Discussion and Simulation of Old Crude Terminals Directing Toward the New Standards

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Abstract—The crude oil terminals often have large throughputs, and the fire risk of crude oil is high. Hence, the fire design standards are becoming more and more stringent, which makes it difficult for some old crude oil terminals to meet the relevant provisions of the new standards. In this study, we took a typical old crude oil terminal as an example, and utilize TNO software simulation to assessment the pool fire consequences. Several issues caused by the changes in the old and new standards are analyzed, such as the fireproof distance, explosion-proof and fireproof. Furthermore, we have put forward targeted solutions and treatment principles to help enterprise better deal with them.

Keywords-Old Crude Terminal; Pool Fire Simulation; Fireproof Distance

1 INTRODUCTION

With the rapid development of the global chemical industry trade, the Chinese coastal and inland river chemical terminals have shown a diversified, large-scale, and specialized development. The 300,000 ton-class crude oil terminals were almost all over the coast, and the 450,000 ton-class crude oil terminals have been put into use in Dalian Port, Zhoushan Port, and Qingdao Port [1]. Due to the high fire risk of the crude oil terminal, its fire protection design standards have always been the focus of research at home and abroad. For formulating standards, it is often necessary to take into account many factors, such as scientifically, normativity, effectiveness, universality, etc. However, the old crude oil terminals often difficult to carry out the provisions of the new standards due to geographical or technical constraints. Under the requirements of safety first and economic development, the applicability of standards has become the focus of the safety industry. This study took a typical old crude oil terminal as an example, analyzed the problems existing in implementing the new standard, and provided a scientific solution based on the actual situation to achieve people-oriented and safe development.

2 OVERVIEW OF THE TERMINAL SITUATION

The terminal is located in Bohai Bay. It was designed in 2005 and put into operation in 2011. The vessel is a 300,000 ton-class crude oil tanker. The hydraulic structure is a 450,000 ton-class

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crude oil tanker. This terminal is a typical island berth. It consists of a working platform, two breasting dolphins, and six mooring dolphins. The total length of the berth is 520 m, and the size of the terminal working platform is 45m × 35 m. There are four oil delivery arms, pipelines, and a comprehensive building (including a terminal control room). Water, electricity, communication, lighting, monitoring, firefighting, lifesaving, and other facilities are available. The comprehensive building is a reinforced concrete structure with a total of three floors, which is a first-class fireproof building. The first floor is the foam fire pump room, the second floor is the process fire control room and the power distribution room, and the third floor is equipped with a waiting area and a conference room. The wall facing the terminal is provided with explosion-proof glass windows. This terminal is connected to the rear reservoir area through an approach trestle. The main operation technology is crude oil discharging ships, and there is no monitoring of firefighting boats and multi-purposed fire tug during the operation.

The schematic of the general layout of the terminal is shown in Figure 1.

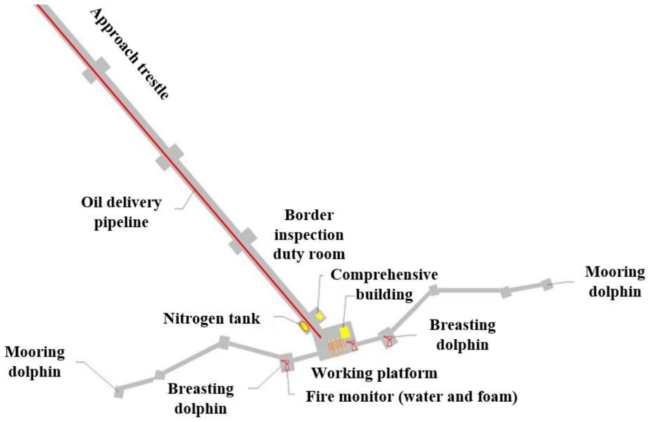

Figure 1. Schematic of the general layout of the crude oil terminal

There were two electric foam fire pumps equipped in the foam fire pump room. In October 2017, the enterprise changed the foam pump drive device from an electric motor to a diesel engine and added diesel engine control cabinets, exhaust pipes, fire arresters, and mufflers. In 2020, they adjusted the routing of fire water and fire foam outlet pipelines. Changed the original laying close to the terminal surface to laying on the pipe gallery and added height limit signs and warning signs.

Table 1 listed the main fireproof distance of the terminal platform. The distance between the terminal front line and the comprehensive building which includes a terminal control room and a fire pump room does not conform with the safety regulations. That means if an accident like pool fire happens in the terminal platform area, people or pump in the comprehensive building will be in danger.

