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Incident analysis of Bucheon LPG filling station pool fire and BLEVE

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Abstract

An LPG filling station incident in Korea has been studied. The direct cause of the incident was concluded to be faulty joining of the couplings of the hoses during the butane unloading process from a tank lorry into an underground storage tank. The faulty connection of a hose to the tank lorry resulted in a massive leak of gas followed by catastrophic explosions. The leaking source was verified by calculating the amount of released LPG and by analyzing captured photos recorded by the television news service. Two BLEVEs were also studied.

Keywords: LPG filling station; Cause of incident; LPG unloading; Pool fire; BLEVE

1. Introduction

Since the early 1960s, when liquefied petroleum gas (LPG) was first introduced in Korea, the consumption of LPG has been increasing constantly and playing an important role as a clean, convenient, and environmentally friendly fuel for both industrial and residential applications. In 2003, approximately 8,231,000 households consumed LPG, representing 49% of the total household fuel demand in Korea. The amount of LPG consumption reached about 7,304,000 metric tons accounting for 32% of gas fuels consumed in Korea [1].

In 2003, the number of LPG vehicles in Korea was 1,423,000 and accounted for 11% of the total number of vehicles on the road in Korea [2]. As a result, the number of stations for refueling LPG has also seen a remarkable increase. LPG (propane and butane) filling stations in Korea can be divided into three types: (1) cylinders only filling station, (2) combined station for cylinder filling and vehicle refueling, and (3) vehicle-only refueling station. As shown in Table 1, the number of LPG stations has been increasing every year, keeping pace with the increasing use of LPG vehicles.

According to the statistics, in Korea 41 incidents occurred at LPG filling facilities during the last decade, resulting in 8 fatalities and 138 injuries. The normalized consequence per incident from filling facilities is 3.7 persons/incident, which is relatively high compared to average 1.6 persons/incident for all LPG incidents [3].

Currently, the situation with LPG filling stations is getting worse in Korea. In particular, with the expansion of the cities, many LPG filling stations are located in the middle of residential areas thus, the surroundings of LPG stations are always congested and populated. On the other hand, gas transferring as well as filling operation is conducted around the clock to meet the increased demand. Research by Mannan et al. indicates several areas of concern with regard to propane filling hoses [4]. A review of several US incident databases revealed 10 LPG incidents in 1998 in which transfer hose was the equipment involved [10]. Records for two of the incidents indicate that more than 600 people were evacuated due to the release of propane. Fortunately, none of these incidents resulted in fatalities. As for the causes, equipment failure led to six of these incidents, human error was identified as the cause of three incidents, and the cause for one of the incidents could not be determined (Tables 2 and 3).

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Nomenclature

A	leaking area (m^2)
D	diameter of pool fire (m^2)
g	gravity acceleration coefficient (m/s^2)
L	length of flame (m)
$\dot{m}$	mass combustion rate of LPG ($kg/m^2\,s$)
$\dot{m}_\infty$	mass combustion rate of LPG for a pool of infinite diameter ($kg/m^2\,s$)
P_g	gauge pressure (Pa)
$\dot{Q}$	mass leaking rate of liquid at equilibrium ($kg/m^3\,s$)
u	wind velocity (m/s)
u_c	characteristic velocity (m/s)
u^*	dimensionless velocity

Greek letter

ρ_a	density of ambient air (kg/m^3)

Table 1
Classifications of LPG filling stations in Korea

	1999	2000	2001	2002	2003
Cylinder	41	48	48	87	126
Cylinder + vehicle	188	212	258	419	584
Vehicle	433	508	627	761	894
Total	662	768	933	1041	1604

2. Description on the Bucheon accident

2.1. Description of filling station

The schematic layout of Bucheon LPG filling station is illustrated in Fig. 1. The whole area is about 540 m^2 with the main facilities consisting of eight cylinder-filling ends and four vehicle-refueling dispensers. Propane is unloaded from tank lorry of 15 t capacity to an underground storage tank of 29.9 t capacity through unloading arm at vapor pressure. Butane is unloaded from tank lorry of 12 t capacity to an underground storage tank of 39.9 t capacity through flexible hose at vapor pressure. LPG is unloaded to the underground storage tank through 50 mm diameter pipeline equipped with 15 mm diameter vent valves. LPG tank lorries are equipped with safety valve, pump, flexible hose with coupling connections to underground storage tank.

