hazards to the people, environment and asset. Some of the hazards such as fire, static electricity, transportation etc. are accidents which occur at the oil terminals. Many industries are using different risk assessment methods to priorities hazards linked to their work activities. In this study, a new risk and safety analysis model, known as quantitative risk assessment (QRA) for tank farm was applied. QRA is an effective planning tool used in chemical processing plant, to help at forecasting the potential major accident occurrences, so that suitable mitigating and preventive measures can be implemented. QRA was conducted on a selected NNPCL Maiduguri depot tank farm with specified objectives. The three main objectives for this study are hazard identification, risk evaluation using qualitative and quantitative risk assessment by using the hazard and operability analysis, HAZOP and failure mode effect analysis (FMEA) methods. It was found that hazard occurrences were from various categories namely general management, hazardous chemical exposure and fire safety etc. In this research work, two scenarios was established and the estimated risks are associated to the petroleum tank farm activity such as leakage at dispenser area due to poor safeguarding systems, underground fuel leakage during unloading due to fittings failure and storage tank explosion due to high pressure. However, in summary, complete planning which combines all aspects are deemed necessary so that the impact of the associated risk from the operational, storage and maintenance of petroleum tank farm can be identified and minimized during the activities by working out the FMEA method sheet.

Keywords: Leakage, hazard, hazard risk and unload

1.0 INTRODUCTION

Petroleum and chemical products are primary resources in our life and considered as one of the most important basic building blocks for sustainable development. The growing demand of hazardous chemicals has brought a significant increase in risk to human and its environment. Hazardous chemicals have intrinsic hazards for the environment, which may damage the human and properties around the accident. Occupational and safety health administration (OSHA) has defined a hazardous chemical as any chemical, which has a physical hazard such as (fire and explosion) or a health hazard such as (acute or chronic effects). The results of a historical analysis have shown that 17% of major accidents in the chemical industries were during storage processes. According to the national fire protection agency (NFPA) report in 2009, 13% of the fire accidents that occurred in the USA took place in storage farms, causing death or injury for workers, tens million dollars as losses and cause huge environmental pollution. Many catastrophic accidents happened in the history such as Bhopal disaster in 1984, which caused thousands of fatalities and tens of thousands of people were injured. The possible hazards are a function of both the inherent nature and the involved quantity of the chemical**.** Therefore, it is important to conduct a profound and adequate hazard analysis of the oil storage facility to figure out the potential scenarios having damage to life and property as well as provides a clear picture for the decision makers to be satisfied with the safety levels in the storage tank farm. Hazard analysis is an important process and has a vital role in studies related to hazardous chemicals handling. Hazard identification (HAZID) is the initial step in any hazard analysis process and includes the identification of all possible accidents in the facility. The most used technique in HAZID is HAZOP stud. HAZOP is a systematic review of the design and operation of the system to predict the possible accidental leaks of hazardous material Dantsoho, A. M. (2015), (Candreva et al., 2015). The analytical tools that can be used to defined hazards are the FTA and ETA. The FTA is a systematic and deductive approach that focuses on hazardous outcomes (top event) and develops further to the basic causes (bottom event) that lead to such unwanted outcomes, while the FTA is used widely in hazard analysis of the various storage facilities. ETA is a graphical and inductive tool that presents all the final consequences resulting from a particular initiating event, with considering the states (failure/success) of the installed safety barriers. The accidents frequencies can be estimated by ETA if the data about initiating and heading events are known. Otherwise, it can be derived from databases such as OGP or HSE. The focus on this research is to evaluate the safety of petroleum tank farm of NNPCL Maiduguri Depot Plant.

2.0 BACKGROUND LITERATURES

Rapid development of petroleum and chemical industries has attracted the use of large-scale atmospheric storage tanks Ibrahim and Sayed (2018), (Kong et al., 2018) (Fanelli, (2012); Argyropoulos *et al.*, 2012). Safety of tank farms is very important, especially now that the number of tank farms sited in port environment is increasing drastically. Tank farms are important storage facilities that can be used to store petroleum products and other hazardous chemicals in ports environment. These large scale tanks filled with highly flammable liquid have high potential risk and once there is leakage, the consequences are serious environmental pollution, fire and casualties etc. (Fanelli, (2012). Therefore, safety management of tank farms needs urgent attention, in order to prevent catastrophic accidents. The summary of literature studies were presented in Table 1.