Table 1 The main fireproof distance of the terminal

Starting point	**Ending point**	**Standard distance**	**Judging distance**
Terminal front line	Fire control room	20 m	Does not conform current

			standards
Terminal front line	Transformer and distribution room	20 m	Conform
Terminal front line	Foam fire pump room	20 m	Does not conform current standards
Terminal front line	Oil delivery arms	3.0 m	Conform
Oil delivery arms	Oil delivery arms	3.5 m	Conform
Terminal control building	West side process pipeline	18 m	Conform

3 DANGEROUS CHARACTERISTICS OF CRUDE OIL

3.1 Flammable and explosive properties.

The fire risk of crude oil is classified as Class A. The explosion limit of crude oil is 2.1 to 5.4% (V), and the lower explosion limit is low. Once the combustible liquid vapor is mixed with air, and the concentration is within the explosion limit, exploding will happen when it encounters the ignition source.

3.2 Easy to evaporate.

Crude oil is a volatile substance. Once the volatile vapor is mixed with air, and the concentration is within the explosion limit, exploding will happen when it encounters the ignition source.

3.3 Toxicity.

The liquid and steam of crude oil have toxic effects on the human body. A large amount of inhalation of high concentration of crude oil vapor can cause anesthesia symptoms, gait instability, nausea, vomiting, and even coma. In addition, some crude oil contains sulfur, such as Venezuelan fuel oil, which may volatilize toxic gases such as H_2S.

3.4 Easy to diffuse and flow.

Crude oil is transported in the case of heat tracing. Once the crude oil leakage occurs, it is easy to diffuse and flow around due to its low viscosity. Under the action of environmental factors such as wind speed, wind direction, and temperature, crude oil will continue to evaporate. Furthermore, the oil vapor will spread to the surrounding area after mixing with air, causing environmental pollution in a large range, and may even cause fire and explosion accidents.

3.5 Easy to accumulate static.

Crude oil has poor conductivity. In the case of flow, shaking, and ejecting, the electrostatic charge is generated at a higher rate than its release rate, resulting in electrostatic charge accumulation. Electrostatic discharge is one of the important causes of fire and explosion accidents.

3.6 Corrosive.

Some crude oil has a high sulfur content, which has corrosive effects on equipment such as oil pipelines, pumps, and valves. If the anti-corrosion measures are not implemented, it is easy to cause corrosion perforation and oil leakage.

4 PROBLEMS AND SOLUTIONS OF THE OLD AND NEW STANDARDS

This terminal was designed in 2005 and put into use in 2011. The design standards were mainly based on the Code for Fire Prevention Design of Oil Handling Terminals (JTJ237-1999), and Code of Design for Low Expansion Foam Extinguishing System (GB50151-1992). At present, the above two standards have been updated to Code for Fire Protection Design of &Petrochemical Terminals (JTS 158-2019) and Technical Standards for Foam Fire Extinguishing Systems (GB 50151-2021). The design of the general layout of the terminal, loading and unloading process, safety protection facilities and measures, distance from the surrounding facilities, power supply and distribution system, lighting system, lightning protection and anti-static grounding system, communication and control system, and other supporting systems meets the standard requirements of the construction period. However, with the implementation of the new standard, the following problems have emerged.

4.1 Main issues

4.1.1 Fireproof distance.

The working platform within 15 m from the terminal is classified as explosion hazard area two. The comprehensive building is 20 m away from the terminal, which is outside the explosion-proof area. The first floor is the foam fire pump room, and the second floor is the fire control room. The Code for Fire Prevention Design of Oil Handling Terminals" (JTJ237-1999) required that "less than 35m away from the fire pump house is not suitable"[4]. Noting that the fireproof distance requirement in the standard calls for "not suitable" and is not mandatory. Additionally, the Code of Design for Low Expansion Foam Extinguishing System (GB50151-1992) does not require the fireproof distance of the foam fire pump room [5]. According to the above two standards, this terminal didn't consider the recommended 35 m spacing in the design stage, which is not a design violation. However, the design of this terminal does not meet the current requirement of "the distance from the fire control room should not be less than 35 m" in the Code for Fire Protection Design of &Petrochemical Terminals (JTS 158-2019) [2]. At the same time, it does not meet the requirement of "the distance from the foam fire pump station should not be less than 35 m" in the Technical Standard for Foam Extinguishing Systems (GB50151-2021) [3].

4.1.2 Reconstruction of smoke exhaust facilities

The fire-fighting foam pump is changed to diesel engine-driven and equipped with smoke exhaust facilities. In this case, the firefighting foam pump room may be classified as an open fire or spark-emitting place. According to the existing standard requirements, the distance between the foam fire pump and the front line of the terminal should be 40 m. After on-site inspection, the smoke outlet exits from the east side wall and has an elbow to turn to the north side. The oil transfer arm at the front of the terminal is provided with a fire arrester and muffler. This design significantly reduced the possibility of causing oil and gas fires in the terminal loading/unloading areas. In addition, the modified foam pump is a backup pump, which is only used in the state of a fire accident. The risk of a spark accident caused by the smoke exhaust port is much lower than an open fire that has already occurred. Therefore, the firefighting foam pump room cannot be identified as a spark-emitting place.

