Risk Assessment of Mounded Storage Tanks

Chenyang Du, Chang Liu, Jun Yuan, Ce Song, Xin Cheng, Xiaowei Li*

China Special Equipment Inspection And Research Institute, Beijing 100029, China.

*Correspondence: lixiaoweicg@163.com

Abstract. The Mounded Vessel is the third form different from the above ground and buried storage containers. In this paper, qualitative and quantitative assessment methods are comprehensively used for risk assessment of Mounded Vessel. Quantitative calculation method is used for failure probability, and qualitative calculation method is used for failure consequence. By comparing and evaluating the risk level of propylene Mounded Vessel and above ground propylene spherical tanks with similar parameters, it is concluded that the failure consequences of Mounded Vessel are smaller, the risk level is lower, and the safety is higher.

Keywords: hazardous chemicals; the mounded vessel; RBI; Security

1 Introduction

A mounded storage tank is a type of steel vessel externally covered by silty soil with only the relevant nozzles (for feeding and discharging, unloading, sewage disposal), man-holes, gauge pipe orifices and safety accessories beyond the overburden soil layer. It is used to store a medium at ambient temperature. Mounded equipment is barely susceptible to aboveground thermal radiation and explosive shock[1,2]. Moreover, when the equipment explodes due to failure, silty soil also absorbs some explosion energy, thereby reducing the failure consequence of equipment. Therefore, a shorter safe distance can be set for the mounded storage tank, so as to improve the land utilization rate and save land resources. Vegetation can also be planted in the surface soil to maintain the temperature stability of the internal medium, reduce evaporation loss and beautify the environment [3-5].

Risk assessment is an evaluation method to analyze the failure possibility and consequences of equipment, to obtain the overall risk level of equipment. At present, it has been widely used in various fields [6-9] and in the field of special equipment safety [10-13], and satisfactory results have been achieved.

At present, the risk assessment of pressure vessels is widely conducted under mature conditions. In China, risk assessment is generally carried out in accordance with TSG 21-2016[14] and GB/T 26610[15] standards. The mounded storage tank is also a type of pressure vessel, for which risk assessment can be implemented in accordance with GB/T 26610.

H. Kassim et al. (eds.), *Proceedings of the 2023 8th International Conference on Modern Management and Education Technology (MMET 2023)*, Advances in Social Science, Education and Humanities Research 798,
https://doi.org/10.2991/978-2-38476-146-3_13

2 Damage modes of mounded storage tank

The mounded storage tank is externally covered by soil, with its inner and outer walls exposed to the medium and soil only, and its temperature is not high, so its main damage modes are internal and external corrosion thinning, internal stress corrosion cracking, mechanical damage and low-temperature brittle fracture.

(1) Internal corrosion: General or local corrosion caused by chloride, halide, hydrogen sulfide, carbon dioxide, and low-molecular weight organic acids (e.g., formic acid, acetic acid, ethanedioic acid, benzoic acid, etc.), which are contained in the medium stored in the mounded storage tank, when they are exposed to metal.

(2) External corrosion: Corrosion of metal caused by the external environment of the mounded storage tank. For example, soil corrosion occurs when metal is exposed to the sand bed and soil. Soil corrosion mostly exists as local corrosion characterized by corrosive pitting. Soil microbes (bacteria, algae, fungi and other active organic matter) cause microbial corrosion, which usually exists in the form of local subscale corrosion or microbial cluster corrosion. Microbial corrosion in carbon steel is generally cup-shaped pitting corrosion.

(3) Stress corrosion cracking: Caused by carbon dioxide, wet hydrogen sulfide, etc., which are contained in the internal medium stored in the mounded storage tank, when they are exposed to metal.

(4) Mechanical damage: Scouring, mechanical fatigue, vibration fatigue and other forms of damage caused by internal medium motion, repeated filling and vibration load.

(5) Low-temperature brittle fracture: According to the working temperature of the mounded storage tank, low-temperature brittle fracture does not occur under normal circumstances, but adequate measures should be taken to prevent low-temperature brittle fracture during a hydraulic test or emergency draining or when there is permafrost.

3 Risk assessment of mounded storage tank

There are two sources of equipment risks: First, failure possibility; second, failure consequence. The product of the two risk factors is used to determine the risk magnitude. The assessment methods are divided into qualitative analysis and quantitative analysis. Considering the objectivity and accuracy of risk assessment, quantitative analysis and qualitative analysis can be used in combination for risk assessment of the mounded storage tank.

