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Lessons learned from analyzing a VCE accident at a chemical plant

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ABSTRACT

On June 5, 2017, there was a Vapor Cloud Explosion (VCE) at *JinYu* Petrochemical Co. Ltd. During unloading of liquified natural gas, the gas leaked from the truck and formed a vapor cloud, then the vapor cloud met with the electrical sparks in the plant laboratory, and an explosion occurred. This incident caused significant casualties and property loss. The main causes of the accident are demonstrated by a fishbone diagram. The major causes include (a) defective design, (b) noncompliance with standard operation procedures (SOPs), (c) the presence of ignition sources, (d) ineffective enforcement of safety rules, (e) inadequate design of emergency facilities, and (f) delayed emergency response. The analysis reveals that process safety management (PSM) is a crucial factor in the success of chemical plants, especially for small and median-scale companies in developing countries. Dispersion phenomenon of liquefied gas is simulated by commercial Computational Fluid Dynamic (CFD) software. The simulation results approximately agree with the real incident. The simulation indicates that a visual and quantitative consequence analysis can provide general guidance for PSM. Finally, based on various PSM conditions (good, normal, weak, and bad), the probabilities of VCE generated from leakage are obtained by an event sequence diagram (ESD) and Monte Carlo methodology. By comparing the quantitative probability values in four different PSM situations, the results show that emergency management associated with effective PSM is crucial to avoid VCE incidents.

1. Introduction

A large number of catastrophic accidents have occurred in chemical process industries in the past decades. The most common examples of these accidents are Vapor Cloud Explosions (VCE). There were about 174 vapor cloud explosion (VCE) accidents worldwide that were reported between 1940 and 2010 (Zhu et al., 2015). For example, the liquid petroleum gas explosion in Mexico in 1984 and the explosion at British Petroleum's Texas City refinery in 2005 were noteworthy incidents. These incidents revealed that effective safety management of hydrocarbons and reactive chemicals (*e.g.*, hydrogen, methane, acetylene, ethylene, and liquid petroleum gas) could substantially reduce the risks in chemical plants. Additionally, past cases showed that VCE accidents could occur in any part of the operating processes for hazardous chemicals including preparation, utilization, storage, transportation and disposition. Defective design of facilities, imperfect equipment maintenance, human error in operations and lack of safety rule enforcement by management are important factors that can cause accidents. Much research has been done on the causes of VCE accidents (Chang and Lin, 2006; Konstandinidou et al., 2011). Furthermore, qualitative risk analysis, consequence analysis and study of the domino effect have been conducted (Cozzani et al., 2014; He et al., 2017; Hemmatian et al., 2014; Vílchez et al., 2011; Villa et al., 2016). Because of these studies, process safety management (PSM) is now recognized as essential for chemical plants. However, a few companies still lack of an awareness of process safety, especially in some developing countries (Khan et al., 2015; Knegtering and Pasman, 2009; Zhao et al., 2014; Atkinson et al., 2015; Sharma et al., 2013; Li et al., 2014; Zhang and Zheng, 2012). The objective of this paper is to analyze the potential causes of an incident occurred in Shangdong, China on 2017, as well as to reveal the importance of PSM implementation and quantitative risk assessment.

2. Description of a VCE incident

On June 5, 2017, liquefied petroleum gas was released during the unloading process at *JinYu* chemical plant in China's Shandong Province (Work Safety Committee of the State Council in China, 2017). Since liquefied petroleum gas is a heavy gas, after it leaked, it settled near the ground. When the gas cloud encountered an ignition source, the explosion occurred. Ten people died, and 9 were injured in the incident. The plant was damaged. Facilities, including 15 carrier

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Fig. 1. Plant layout drawing.

vehicles of hazardous chemicals, 1 spherical tank, 2 vault tanks, production equipment, laboratory, control room, office buildings, surrounding enterprises and social vehicles were also damaged. In addition, 6 spherical tanks caught fire, and several pipeline systems collapsed.