Table 1 Summarised version of reviewed investigations

Author(s)	Investigation and Tank farm capacity	Research Benefits/Product storage	Remarks
Goethals *et al.*, 2008	Tank farm operations were associated with high risk due to its content. The volume of a tank farm is over 100,000m^3.	The tank farm can store crude oil, oil products, gasoline/naphtha, petrochemicals, Liquefied Petroleum Gas (LPG), waste oil water, NH_3, HCl acid, NaOH, molten sulfur etc.	The hazardous nature/quality of the cargo that the tank farm stores posed to be a treat to the system operational efficiency.
Fanelli, (2012)	Large scale tanks filled with highly flammable liquid have high potential risk and once there is leakage, the consequences are serious environmental pollution, fire and casualties.	Identifies measure to prevent leakages and improve on safety standard.	The safety management of tank farms need urgent attention, in order to prevent catastrophic accidents.
Argyropoulos *et al.*, 2012	The roof has the ability to rise and fall on the stored-fuel surface, in order to prevent the large volumes emittance of fuel-vapours.	The tank can be used for storage of fuel-oils, asphalt, vacuum or atmospheric residue. Therefore, the use of insulation, steam or coil heating in these types of tanks is necessary for keeping its content in a liquid state.	The tank can also be used to store other products like jet fuel, diesel and gasoline. And can prevent the dissemination of the oil leakage to the surrounding.
Jian et al., 2022	An Integrated framework of safety performance evaluation for oil and gas production plants: Application to a petroleum transportation station.	High integral framework to identify measures to prevent leakages and improve on safety standard.	Advanced safety management of tank farms need urgent attention, in order to prevent hazards and catastrophic accidents.

The two examples of tank farm roofing methods are cited as follows:

a) Fixed roof tanks with internal floating roof. This type of storage tank is a combination of cone roof tank and open top floating roof tank as illustrated in Figure 1 (Argyropoulos *et al.*, 2012).

b) Open top floating roof tank (simple pontoon or double deck). It is also designed in line with API standard and is made up of a vertical, cylindrical above ground shell similar to the conical roof tank, but with a pontoon type roof as shown in Figure 2 (Argyropoulos *et al.*, 2012).

Figure 1: Fixed roof tank **Figure 2:** Floating roof tank

The depicted picture presented in Figures 1 and 2 are sourced from (Argyropoulos et al., 2012).

3.0 MATERIALS AND METHODS

3.1 Materials: Process data from the NNPCL Maiduguri depot was collected**,** discussion with the field engineers and summary of questioner comments from the operator were obtained.

3.2 Methodology: two methods were used as risk assessment tools to evaluate the various potential hazards in petroleum tank farm. They are:

a) HAZOP (Hazards and Operability Study) for temperature and level parameters are respectively detailed in Tables 2 and 3.
b) FMEA (Failure Mode Effect Analysis)

Table 2: HAZOP (Parameter: *Temperature*)

Guide words	Deviations	Potential cause	Potential consequences	Existing safeguard/ control	Recommendation
MORE	More/ high temperature inside the storage tank	Failure of automatic temperature control system, Poor ventilation.	Possible explosion due to rising in temperature.	No existing safeguards provided by the unit yet	Temperature level indicator to be installed

		Thermal expansion of product in the storage tank due to strong sunlight or fire.			