3.1 Failure possibility calculation

According to the national standard GB/T 26610.4[21], the failure possibility F of pressure equipment can be calculated using the following equation:

$$F = F_G \times F_E \times F_M \times F_L \tag{1}$$

where F_G represents the failure possibility of similar equipment;
F_E represents the correction coefficient of equipment;
F_M represents the assessment coefficient of management system;
F_L represents the impact factor of defect beyond tolerance.

F_G: The failure possibility of similar equipment. The scale of damage is expressed in 6mm (1/4 inch), 25mm (1 inch) and 100mm (4 inches), as well as four typical sizes of complete rupture. According to the type of equipment, the generic failure probability of the expected damage scale is selected from the generic accident frequency database.

F_E: The correction factor of equipment. It consists of four parts: technical module factor, general condition factor, mechanical factor, and process factor. The four correction factors can be determined according to the actual situation of the equipment. The correction coefficient of the equipment can be determined by adding up these four factors. Among them, the technical module factor is the most important correction factor, and its value is generally 10 to 100 times the sum of the other three factors, so it is decisive to the correction coefficient of equipment. The technical module factor is used to evaluate the effect of potential damage modes of equipment on failure probability. According to the specific damage modes of the mounded storage tank, the corresponding technical module factor can be selected for calculation.

F_M: The assessment coefficient of management system. According to the scoring sheet offered in Appendix B of GB/T 26610.4, the management system is evaluated with regard to each functional department of the enterprise to which the equipment belongs. The final scoring results are summarized and the logarithm of it is taken to convert the management system score into the assessment coefficient of management system.

F_L: The impact factor of defect beyond tolerance. When there is a defect beyond tolerance in the equipment assessed, it is determined in accordance with the original manufacturing quality of the equipment and whether there exists a time-dependent damage mechanism. FL=1.0 if there is no defect beyond tolerance in the equipment assessed.

3.2 Failure consequence calculation

In terms of failure consequence, the characteristics of medium and other parameters, such as discharge capacity and discharge rate, are primarily taken into account, while the casualty scale caused by equipment failure and the lethal area caused by toxic medium leakage are taken as measurement indexes for consequence determination. Failure consequence is characterized in two forms, i.e., area consequence and economic consequence. The economic consequence is divided into three types: equipment loss, shutdown loss and environmental cleanup, while the area consequence is divided into two types: personal casualty and equipment breakdown.

It is suggested that the failure consequence of mounded storage tanks should be calculated using the qualitative computation method offered in GB/T 26610.3[20].

The mounded storage tank is covered by soil. Therefore, the area of impact from its combustion explosion is smaller than that of conventional vessels laced on the ground. Zhou Jiahong[16] used the G. M. Reichhoff formula to comparatively study the personal injury and building damage caused by the explosion of a storage tank in the air and in silty soil, finding that the casualties, serious injury and safety radius of the explosion in silty soil are just 74.5%, 57.6% and 40.7% of that in the air, respectively; the severe building damage, slight damage and safety radius of the explosion in silty soil are just 35.1%, 19.3% and 12.9% of that in the air, respectively. This set of data shows clearly that the consequence of the explosion of a mounded storage tank is much less severe than that of a conventional one placed on the ground. This is due to the reason that soil absorbs some explosion energy, so that the explosion shock wave attenuates to a certain degree.

4 Examples of risk assessment of mounded storage tank

There was a mounded propylene storage tank put into use in China in 2020, with a capacity of 3,300m^3, working at room temperature under the working pressure of 1.56MPa. Other parameters are as follows: inner diameter 7600mm, length 68700mm, filling factor 0.9, and wall thickness 48mm (cylinder)/seal head (semi-spherical head). The medium is propylene, and material is A516 Gr.70. The tank has not undergone an overall inspection yet so far, and the wall thickness monitoring system has not identified any obvious corrosion yet.

4.1 Failure possibility calculation

F_G, the failure possibility of similar equipment, is selected for the storage vessels specified in GB/T 26610.4. Since there are 4 possible leakage sizes, the failure possibility of similar equipment for this mounded propylene storage tank should be the sum of the 4 leakage size probabilities, i.e., FG=0.000156.

F_E: The correction coefficient of equipment. As mentioned earlier, what has the greatest influence on the correction factors of equipment is the technical module factor, whose value is 10~100 times the sum of the general condition factor, mechanical factor and process factor. Therefore, the technical module factor should be taken into consideration when the correction factors of equipment are calculated.