4.1.3 Regional explosion and fire protection

To facilitate fire control, operation observation, and lighting, the terminal control building is provided with explosion-proof glass windows on the wall facing the front of the terminal. The windows are not in line with the standard of the Code for Fire Protection Design of &Petrochemical Terminals (JTS 158-2019), which stipulates that "doors and windows facing explosion-hazardous areas should adopt Class-A fireproof doors and windows" [2]. Code for Fire Protection Design of Oil Handling Terminals (JTJ237-1999) also stipulates the installation of fire doors and windows. "The doors and windows of the transformation and distribution room should be located outside the explosion-hazardous area. When inside the explosion-hazardous area, they should choose fixed airtight windows."[4] The terminal control building is outside the explosion hazard area, so it is not a design violation.

4.2 Fire simulation analysis

4.2.1 Simulation software.

The ETTECTS software of the Netherlands National Institute of Applied Sciences (TNO) was used to calculate the consequences of typical terminal fire accidents, and the corresponding graphic was depicted.

4.2.2 Judgment standard of accident consequence.

Leakage usually does not cause casualties when receiving, unloading, and transporting crude oil terminals. Once the ignition source ignited the leaked goods, a pool fire will occur. The standard for thermal radiation damage reflects the harm caused by thermal radiation intensity and exposure time to the human body and equipment. Pool fire burns steadily and lasts longer. It is the steady-state fire. The thermal radiation damage standard for steady-state fire is shown in Table 2. This standard is formulated in Appendix H of the Guidelines for Quantitative Risk Assessment of Chemical Enterprises (AQ/T3046-2013).

Table 2 Standard Of Thermal Radiation Damage

Thermal radiation intensity (Kw/m^2)	**Types and extent of damage**	
	Personnel	***Equipment***
37.5	100% of personnel will die within 1 minute, and 1% will die within 10 seconds.	Operating equipment damage

12.5	1% of personnel will die within 1 minute and suffer the first-degree burn within 10 seconds.	The minimum amount of energy required to burn wood and melt plastic pipes.
4.7	Exposure to this intensity for 16s can cause skin pain. When there is no thermal radiation shielding, the operator can stay for several minutes wearing protective clothing.	—
1.6	Even if exposed to this intensity for a long time, people will be in no discomfort.	—

4.2.3 Selection of fire accident scenarios.

Herein, crude oil was selected for simulation evaluation due to the single type of loading and unloading at this terminal. The loss of containment (LOC) events in ship loading and unloading are shown in Table 3. In the actual production process, the leakage duration generally does not exceed 5 minutes due to the adoption of pressure, flow monitoring, and personnel to patrol the operation site.

Table 3 The Loss of Containment Scenarios in The Process Of Ship Loading And Unloading

Scenario number	**Scenarios of ship loading and unloading operation**	**Location**	**LOC events**
NO.1 leakage aperture: 400 mm	DN400 crude oil loading arm was used for handling operations	Terminal platform	The oil loading arm was completely ruptured, and oil flowed from both sides of the rupture.
NO.2 leakage aperture: 40 mm	DN400 crude oil loading arm was used for handling operations	Terminal platform	Part of the oil loading arm was broken or leaking. Crude oil flowed through a void with an equivalent diameter of 10% of the nominal diameter (the maximum diameter is 40mm).

4.2.4 Selection of meteorological diffusion conditions.

The meteorological diffusion conditions that play a major role include wind speed, wind direction, atmospheric stability, mixing layer height, and temperature. The meteorological diffusion conditions are selected according to the natural conditions of the area where the terminal is located (Table 4).

Table 4 Selection of Meteorological Diffusion Conditions

Meteorological factor	Results
Wind speed	5.3 (m/s)
Wind direction	S
Temperature	11.4 ℃
Relative humidity	66%
Atmospheric stability	D

4.2.5 Fire accident simulation.

Under the above simulation conditions, the calculated pool fire characteristic parameters and the damage distance of flame thermal radiation are shown in Table 5. Herein, damage distance is the distance between the downwind of the pool and the pool edge. The thermal radiation damage area of the simulated pool fire accident is shown in Figure 2 and Figure 3.