Table 3: HAZOP (Parameter: *Level*)

Guide words	**Deviation**	**Potential Cause**	**Potential consequences**	**Existing safeguard/ control**	**Recommendation**
MORE	More level in the storage tank	1. Expansion of oil in case of exposure to higher temperature 2. The level indicator is not functioning 3. Opening of a wrong valve	There will be a high possibility of crude oil leakage to the atmosphere, which may initiate fire if there is any ignition source	Level indicator	1.Top of the tank should be attend to 2. Make sure level indicators with alarms are working properly.
LESS	Low level in the tank	Weak joint between the roof and the tank shell. Cracking or corrosion of tank Rapture of tank due to integrity loss	May heat nearby tanks and can cause possible burns to workers due to exposure to heat radiation	High level interlock	Tank should be vented to safer location

FMEA - Failure mode and effects analysis is a powerful tool for identifying and assessing potential failures, (Cicek, 2010), (Argyropoulos et al., 2012) and actions needed in eliminating the cause of error (Candreva et al., 2015). FMEA procedure commences with reviewing design details, illustrating equipment block diagram and recognizing overall potential failures, respectively. Following the recognition of all possible causes and effects should be classified to the related failure modes. After this practice, priority of failures due to their disaster effects should be ranked by a Risk Priority Number (RPN), which is the multiplication of severity of failures (S), their portability of occurrence (O), and the possibility of detection (D). RPN is the Priority potential level of failure, which shows the higher RPN value then the higher risk received. Value of S, O and D obtained through discussion process with the chief engineer, engine crew and port engineer where they have more than ten years' experiences working on board. Furthermore, The Value of S, O and D calculate obtained in the worksheet using calculation as below:

$$RPN = S \times O \times D \quad (1)$$

Where:

RPN = Risk Priority Number
S = Severity
O = Occurrence
D = Detectability

Here, FMEA will be carried out on some of the major components relating to the storage tank unit.

3.3 Data Classification and Analysis

Table 4: Show the severity criteria of failure of hazardous level

Severity	Criteria	Ranking
Dangerously high	The failure effect is hazardous for customer/user safety	10
Extremely high	The same as above only with warning	9
Very high	The product is not operative High	8
High	High degradation of product and customer dissatisfaction	7
Moderate	Partial malfunction of the product and customer dissatisfaction	6
Low	The product could be reworked and some customer dissatisfaction	5
Very low	The failure could be noticed by many customers	4
Minor	The failure could be noticed by few customers	3
Very minor	The failure is not apparent to the customer	2
None	No Effect	1

Table 4 identifies the serenity criteria of failure of hazardous level. The ranking is high at 10 grades when the tank is highly dangerous, while at 0 grades it is absolutely have no effect (zero-danger). The zero-grades are the best practice in engineering.

Table 5: Shows the occurrence ranking criteria

Occurrence	Description	Frequency	Ranking
Very High	Failure is almost inevitable	1 in 2	10
		1 in 3	9
High	Repeated failure	1 in 8	8
		1 in 20	7
Moderate	Occasional failure	1 in 80	6

		1 in 400	5
		1 in 2.000	4
Low	Relatively few failures	1 in 15.000	3
		1 in 150.000	2
Remote	Failure in unlikely	1 in 1.500.000	1

Table 5 depicts the occurrence ranking criteria: very high at low frequency at 10-grades, while it is remote where failure is very unlikely, at high frequency at 1-grades ranking.

Table 6: Shows the detectable ranking criteria

Detectability	Criteria	Ranking
Absolute Uncertainty	Impossible to detect the failure	10
Very remote	Very difficult to detect the failure	9
Remote	Difficult to detect the failure	8
Very low	Very low chance to detect failure	7
Low	Lob chance to detect failure	6
Moderate	Moderate chance to detect failure	5
Moderate High	Moderately High chance to detect failure	4
High	Probably the current Control Will detect the failure	3
Very High	High probably the current Control Will detect the failure	2
Almost certain	Surely the current Control Will detect the failure	1

Table 6 shows the detectable ranking criteria where the detectability at 10-grades is high and low at 1-grades. The unit is attached to some components like the storage tank itself, high pressure fuel pump, and transfer pump and so on. Of which when they are not properly controlled, they will not function properly. Therefore a careful attention must be given to the study of these components to study their failures, causes and a careful control recommendations to be given in order to avoid malfunctioning which may likely lead to accidents. Table 7 shows the FMEA worksheet addressing the failure modes, detections and RPN etc.