According to the basic information about mounded propylene storage tank evaluation, the tank may suffer from corrosion thinning on its inner and outer walls and wet hydrogen sulfide stress corrosion cracking inside. Fatigue damage is excluded because the tank was just put into service recently and has not been filled with a medium for too many times. Besides, the possibility of brittle fracture is extremely low, so it is also excluded this time. To sum up, for the technical module factor, thinning sub-factor and stress corrosion cracking sub-factor need to be calculated.

Thinning sub-factor calculation:

The medium stored in the tank is propylene, which may contain traces of H_2S, which causes acid water corrosion in the presence of water. Moreover, before the storage tank was put into service, it had been considered that it might fail to go through a periodic inspection. So, its internal and external surfaces are covered with an anticorrosive coating, and equipped with corrosion probes. The monitoring data show that there is no obvious corrosion thinning. In summary, it is assumed that this tank suffers from general corrosion, and the corrosion rate is set to 0.05mm/year. Although the tank does not suffer from atmospheric corrosion because its internal and external surfaces are covered by soil, it may suffer from soil corrosion. The corrosion rate is also set to 0.05mm/year. The total wall corrosion rate is 0.1mm/year.

Service length a=2 years, total corrosion rate r=0.1mm/year, and wall thickness t=30mm (head thickness), so ar/t=0.0067.

Inspection is considered invalid because no test has been conducted. The thinning sub-factor is set to 1.

Safety factor correction: the operating pressure is 1.56 MPa, and the safety factor is set to 0.5.

Online monitoring correction: the tank is equipped with corrosion probes there is hardly any liquid flowing in the tank, the online monitoring correction factor is set to 10, based on acid water corrosion (not greater than 6.10mm/s).

So, the final thinning sub-factor is equal to initial thinning sub-factor× safety factor/online monitoring factor =0.05.

Stress corrosion cracking sub-factor calculation:

There is H_2S in the medium in the mounded propylene storage tank, indicating that there may be a sulfide stress corrosion cracking mechanism. The sulfide stress corrosion cracking factor is co-determined by the maximal severity index of stress corrosion cracking and the frequency of inspections with the highest validity.

The mounded propylene storage tank made of A516 Gr.70, which is not highly sensitive to sulfide stress corrosion cracking, so it is set to a low value. According to Table D3 in GB/T 26610.4, the severity index is 1. The tank has not been inspected yet since it was put into use. According to D.10 in GB/T 26610.4, the stress corrosion cracking sub-factor is 1. The factor is adjusted to be 2.14 with time going by.

The total technical module factor is equal to the sum of thinning sub-factor and stress corrosion cracking sub-factor, 2.19.

F_M: The assessment coefficient of management system: According to the results of assessment, the management factor F_M=1.0.

F_L: The impact factor of defect beyond tolerance: There is no defect beyond tolerance in this device, F_L=1.0.

Therefore, the failure probability F is 0.00034164, and the failure possibility is 3, according to Table 1.

4.2 Failure consequence calculation

The medium in the mounded propylene storage tank is propylene, which is flammable and explosive but slightly toxic. Therefore, for consequence calculation, personal injury caused by combustion explosion is primarily taken into consideration and expressed in area (m^2).

The calculation can be conducted by referring to qualitative consequence calculation method offered in GB/T 26610.3, because the area of impact from the combustion explosion of a mounded storage tank is smaller than that of an aboveground device[17-19]. Therefore, the calculated consequence area is multiplied by an overburden mitigation factor to determine the final consequence level.

The chemical factor CF=12 according to the characteristic parameters of propylene.

The damage quantity factor DQF = 45 according to the density of liquid propylene and the filling capacity of the propylene tank.

According to the boiling point and autoignition temperature of propylene at normal atmospheric pressure, , the state factor SF=6 and AF=13.

The propylene in the tank is liquid, and the pressure factor PRF=-10.

According to the score of 10 items in Section 6.3.2.6, GB/T 26610.3, the safety protection factor CRF=-8.

According to the sum of the above 6 items, the area of impact from initial combustion explosion is 58.

Considering the characteristics of mounded equipment, the area of impact from its explosion is smaller than that of aboveground equipment. So, the damage distance to buildings is taken into consideration only. According to the research data from Zhou Jiahong[16], the damage to buildings caused by equipment explosion in soil is only 35.1% of that in the air. Therefore, the consequence of mounded equipment assessment can be multiplied by a consequence mitigation factor, 0.4, to reflect the role of overburden soil in reducing consequence.