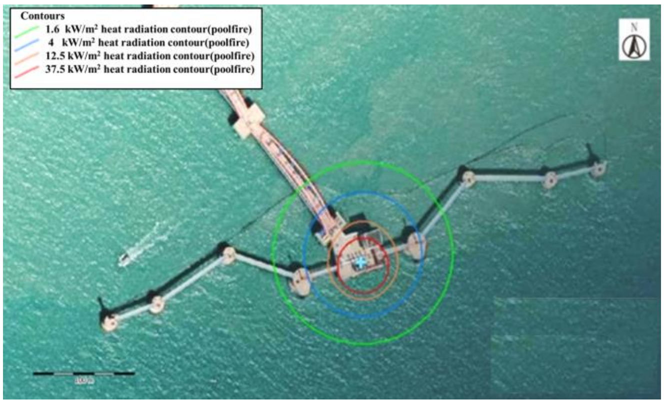

Figure 2. Diagram of impact area by the pool fire (leakage aperture: 400mm).

Figure 3. Diagram of impact area by the pool fire (leakage aperture: 40mm).

As shown in Table 5, Figures 2 and 3, when a fire occurs, the personnel and equipment facilities at or around the fire site will suffer from fatal injury and strong thermal radiation. Moreover, the adjacent pipeline and other equipment, after suffering fire damage, are likely to occur a secondary fire explosion accident. There is still a possibility of hazards to the dock platform and nearby loading and unloading facilities.

Table 5 Summary of Accident Consequence Simulation Results

Dangerous source	**Leakage aperture (mm)**	**Accident types**	**Classification standard**	**Maximum influence range (downwind distance (m))**
DN400 crude oil loading arm was used for handling operations	Scenarios one: 400 (Completely ruptured)	Pool fire	1.6 (kW/m^2)	105
			4.0 (kW/m^2)	75
			12.5 (kW/m^2)	46
			37.5 (kW/m^2)	29
	Scenarios one: 40 (Partial ruptured)	Pool fire	1.6 (kW/m^2)	32
			4.0 (kW/m^2)	25
			12.5 (kW/m^2)	16
			37.5 (kW/m^2)	8

Figure 2 shows that the thermal radiation damage from the pool fire has a serious impact on the terminal complex building. The red area indicates that the thermal radiation intensity exceeds 37.5 kW//m^2. Workers in this area can be seriously threatened, with 100% death within 1 minute. The orange zone (outside the red zone) is the area where the thermal radiation intensity exceeds 12.5 kW//m^2, which seriously threatens the safety of workers and equipment. Once personnel is in the area, the death rate increases substantially. The blue area (outside the orange area) is where the heat radiation intensity does not exceed 4 kW/m^2. The threat to staff in this area is minor, but workers have a possibility of death. The thermal radiation intensity outside the green zone is low (1.6 kW/m^2), which is a safe zone.

4.3 Analysis and solutions

4.3.1 Fireproof distance.

According to the Technical Standard for Foam Extinguishing Systems (GB50151-2021), the fireproof distance between the front line of the terminal and the foam fire pumping station has been forced to be no less than 35 m. If the fire control room is arranged near the front line of the terminal, it will increase the safety risk of personnel and equipment in the event of a fire accident. The terminal control building should be relocated and reconstructed or take enhanced protection measures (such as installing firewater curtain sprinklers on the front side of the terminal) to ensure production safety.

4.3.2 Fire prevention measures.

Although glass windows can withstand large explosion shock waves, they do not necessarily have good fire resistance. Class A fire doors and windows have the characteristics of fire integrity, heat insulation, and impact resistance at the same time. The production safety accidents of crude oil terminals are mainly caused by leakage and fire. Among them, thermal radiation is the primary cause of injury. Therefore, it is recommended to replace the doors and windows facing the explosion hazard area of the terminal with Class A fireproof doors and windows.

4.3.3 Simulation results.

When a fire occurs on the terminal platform, both the personnel and equipment facilities at or around the fire site can suffer from strong thermal radiation. In an accident, the existing distance is not enough to meet the safety distance of field operators. Therefore, the enterprise should ensure the reliability of safety control measures to reduce the severity of accident consequences.

5 CONCLUSIONS

The implementation of new and old standards should not be managed strictly and tightly. The principle of the old and light [7] listed in China's Criminal Law and the law non-retroactive [8] listed in Legislation Law should be used reasonably in production safety-related regulations. Therefore, the old terminals which are outdated production processes and defective equipment and facilities should be eliminated, and taken steps to improve. When the new requirements are not changed essentially, enterprises should make adjustments according to the actual situation. Hardware facilities should be judged based on design standards, and measures should be taken in the order of process improvement, strengthening, and isolation. Overall, improving safety production conditions, strengthening safety production management, preventing and resolving major safety risks from the source, and improving safety production levels are guarantees to ensure safe production.

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