Table 7: Shows the FMEA worksheet

Item	Function	Failure mode	Effect	Severity (S)	Cause	Occurrence (O)	Detection	D	RPN
Fuel storage Tank	fuel storage	external leakage	fire, explode, environmental pollution	10	corrosion	1	visual, fuel leakage	7	70

Transfer Pump	fuel transfer	fail operation	engine stop, flat out	6	drive fail to run	4	detected, alarm	2	90
fuel supply pump	Flowing the fuel to tanks	external leakage	Seems dirty	3	weak of seal	3	visual, fuel leakage	7	63
fuel filter double stage (primary)	Separate oil with high sediment dirty	Filter blocked	Less perform, stopped Working	4	fuel dirty	9	visual, open the fuel filter	7	252
fuel filter double stage (secondary)	Separate oil with fine dirt	Filter blocked	Less perform, stopped Working	4	fuel dirty	9	visual, open the fuel filter	**7**	252

4.0 RESULTS AND DISCUSSIONS

4.1 Results

Table 8: Show some selected product tanks, storage capacity and roofing type

Tank number	Products	Tank capacity (m^3)	Tank type
203	Premium Motor Spirit	5587	Floating tank
204	Premium Motor Spirit	5587	Floating tank
205	Premium Motor Spirit	9775	Floating tank
206	Premium Motor Spirit	9775	Floating tank
201	Dual Purpose Kerosene	9800	Floating tank
202	Dual Purpose Kerosene	5587	Floating tank
101	Automotive Gas Oil	8160	Fixed tank
102	Automotive Gas Oil	9530	Fixed tank
103	SLOP	155	Fixed tank
104	SLOP	155	Fixed tank
105	SLOP	155	Fixed tank
106	SLOP	155	Fixed tank

Table 8 is the results carried out on some selected product tanks, storage capacity and roofing types.

4.2 Standard Operating Conditions of the Storage Tanks:

- Storage tanks should be at least 100 feet from water well.
- Tanks should be down scope from water well.
- Products should be kept at a temperature below 65^{o}C.
- Products should be kept at a pressure between 13 to 15 bars.
- Storage tanks are kept at a position adjacent to fire and for easy access to firefighting equipment.
- Tanks should be given a space of Snot less than 1m apart.
- Floating tanks are normally kept near atmospheric pressure

The above operating conditions are applied to both floating tanks and fixed roof tank, which are the selected tanks used by the unit as seen in Table 4 above.
Although there was no records of pressure gauge values due to malfunction of the pressure valve, temperatures were manually taken daily by hand deep method into the tanks due to malfunction of the automatic temperature level indicator system. At such, temperature and pressure gauge values are not usually recorded. Though, a temperature range for fourteen months is presented below as locally recorded by the operators as shown in Table 9.

Table 9: Temperature values taken at average range for 14 months from 2019 to 2020

Month	Temperature range(^{o}C)
September 2019	20-23
October 2019	20-25
January 2020	25-28
February 2020	25-30
March 2020	28-32
April 2020	30-35
May 2020	30-38
June 2020	35-38
July 2020	35-42
August 2020	20-24
September 2020	20-22
October 2020	22-25
November 2020	25-28
December 2020	20-24

4.2 Discussion of Results

Based on FMEA worksheet on the Table 7 with the existence of cause and effect on the fuel system also be able to use as supporting equipment to identify failure arise on the component. FMEA is a proactive analytical tool to assist engineers in order to define, identify and eliminate potential failures, constraints, inaccuracies or other systems, design and/or operations. Items where the failure has the highest severity is fuel storage tank, because it is to store the fuel, on the (Table 4) this failure has occurrence remote. The failure mode has highest severity level is leakage. This component on the fuel system is potentially dangerous to start from the pollution of the deport environment to the occurrence of fire.