The final consequence area is 23.2, and the consequence grade is B according to GB/T 26610.3.

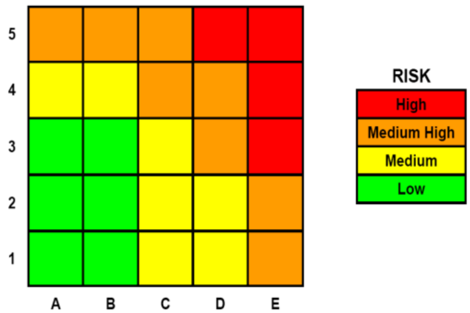

Fig. 1. Risk Level Matrix

According to the risk matrix diagram (See Figure 1), the risk level of mounded propylene storage tank is low.

4.3 Risk level comparison

At present, propylene storage spheres are generally used for propylene storage in China's petrochemical industry. This time, a 3000m3 propylene storage tank was selected for risk assessment to compare the risk level of aboveground propylene storage spheres with that of mounded propylene storage tanks (3300-m3).

The basic parameters of a 3000-m3 propylene storage sphere owned by a petrochemical plant are as follows: Put into use in 2019, operating pressure 1.77 MPa, operating at normal temperature, diameter 18,000 mm, filling factor 0.9, wall thickness 54 mm, material Q345R, medium propylene, insulated. A comprehensive inspection was carried out for the first time in 2022. The measured minimum wall thickness was 53.7mm, and the inner surface was covered with 50% magnetic powder; defects were not identified in 50% ultrasound check, and obvious corrosion was not identified in macroscopic inspection.

Quantitative failure probability was calculated according to GB/T 26610.4. For the technical module factor, the thinning sub-factor, stress corrosion cracking sub-factor and external damage sub-factor were taken into consideration. Calculations were made by the above steps. The thinning sub-factor was 0.5; the stress corrosion cracking sub-factor was 10; the external damage sub-factor was 0.5.

The failure probability of similar equipment, correction coefficient of equipment, evaluation coefficient of management system and impact factor of defect beyond tolerance were calculated, respectively, results as follows: FG=0.000156, FE=2.0, FM=1.0 and FL=1.0. Finally, the failure probability of this propylene storage sphere was found, 0.000312, and the failure probability was 3 according to the table.

Qualitative failure consequence was calculated according to GB/T 26610.3. The chemical factor CF=12, damage quantity factor DQF=45, state factor SF=6, autoignition factor AF=13, stress factor PRF=-10, and safety protection factor CRF=-5. The sum of the factors was 61, and the consequence was D according to the table. The risk level was medium to high.

Table 1. Comparison of risk level between mounded storage tank and aboveground storage sphere

Equipment	Capacity	Failure Possibility	Failure Consequence	Risk Level
Mounded propylene storage tank	3300m^3	3	B	Low risk
Propylene storage sphere	3000m^3	3	D	Medium-high risk

5 Conclusions

The risk assessment of the mounded storage tank was conducted by combining qualitative and quantitative assessment methods together. In terms of failure probability calculation, a quantitative approach was primarily adopted. The technical module factor was determined and calculated according to the damage modes of the mounded storage tank. In terms of failure consequence calculation, a qualitative approach was primarily adopted. The risk assessment results show that the mounded storage tank is a low-risk device with failure probability of 3 and failure consequence of B.

A mounded propylene storage tank and an aboveground propylene storage sphere, two devices with similar parameters, were compared. The results show that there is a slight difference in failure possibility between the mounded propylene storage tank and the aboveground propylene storage sphere, but the failure consequence and risk level of the former are much lower than that of the latter. The reason is that the mounded propylene storage tank is covered with silty soil, which exerts a good butter effect by fully absorbing the impact energy generated by the explosion of the mounded storage tank, greatly mitigating the consequence. Moreover, the overburden soil layer also protects the tank from terrestrial thermal radiation, explosion shock wave and flying objects, keeping it safe.

Author contributions

C.D.: writing—original draft preparation; C.L.: writing and data curation; J.Y.: validation; C.S.: Supervision; X.C.: Supervision; X.L.: writing—review and editing n. All authors have agreed to submit the manuscript

Funding

There is no fund support for this study.

Competing interests

The authors declare no competing interests.