Table 2
Incidents at LPG filling stations in Korea

Year	No. of incidents
1992	3
1993	3
1994	3
1995	3
1996	7
1997	6
1998	3
1999	1
2000	3
2001	2
2002	3
2003	4
Total	41

Table 3
Classification of incidents at LPG filling stations in Korea

Classification	No. of incidents
Explosion	11
Fire	14
Release	14
Burst	2
Total	41

Propane is pumped to the cylinder filling area at about 0.8 MPa of operating pressure and butane is pumped to vehicle dispenser at about 0.5 MPa of operating pressure through 50 mm diameter pipeline. The filled cylinders are stored at stack area or loaded on cylinder truck to be distributed to the agents.

On September 11th of 1998, a loaded propane tank lorry was parked nearby the filling area, while a butane tank lorry was getting ready to unload butane. Around 2:00 pm, the butane tank lorry driver started the initial procedure of unloading. He connected the coupling hose from the tank lorry to the underground storage and switched on the compressor. Although the safety manager was required to monitor the whole procedure, he was not there and the tank lorry driver conducted the procedure by himself without checking whether the LPG was unloaded properly. Instead, he entered the office and took a rest.

2.2. Incident chronology

On September 11th of 1998, a fire and BLEVE (Boiling Liquid Expanding Vapor Explosion) were observed at Bucheon LPG filling station in Korea as shown in Fig. 2. A camera of Korea Broadcasting System (KBS) captured a major part of the incident. Prevailing weather conditions were 2 m/s wind speed in north-north-west direction and 30 °C atmospheric temperature.

According to witnesses, gas leak was observed about 2:06 pm and fire was observed around the butane tank lorry about 2:10 pm. The fire was reported to a fire station at 2:11 pm. The television camera started recording the incident at 2:20 pm. As seen in Fig. 3, considerable amount of heavy smoke was observed, which may be attributed to liquid phase combustion of LPG, i.e., pool fire [5]. Soon after recording began, glass windows at nearby building were observed undamaged, which may indicate that VCE (vapor cloud explosion) had not occurred, in spite of delayed ignition. By about 2:22 pm, fire could not be seen at area *G* as seen in Fig. 4.

Photo captured at about 2:23 pm shows two kinds of LPG fire at the cylinder filling area as shown in Fig. 5. The one with heavy smoke (left side) is a pool fire of liquid phase LPG, and the other without smoke (right side) is combustion of gas phase LPG that leaked through the safety valve of the LPG cylinder heated by the nearby pool fire. The length of pool fire was estimated to be