As shown from Tables 4 - 9, the failure caused the highest occurrence is fuel purity (dirty fuel), the dirty fuel caused blocked on the system therefore the failure mode has the most frequent rank. Regarding on the Table 4 the dirtiness of fuel causes blocked on s fuel filter. The fuel dirty affected to the system start from the unclean air, water sediment from the condensate air in the fuel tank, rusty fuel tank and others. though, this is not a fatal impact, unclean fuel can disturbs the system operation, if there is no intervention and can therefore cause failure on the other components hence impacting the system downtime in period of time and take a long time to repair the system to operate properly (Zennir et al., 2014), (Wang et al., 2013). More also as shown from the Table 7 above is the RPN of each component as shown on the table. It can be observed that double stage fuel filter has the highest rank by 252. This happens because the level of severity is 4, if this occurs will cause the system to be stopped, High occurrences with a rating of 9 is quite time consuming for repairing, and detection is slightly difficult because it has to open the case filter. The other high RPN is the transfer pump with a rating of 90; transfer has a lower point than double stage fuel filter because to detect the occurrence is a little easier (Jian et al., 2022).

As mentioned above, the possible accident that can likely occur as a result of this is fire and explosion. Even though fires or explosion accidents are usually rare in tank farms, it is of paramount importance to prevent such from happening.

Below are some of the common expecting events that can lead to ignition of fire in the storage tanks:

Fixed roof tanks;

- High temperature
- Holes in the roof
- Over filling
- Leakage from tank bottom or shell
- A very high pressure

Floating tanks;

- Tank over fill
- Leakage from tank bottom or shell
- Accumulation of liquid on the roof
- Spillage around the area during preparation or maintenance
- External events such as terrorism and earth quake

Possible solution:

To know, identify and eliminate possible failures, challenges, malfunctions or other systems, design / or operations using the FMEA worksheet (Table 7) will be more effective. With the RPN, it can use by the operator or the technician help them to determine the priority or the importance of care and attention that should be put in place. Subsequent to determining the component with critical criteria can be optimized maintenance time on fuel system components. Other safe or control measures to be taken include:

- Monitor tank fill levels as a routine operation
- Responding to high or low level alarms

- Operators should be trained very well

There should be weekly/ monthly checks such as:

- How clean the roof is
- Check for leakage signs
- Bottom and shell checks.

However, in comparison with some literatures, there has been some major work on tank fires and there prevention methods. For example, a hand book on '*Liquid Hydrocarbon Tank Fires'* IChemE (2008). It talks about Maximum Feasible Fire Extinguishment.

Below is there argument:

According to evidence from actual incidents that have occurred throughout the world over the past few years, extinguishing a full surface fire in a large tank (over 46 m or 150 ft. in diameter) using mobile equipment is feasible (tanks up to 83 m (272 ft.) in diameter have been successfully extinguished using only mobile equipment) but needs careful planning, large delivery devices and support equipment and well trained teams of operators. In accordance with the LASTFIRE study, a risk analysis should be carried out to assess the feasibility and justification of attempting to extinguish full surface fires. In the event that it is thought feasible then mobile monitors or fixed systems can be considered according to local circumstances. Reputation and media attention issues should be included in any assessment.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After carrying out this study, a conclusion has been reached. The following points are derived from the study as conclusions:

- ✓ Hazard analysis study has been conducted for the crude oil storage tank farm.
- ✓ HAZOP study has identified all possible deviations in parameters from design intent (level, flow, and temperature), which could finally lead to oil leakage or extra pressure and consequently result in undesirable events such as fire and explosion.
- ✓ Failure Mode Effect Analysis of crude oil storage tank fire and explosion has been drawn. Evaluations were carried out. The results indicate that the item with the failure severity is the fuel storage tank. The failure mode that has the highest severity level is leakage. Which is potentially dangerous to cause pollution around the deport environment and also causing fire and explosion outbreak.
- ✓ These causes must be given critical attention to mitigate the severity and occurrence of accidents in the unit.