Data Availability Statement

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request

References

1. Lu QS, Guo CG. Analysis and Design of Large-scale Horizontal LPG Mounded Bullet Tank [J].*Journal of Lanzhou University of Arts and Science(Natural Sciences)*,2022,36(3):68-73
2. Xu JH. Investigation on Pressure Resistance and Safety of Cover Soil Spherical Tank [D]. *Dalian University of Technology*,2021
3. Xia W. Design and application of mounded storage tank for pressurized storage of liquefied hydrocarbon at ambient temperature [J]. *Petroleum Engineering Construction*,2018,44(3):1-6
4. Wang T, Xia W. Construction techniques of mounded vessels for pressurized storage of liquefied hydrocarbons at ambient temperature [J]. *Petroleum Engineering Construction*,2020,46(4):51-57
5. Du CY,Li XW,Liu C et al. The Present Situation and Prospect of Mounded Vessel [J]. *China Special Equipment Safety*,2023,39(2):12-15

6. Koelmans, A. A., Redondo-Hasselerharm, P. E., Nor, N. H. M., de Ruijter, V. N., Mintenig, S. M., & Kooi, M. (2022). Risk assessment of microplastic particles. Nature Reviews Materials, 7(2), 138-152.
7. Whiting, D., Lichtenstein, P., & Fazel, S. (2021). Violence and mental disorders: a structured review of associations by individual diagnoses, risk factors, and risk assessment. The Lancet Psychiatry, 8(2), 150-161.
8. Ranasinghe, R., Ruane, A. C., Vautard, R., Arnell, N., Coppola, E., Cruz, F. A., ... & Zaaboul, R. (2021). Climate change information for regional impact and for risk assessment.
9. Dolce, M., Prota, A., Borzi, B., da Porto, F., Lagomarsino, S., Magenes, G., ... & Zuccaro, G. (2021). Seismic risk assessment of residential buildings in Italy. Bulletin of Earthquake Engineering, 19, 2999-3032.
10. Saisandhiya, N. R., & Babu, M. K. V. (2020). Hazard identification and risk assessment in petrochemical industry. International Journal for Research in Applied Science and Engineering Technology, 8(9), 778-783.
11. He, R., Zhu, J., Chen, G., & Tian, Z. (2022). A real-time probabilistic risk assessment method for the petrochemical industry based on data monitoring. Reliability Engineering & System Safety, 226, 108700.
12. Li, Y., Li, Y., Wang, K., Zhang, Y., Wang, Z., & Zhao, S. (2022, August). Bayesian network based on dynamic risk assessment for petrochemical sites—A case study of oil tank. In 2022 IEEE International Conferences on Internet of Things (iThings) and IEEE Green Computing & Communications (GreenCom) and IEEE Cyber, Physical & Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Congress on Cybermatics (Cybermatics) (pp. 385-390). IEEE.
13. Lu, D., Cong, G., & Li, B. (2022). A New Risk Assessment Model to Check Safety Threats to Long-Distance Pipelines. Journal of Pressure Vessel Technology, 144(5), 051801.
14. TSG 21-2016. Supervision Regulation on Safety Technology for Stationary Pressure Vessel [S]. Beijing: Xinhua publishing house,2016
15. GB/T 26610. Guideline for implementation of risk-based inspection of pressure equipment system [S]. Beijing: China Zhijian Publishing House,2011,2014
16. Zhou JH, Xu KL. Source Intensity Estimation on Underground Storage Tank Explosion [J]. Journal of Safety Science and Technology, 2005,1(6):47-50
17. Bao HZ. Simulation and Evaluation on the Damage Scope of Underground Oil Tank Accidents [J]. *China Safety Science Journal*, 2010, 20(8): 102-105.
18. Dang HB, Xuan XY, Yang LL. Quantitative Analysis on the Fire and Explosion Hazard of Oil Storage Tanks at Filling Stations [J]. *Storage, Transportation & Preservation of Commodities*, 2007, 29(3): 122-123.
19. Li QG, Song WH, Xie F et al. Mathematical Simulation of the Damage Scope of Fire and Explosion Accidents in the Oil Storage Area of Gas Stations [J]. *Journal of Nankai University*, 2011, 44(5): 7-13.
20. GB/T 26610.3. Guideline for implementation of risk-based inspection of pressure equipment system—Part 3:Qualitative approach to risk [S]. Beijing: China Zhijian Publishing House,2014
21. GB/T 26610.4. Guideline for implementation of risk-based inspection of pressure equipment system—Part 4: Quantitative analysis approach of failure likelihood [S]. Beijing: China Zhijian Publishing House,2014