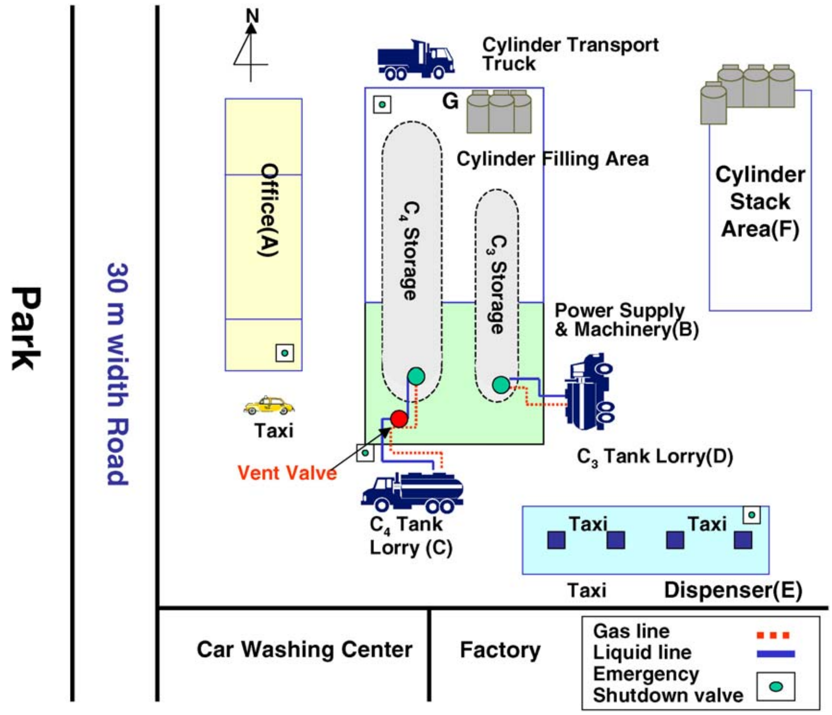

Fig. 1. Schematic diagram of Bucheon LPG filling station.

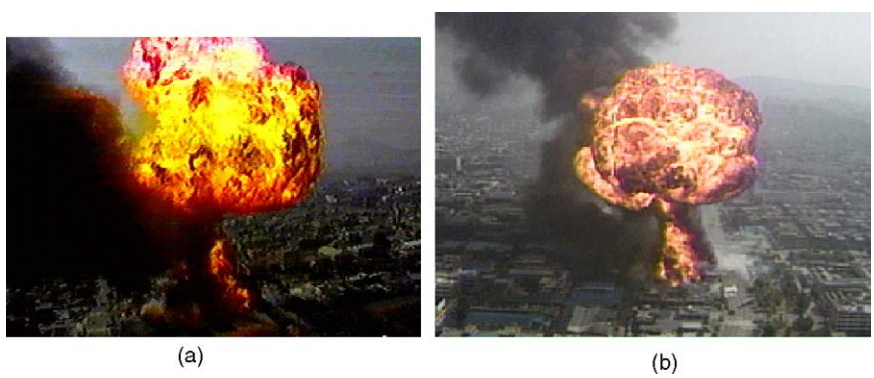

Fig. 2. Explosion of Bucheon LPG filling station by butane (a) and propane (b).

Fig. 3. Fire with heavy smoke at Bucheon LPG filling station.

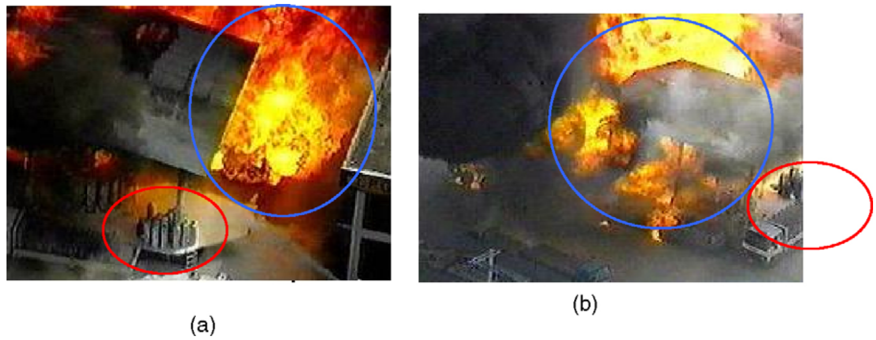

Fig. 4. Pool fire captured from north (a) and northeast (b) of the LPG filling area after about 12 min of fire.

Fig. 5. Pool fire captured from northeast of the LPG filling area after 13 min of fire.

about 20 m by comparison with the nearby building as seen in Fig. 6.

As shown in Fig. 7, a small flame was observed at the propane tank lorry, which was attributed to a flame of purged propane through the safety valve. At about 2:25 pm, the first BLEVE was observed at the propane tank lorry with duration of 9 s. Around 2:27 pm the second BLEVE was observed at the butane tank lorry with duration of 7 s as shown in Fig. 2. The BLEVE durations were decided from the video recorded by the television camera. As a result of the explosions, the body and rear parts of the propane tank was propelled 28.5 and 12.6 m, respectively, from the propane tank body that was deformed to a plate shape as in Fig. 8. The front part of the butane tank was propelled 67.4 m from the plate-shape deformed butane tank body as in Fig. 9.

