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Confined vapor explosion in Kaohsiung City – A detailed analysis of the tragedy in the harbor city

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ABSTRACT

On the midnight of July 31st, 2014, a catastrophic vapor explosion occurred in the downtown of Kaohsiung city. The incident was initiated from a leak of an underground pipeline transporting pressurized propylene liquid. Analysis of pipeline operation logs and pipeline break release modeling suggested that at least 90,000 kg of propylene leaked, entered the underground trench and spread into the trench 4.5 km in distance before meeting an ignition source some three hours later after the leak. The ignition caused a significant confined vapor explosion which blew out the road above the underground trench, damaged more than one hundred vehicles on the road with thirty two fatalities and more than three hundred injuries. This article will first describe the background of the pipeline installation follows by an in-depth look at the explosion incident covering the events leading to the explosion, explosion damage, cause of the leak, spread of the leak, identification of a probable ignition source, and root causes in safety culture. Finally, lessons learnt and recommendations are given to prevent and mitigate the occurrence of similar incidents.

1. Introduction

Vapor cloud explosion (VCE) is one of the most destructive events in the chemical process industries (Crowl and Louvar, 2011). Vapor cloud explosion is normally initiated by leak of a large amount of flammable vapor, dispersion of the vapor cloud in air, and finally ignition of the cloud leading to combustion, flame propagation and generation of overpressure. In most cases, the mode of flame propagation is deflagration. In certain extreme conditions, a detonation might occur (CCPS, 1994, 2010). The destructive nature of vapor cloud explosion has been documented in well known incidents such as Flixborough explosion in 1976, Pasadena explosion in 1989, and more recently the BP Texas City explosion in 2005 (Lees, 1996; Crowl and Louvar, 2011; CCPS, 2010).

Vapor cloud explosion is normally defined as an explosion occurring outdoors (CCPS, 1994). It is rare that a large scale vapor cloud explosion occurred in a confined space. This is in part due to the fact that most chemical process equipment was installed outdoor. There remained a few cases with leak of flammables in indoor installations that created significant confined vapor explosions. The amount of flammable vapor in confined vapor explosion was however generally smaller than those of unconfined VCE. For example, 386 kg of heptane vapor from a heating tank containing 4,500 kg of flammable liquid was considered the source of confined vapor explosion in the CAI/Arnel explosion in 2006 (CSB, 2008). This is about one to two order of magnitude smaller than the 30,000 kg of cyclohexane vapor in the Flixborough explosion (Crowl and Louvar, 2011), 38,600 kg of olefins vapor in the Pasadena explosion (Crowl and Louvar, 2011), and 28,700 L of hydrocarbon liquid vaporized in the BP Texas City explosion (CSB, 2007).

In 2013, a devastating confined vapor explosion occurred in storm drains in Qingdao, China, which resulted in 62 fatalities and 136 injuries (Zhu et al., 2015). The explosion was resulted from a leak of a crude oil pipeline with about 2,000,000 kg of crude oil spilled into the city storm drains and spread several kilometers upstream and downstream. The leak was attributed to corrosion from seawater in the drain where the pipeline was exposed directly. The amount of vapor for explosion was however not estimated. A larger but less documented incident was the gas explosion in

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Guadalajara, Mexico, in 1992 (Andersson and Morales, 1992; ARIA, 2007) in which gasoline was leaked into sewer through a corroded pipeline. There were 252 fatalities and more than 1500 injuries. Key factors contributing to the large number of fatalities and injuries in these two incidents are due to the very large quantity of flammable mass leaked and they occurred near or inside the well-populated communities in addition to the confinement in the sewer or drain. An incident with similar quantity of flammables in a normal chemical process plant would cause smaller, although still significant, impact owing to reduced population and confinement. With growing process industries and city development, confined vapor explosion will be the major hazard that must be carefully assessed when process industries interact with the city.

In the present work, we described a destructive confined vapor explosion occurred in the downtown of Kaohsiung City, Taiwan, on the midnight of July 31st, 2014. The incident was initiated from a leak of a corroded underground pipeline transporting pressurized propylene liquid. The leak entered the underground storm water trench, spread more than 4.5 km, and finally met an ignition source some three hours later after the leak. The ignition caused a significant vapor explosion which blew out the road above the underground trench, damaged more than one hundred vehicles on the road with thirty two fatalities and more than three hundred injuries. Detailed analysis are provided on the background of the pipeline installation, events leading to the explosion, explosion damage, cause of the leak, spread of the leak, identification of a probable ignition source, and root causes in safety culture. Although this incident bears similarities to the Qingdao explosion and Guadalajara explosion, there was a subtle difference in that the present case was a leak from a pressurized, flashing liquid which would vaporize completely upon leak into ambient environment while the later cases dealt with flammable liquids with only partial vaporization. Challenges and recommendations are given to prevent and mitigate the occurrence of similar incidents.