5.2 Recommendations

In this research work, the following were the recommendations:

Human error or factor has always being the main factor in major industrial accident which usually causes fire and explosion. Therefore, the ability of an organization in preventing accidents is indicated by the intervention and response of management to immediately look into operations associating risks. However, the management should take action in controlling these incidents from escalating into an accident

These are but few actions that can be suggested to prevent major accident as follows;

a) Preventive and corrective maintenance program for all equipment associated with fuel delivery systems and other supporting equipment are needed to be done rigorously according to schedule.

b) Comprehensive emergency response plan (ERP) which covers all potential incident scenarios associated to fuel's loss of containment such as fire and explosion so that the impact of accident can be reduced.
c) The establishment of additional mitigation measure such as foam sprinklers for firefighting.

Abbreviations:

FMEA	*Failure mode effect analysis*
ETA	*Electronic test analysis*
FTA	*Failure test analysis*
HAZIP	*Hazard identification*
HAZOP	*Hazard analysis and operability studies*
HSE	*Health and safety executive*
NFPA	*National fire protection agency*
NNPCL	*Nigerian national petroleum corporation Limited*
OGP	*Optical gaging products*
OSHA	*Occupational and safety health administration*
QRA	*Qualitative risk assessment*
RPN	*Risk Priority Number*

Acknowledgement
The authors wish to acknowledge the efforts of the African Journal of Engineering and Environmental Research (AJOEER) for the publication of this article.

REFERENCE

1. Candreva, F., De Rademaeker, E., Gowland, R., Isakov, A., Roberts, A., & Winkelmann, G. (2015). *Safety guidelines and good industry practices for oil terminals*. new york.
2. Cicek, K., Turan, H. H., Topcu, Y. I., & Searslan, M. N. (2010, March). Risk-based preventive maintenance planning using Failure Mode and Effect Analysis (FMEA) for marine engine systems. In *2010 Second International Conference on Engineering System Management and Applications* (pp. 1-6). IEEE.
3. Dantsoho, A. M. (2015). *Risk-based framework for safety management of onshore tank farm operations* (Doctoral dissertation, Liverpool John Moore University).
4. Fanelli, P. (2012). Safety and environmental standards for fuel storage sites: how to enhance the safety integrity of an overfill protection system for flammable fuel storage tanks. *Chemical Engineering Transactions*, *26*, 435-440.
5. Goethals, M., Borgonjon, I., and Wood, M. (2008). *Necessary Measures for Preventing Major Accidents at Petroleum Storage Depots: Key Points and Conslusions*. European Commission.
6. Ibrahim, H. A., and Syed, H. S. (2018). Hazard analysis of crude oil storage tank farm. *International journal of chem. tech research*, 300-308.
7. IChemE (2008): '*Liquid Hydrocarbon Tank Fires'* Institution of Chemical Engineers (IChemE) fourth edition, United Kingdom
8. Kong, X., Zhao, D., and Hu, S. (2018). Environment & Safety Risk Analysis of Storage Tank Accidents Based on Vulnerability, Process Management and Emergency Management. *Chemical Engineering Transactions*, *67*, 457-462.
9. Argyropoulos, C., Nivolianitou, Z., Christolis, M., & Markatos, N. (2012). A methodology for the hazard assessment in large hydrocarbon fuel tanks. *Chemical Engineering*, *26*.
10. Wang, D., Zhang, P., and Chen, L. (2013). Fuzzy fault tree analysis for fire and explosion of crude oil tanks. *Journal of Loss Prevention in the Process Industries*, *26*(6), 1390-1398.
11. Zennir, Y., Ahmed, A. B., and Mechhoud, E. A. (2014, June). Safety study of the industrial systems with FMEA (C): Application to the TK102 storage tank. In *2014 European Control Conference (ECC)* (pp. 2804-2809). IEEE.
12. Jian Kang, Wai Liang, and Laibin Zhang (2022). An Integrated Framework of Safety Performance Evaluation for Oil and Gas Production Plants: Application to a Petroleum Transportation Station. DOI: 10.1016/j.jlp.2014.03.007