Fig. 10 shows the LPG station after the fire was extinguished. Most of the facility except the underground storage tanks were burned out including the gas-filling installations, 5750 LPG cylinders, 12 buildings, 12 tank lorries, 113 vehicles, and 9 fire extinguishers. In addition to 1 fatality and 83 injuries, the incident also caused at least 13 million dollars of economic loss, which consisted of 7.4 million dollars of property damage and 5.6 million dollars of damage compensation.

3. Analysis of the incident

The incidental chronology is very dynamic and rather complicated to be analyzed precisely. In this work, a brief analysis has been conducted on the initial release quantity and fireball phenomena. As seen in Fig. 3, the first part of the incident was the pool fire. The flame length for a tilted flame can be estimated

Fig. 6. Average height of pool fire estimated from office building height.

Fig. 7. Flame surrounding butane tank lorry and small flame by purged butane through safety valve.

Fig. 8. Propane tank lorry after explosion: (a) body and (b) rear part of tank.

Fig. 9. Butane tank lorry after explosion: (a) body and (b) front part of tank.

by the following equation [6]:

$$\frac{L}{D} = \left[\frac{\dot{m}_{\infty}}{\rho_{\mathrm{a}}\sqrt{gD}}\right]^{-0.19}(u^{*})^{0.06} \quad (1)$$

with $u^{*} = u/u_{\mathrm{c}}$ and $u_{\mathrm{c}} = \sqrt[3]{g\dot{m}_{\infty}D/\rho_{\mathrm{a}}}$.

The diameter of the pool fire was estimated by Fig. 6 and Eq. (1). With the flame length $L = 20$ m, $\dot{m}_{\infty} = 0.078\,\mathrm{kg/m^2 s}$ for butane, $\rho_{\mathrm{a}} = 1.3\,\mathrm{kg/m^3}$, $g = 9.81\,\mathrm{m/s^2}$, the diameter of pool fire D is estimated as 7.8 m. Then the amount of LPG involved in the pool fire before BLEVE was estimated by Eq. (2) [7]:

$$\dot{m} = \dot{m}_{\infty}[1 - \exp(k\beta D)] \quad (2)$$

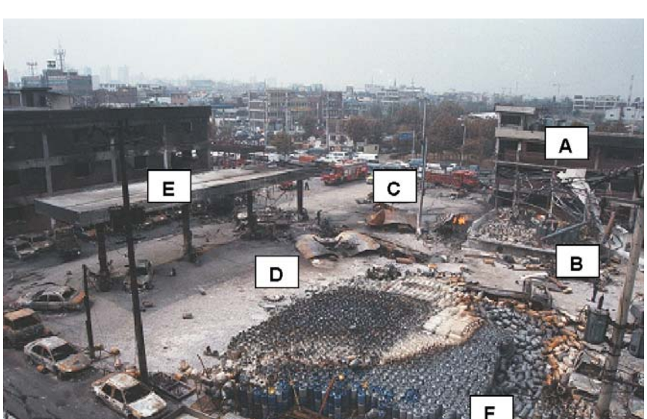

Fig. 10. Bucheon LPG station just after fire was extinguished: (A) office (B) power supply and machinery, (C) butane tank lorry body, (D) propane tank lorry body, (E) dispenser, and (F) LPG cylinder stack area.

where $k\beta = 2.7\,\mathrm{m^{-1}}$ for butane. The combustion rate, $\dot{m}$, can be estimated as $0.078\,\mathrm{kg/m^2\,s}$. The amount of butane involved in the pool fire before the occurrence of BLEVE was estimated to be about 4461 kg. Therefore, more than 4 t of butane has been leaked that resulted in a pool fire. This fire heated the tank lorries, which finally resulted in the BLEVE.

Since LPG unloading and filling activities are conducted simultaneously in a congested area, the potential exposure to fire hazards is quite significant. Degraded attachments or joints at unloading and refueling lines could be the source of small leaks of LPG. Large leaks might result from faulty coupling due to operator error or detached end of dispenser because of lack of awareness and sudden start (and movement) of refueled vehicle. Although smoking in the station area is absolutely prohibited and the drivers are requested to turn off vehicle during refueling, lack of awareness or ignorance to these rules could lead to ignition. In this work, two potential release scenarios were postulated and then examined; one is through the vent valve and the other is through the improperly disconnected unloading hose of the butane tank lorry. Since no unloading activity was being conducted with the propane tank lorry, butane tank lorry was taken as the potential release source. Other potential sources were estimated to be too small to cause such a large pool fire.