2. Background of the pipeline

The petrochemical industry was probably one of the most important as well as the most controversial industry in the short history of industrial development in Taiwan since 1960. Its contribution to economic development was significant and perhaps dominating in its early development up 1990s. After 1990s, the pollution and incidents accompanied by the petrochemical industry has restricted it development. This is particularly true for Kaohsiung City which is a harbor city that houses three major petrochemical complexes as well as providing the harbor terminals for importing and exporting chemicals. Among the three petrochemical complexes, the Tashe Petrochemical Industrial Park was the only one complex that is located away from the coast line. Tashe Petrochemical Industrial Park was originally built near the Taiwan CPC Corporation Kaohsiung Refinery which also housed the No 1, 2, and 5 Naphtha Crackers. The Kaohsiung Refinery was built before the World War II and is the oldest refinery in Taiwan. The No. 1 and 2 Naphtha Crackers were the oldest cracker in Taiwan and were replaced by No. 5 Cracker. The No. 5 Cracker was built around early 1990s in an era of strong environmental consensus and under the condition that it will be closed or relocated elsewhere in 2015. Without the No 5 Naphtha Cracker, Tashe Petrochemical Industrial Park cannot have sufficient raw materials and thus it is necessary to secure stable raw materials supplies. Thus, several long transporting underground pipeline were planned and built between Kaohsiung Harbor and Tashe Petrochemical Industrial Park around 1990s. The geographic location of Tashe Petrochemical Industrial Park necessitates the pipeline routes to pass Kaohsiung City downtown area as shown in Fig. 1.

The pipeline related to the incident is a high-pressure line connecting the LCY Chemical Corporation Tashe Plant and the harbor terminal company, China General Terminal & Distribution Corporation (CGTDC). It is a four inches pipe buried about 1 m below grade with a total distance of about 27 km solely devoted to transporting liquid propylene. Its route was planned in 1986 and operation started in 1993. A total of three underground pipelines, one 8-in ethylene line, one 6-in propylene line, and one 4-in propylene line, were built at the same time by Taiwan CPC Corporation and the 4-in line was transferred to LCY after the erection. Initially, the 4-in line was connected to the Taiwan CPC Corporation Cianjhen terminal. Subsequently, an extension line to CGTDC terminal was built as a second supply source.

At the time of planning, the underground pipeline route, as shown in Fig. 1, had carefully avoided the major downtown residential area and selected the route to pass borders of several downtown chemical plants and railroad maintenance house before entering suburb area. After more than 25 years, all of the chemical plants were either relocated or closed and the railroad maintenance house is being rebuilt as a light rail terminal at time of incident. In fact, most part of the pipeline is now surrounded by commercial and residential buildings. However with the poor geographic location and diminishing supply of raw materials from the nearby refinery, the downstream petrochemical companies in the Tashe Petrochemical Industrial Park rely heavily on the transporting pipelines which demand higher flowrate and thus higher pumping pressure. This is one of the fundamental factors that contributed to the causes of the incident.

3. Event leading to the explosion

The events leading to the explosion comprised of two separate scenes between the pipeline leak in downtown area and the pipeline operation facilities. Unfortunately, there was no communication between the two scenes even after the explosion.

3.1. Pipe leak scene in downtown

On 20:46 July 31st 2014, an unknown vapor cloud was reported to come out intermittently from manholes of the storm trench beneath the junction of Ersheng 1st Road and Kaixuan 3rd Road as shown in Fig. 2. Nearby residents suspected a gas leak and call the Fire Bureau. Subsequent efforts were made to identify the source of the cloud. These efforts are summarized below.

20:52 Fire fighters from Kaohsiung City Fire Bureau arrived the site, secured the area and began spraying water on the cloud. An incident command post was also setup in the north-west side foot path of the road junction.
21:05 Staff from city gas supplier arrived the site and clarified that it was not their pipeline leaking.
21:15 Kaohsiung Mass Rapid Transit Bureau (MRT), who is in charge of the light rail system, was also notified and its engineer arrived the site. They confirmed that there was no construction work on that night and denied any connection with the gas leak.
21:30 Inspectors from Kaohsiung Environmental Protection Bureau (EPB) arrived the site and gas samples were taken and sent back for analysis.
21:45 Kaohsiung Public Works Bureau (PWB) was notified and confirmed that there was only city gas line in the leaking scene. This information was in conflict with the city gas supplier who insisted that it was not their gas line leaking.
21:50 With conflict information on the leak source and unknown leak gases, the on-scene incident commander from Fire Bureau decided to call EPA Southern Environmental Incidents