2.1. Layout of the chemical plant and the leak area

The 86,955-square-meter plant had nine 200 m^3 liquefied gas tanks, which stored propane, isobutane and pentane oil, six 1000 m^3 and six 2000 m^3 liquefied petroleum gas spherical tanks, eighteen 150 m^3 pentane oil tanks, six 3000 m^3 liquefied petroleum spherical tanks, six 2000 m^3 isooctane tanks and four 5000 m^3 sulfuric acid storage tanks. On the east side of these tanks, was the loading and unloading area for the tanker trucks. Fifty meters from the north side of the loading/unloading area was the laboratory. The control room and the factory office building were located at the east side of the loading/unloading. The layout of this plant is demonstrated in Fig. 1.

In the early morning of June 5, a tanker truck arrived at the unloading zone. The driver got out of the truck and tried to connect the omnidirectional loading arm to the tanker's discharge outlet. However, he failed to connect the arm to the outlet properly. Suddenly, large amount of liquefied gases began to leak. And the gases quickly spread over the unloading zone. The location of leakage is shown in Fig. 2.

2.2. The time sequence of the accident

More specifically, at about 1:00 a.m. on June 5, 2017, the driver began to unload liquefied gas by connecting the omnidirectional loading arm to the tanker's discharge outlet. Because of the complicated operating procedures and without supervision, the driver failed to connect them properly. The worker on duty carelessly checked the spot and did not find out any problem. A leakage of liquefied gas began. After a period of 130 s following the release, a cloud of liquefied gas was ignited. A vapor cloud explosion occurred due to an ignition source in the laboratory to the north. As a result, serious damage occurred through a domino effect. Table 1 summarizes the timeline of this incident.

3. The fishbone diagram of the accident

The inadequate piping system was one of the reasons for this VCE accident. The piping system was very complex. It was composed of several rotary joints, varying sizes of multi-section pipes, spherical valves, flanges, quick connectors, and an anti-static device. Thus, any small defect in a small component of the piping system could cause failure to the loading operation. In addition, there were also several potential factors related to process safety: suitable supervision before the loading operation, adequate connection procedures, effective emergency management, frequent safety training for workers, etc. Considering PSM and all the factors mentioned in this paper, the fishbone diagram for this accident is shown in Fig. 3.

Through analysis of the fishbone diagram, we conclude that there were four major reasons for this severe incident. The first factor was a failure by workers to follow operation procedures and unloading procedures. The second factor was a lack of equipment integrity management and safety awareness. For example, there was no reliable leak detection procedure or alarm instrument during unloading procedures so there was no immediate response. The third factor was a failure in conducting consequence measurement of unexpected scenarios and

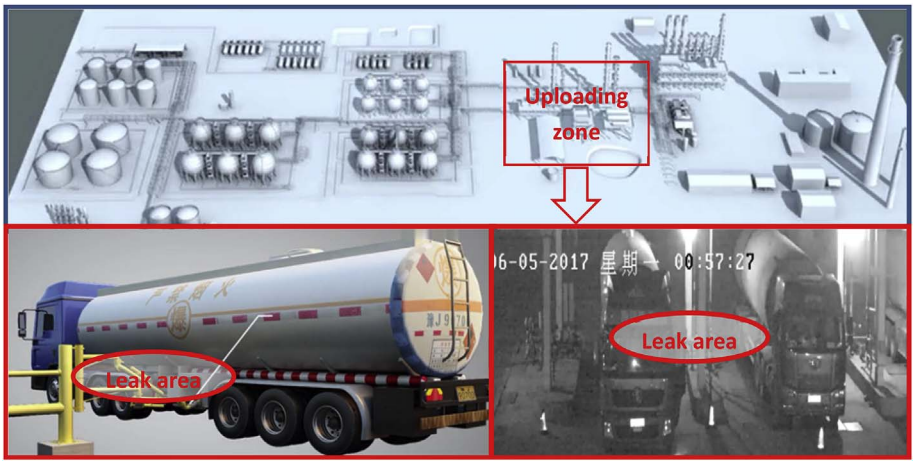

Fig. 2. The leakage location of the loading/unloading zone.