For the disconnected hose scenario, butane is stored under pressure above its boiling temperature. When the unloading hose of the butane tank lorry is improperly disconnected, the liquid will partially flash into vapor upon escaping, presenting a complicated two-phase flow scenario. To tackle this scenario, two calculations are made based on extreme conditions. The real case lies between these two results.

For the first calculation, flashing is assumed to occur external to the hose. The model for incompressible fluid flowing through a hole applies based on this assumption. The initial leaking rate from a completely open hose can be calculated by Eq. (3) [8]:

$$\dot{Q} = AC_0\sqrt{2\rho g_c P_g} \quad (3)$$

Here A is the area of the release (50 mm in diameter for the hose); C_0 is the discharge coefficient (0.81 for a short sections of pipe attached to a vessel); ρ is the density of the liquid butane (600 kg/m^3); P_g is the gauge pressure within the vessel.

For the second calculation, it is assumed to achieve equilibrium flashing conditions and the flow is choked since the fluid is released through a pipe greater than 10 cm and the tank lorry pressure is higher than the saturation vapor pressure [8]:

$$\dot{Q} = AC_0\sqrt{2\rho g_c (P - P^{sat})} \quad (4)$$

Here P^{sat} is the saturation vapor pressure of butane at 30 °C (282 kPa). Therefore, according to the above two calculations, the real release flow rate will be between 25.7 kg/s and 34.8 kg/s with a completely open unloading hose.

For the scenario of release through the vent, it is assumed to achieve equilibrium flashing conditions before the release and the flow is choked. The leaking rate of butane can be estimated by the Eq. (4) which is 1.7 kg/s with a vent diameter of 15 mm and C_0 of 0.61 for a valve.

The total amount of butane released through the vent during 20 min, i.e., before BLEVE started, is estimated to be 2040 kg, which is much less than 4461 kg as estimated by Eq. (1). In contrast, for the completely disconnected hose scenario, the total quantity of butane released is between 30,840–46,080 kg, which is much greater than 4461 kg estimated. Therefore, it is reasonable to conclude that the unloading hose was partially disconnected, but not as bad as completely open, caused the pool fire.

Two fireballs were observed by BLEVE, which can be analyzed by the following equations [9]:

$$t_{BLEVE} = 0.852 M_{fireball}^{0.26} \quad (5)$$

$$D_{max} = 6.48 M_{fireball}^{0.333} \quad (6)$$

The first fireball occurred at the propane tank lorry. The quantity of propane involved in the fireball is estimated as 8.66 t using Eq. (5). The maximum diameter of the fireball is estimated as about 133 m by Eq. (6). It can be seen that the diameter of fireball in Fig. 2 is about 130 m by comparison with the nearby building.

The second fireball occurred at the butane tank lorry. The amount of butane involved in the fireball is estimated as 3.3 t using Eq. (5). The maximum diameter of the fireball is estimated at about 96 m using Eq. (6). It can be seen that the diameter of fireball in Fig. 2 is about 90 m by comparison with the nearby building.

4. Conclusions

An LPG filling station incident that occurred on September 11th of 1998 in Korea has been examined. Potential release sources were evaluated and verified by analyzing captured photo recorded by a TV broadcasting company. Before the BLEVE occurred, the released butane caused a pool fire, which was ignited by an unknown ignition source. During 20 min, about 4.5 t of butane was released and burned, heating up nearby LPG cylinders and two tank lorries parked at the unloading area. The first BLEVE was observed at the propane tank lorry with a maximum diameter of about 130 m while the second one was observed at the butane tank lorry with a maximum diameter of about 90 m.

The direct cause of the incident was concluded to be faulty joining of the couplings of the hoses in the butane unloading process from the tank lorry into the underground storage tank. As a result, more stringent management systems for LPG filling stations have been promulgated and implemented in Korea such as the installation of water curtains at unloading areas, using loading arms instead of hoses, and much larger safety distances between unloading and filling areas.

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