LPG충전소에서 증기운폭발에 의한 화염의 피해에 관한 연구

임사환† · 허용정*
한국기술교육대학교 기계공학과 · *한국기술교육대학교 메카트로닉스공학부
(2010. 3. 11. 접수 / 2010. 6. 8. 채택)

A Study on the Damage of Flame caused by the Vapor Cloud Explosion in LPG Filling Station

Sa-Hwan Leem† · Yong-Jeong Huh*
Department of Mechanical Engineering, Korea University of Technology and Education
*School of Mechatronics Engineering, Korea University of Technology and Education
(Received March 11, 2010 / Accepted June 8, 2010)

Abstract : LPG(Liquefied Petroleum Gas) vehicles in metropolitan area are being applied to improve air quality and have been proven effective for the reduction of air pollutant. In addition, LPG demand is growing rapidly as an environmentally friendly energy source and its gas station is also increasing every year. Consequently, this study tries to find out the influence of flame caused by the VCE(Vapor Cloud Explosion) in filling station on the adjacent combustibles and people by simulating relevant quantity of TNT. In addition, the damage estimation was conducted by using API regulations. If the scale of the radiation heat is known by calculating the distance of flame influence from the explosion site, the damage from the site can be easily estimated. And the accident damage was estimated by applying the influence on the adjacent structures and people into the PROBIT model. According to the probit analyze, the spot which is 30m away from the flame has 100% of the damage probability by the first-degree burn, 99.2% of the damage probability by the second-degree burn and 93.4% of the death probability by the fire.

초 록 : 액화석유가스 자동차는 대도시의 대기환경 개선을 위해 적용되고 있으며 대기 오염물질을 저감시키는데 효과적인 것으로 입증되고 있다. 이와 더불어 환경 친화적인 에너지원으로서 가스의 수요가 날로 급증하고 있으며, LPG 충전소도 해마다 증가추세이다. 따라서 본 논문에서는 충전소에서 증기운폭발에 의한 화염의 영향으로 인간에게 미치는 영향을 알아보고자 한다. 이를 위하여 API에서 규정한 피해예측을 통하여 평가를 실시하였다. 폭발장소에서의 화염에 의해 미치는 영향 거리를 산출하여 거리별 복사열의 크기를 알게 되면 그 지점에서의 피해는 간단하게 예측할 수 있다. 또한 폭발장소 주변에 위치한 인간에게 미치는 영향을 PROBIT 모델에 적용하여 사고피해예측을 평가하였다. 프로빗 분석에 의하면 화염에서 30m 이격된 곳은 1도 화상에 의한 손상확률이 100%, 2도 화상에 의한 손상확률은 99.2%, 화재로 인한 사망확률은 93.4%로 나타났다.
Key Words : damage estimate, gas explosion, fireball, LPG filling station

1. Introduction

LPG(Liquefied Petroleum Gas) vehicles in metropolitan area are being applied to improve air quality and have been proven effective for the reduction of air pollutant[1)].

Especially, USA, EU(European Union), Japan, China etc. have greatly enhanced the car's carbon dioxide emission regulations and fuel efficiency standards since 2,000[2)].

In case of Germany, there were only 30,000 LPG vehicles and 600 LPG stations in 2004 but they were expanded more than 70,000 automobiles and 1,000 stations in 2006[3)].

LPG bus station in Europe appears to be a success, the demand is increasing. To solve the air pollution in urban areas, especially, LPG is projected as a relatively cost-effective alternative[4)].

† To whom correspondence should be addressed.
leemsahwan@kut.ac.kr

Table 1. The state of LPG Consumption (units : 1,000ton)

Section	2004	2005	2006	2007	2008	Rate of increase(%)
Business	2,065	2,184	2,081	1,911	1,679	△5.4
City gas	75	96	69	62	178	2.8
Traffic	3,860	3,968	4,069	4,366	4,379	3.9
Industrial	481	509	504	637	650	4.2
Fuel	1,226	1,236	1,445	1,516	2,045	13.6

These fuel sources for vehicle's operating have been recently turned from gasoline to the gas a little bit. As shown in Table 1, the LPG quantity for transportation has gradually increased an average 3.9% each year[5,6].

Changes to the gas fuel are the problems of the 'survival' beyond the 'quality of life' improvements and revive a new paradigm of 'sustainable development' which pursues economic development in harmony with environmental conservation[4].

When we use gas as fuel, it is effective in improving the environment by significantly reducing air pollutant emissions and it has a good efficiency in terms of economic aspects because of a high-octane number.

However, gas accidents occur with various causes and types. Also, the potential dangerous factors always exist in industry and in the home, and the same types of accidents occur repeatedly[7].

Especially, the representative examples of the accident in gas station occurred in IKSAN gas station (VCE) and BUCHEON gas station(BLEVE) and it resulted in many casualties and loss of enormous property[8-10].

With this as a momentum, the installation of storage tanks type regulations are buried underground or ground type to prevent accidents pursuant to Article 1[facility and technic standards of liquefied petroleum gas business] of Liquefied Petroleum Gas Safety Management and Business Law Enforcement Regulations Article 10[11].

Table 2. The state of LPG filling system(Locating type)

(units : ea)

Section	The storage tank(Locating type)			
	Above ground	Underground		Total
		Burial	Containment	
Total	173	1,703	110	1,986
Vessel	29	38	3	70
Vehicle	33	1,219	36	1,288
Vessel and Vehicle	70	420	70	560
Other	41	26	1	68

LPG storage tank status installed in charging facilities applied by the current regulatory laws is shown in Table 2 and all of the 65% are installed in filling station[5].

According to research results of In-Won Kim (2001)[12], such as LPG gas leak in charging facilities occurred once in 80 years and The most important factors causing the accident were structural defect and external accident.

The storage tank installed above the ground pursuant to the current regulations could cause VCE and BLEVE[13-16] by a gas leak and buried underground type tank is extremely vulnerable to corrosion connoting dangerousness and economical efficiency.

Therefore, this study is to provide the damage distance of gas explosion against the accidents happened by improper handling in the facilities.

2. Theory and Computation Method

The gas explosion is seriously influenced by the explosion pressure, and the variables are fuel, kinds of oxidizer, the concentration and size of vapor cloud, the ignition spot, the strength of ignition source, the size, place, and type of vent, the surrounding obstacles, the method to make the smallest damage and so on[17-20].

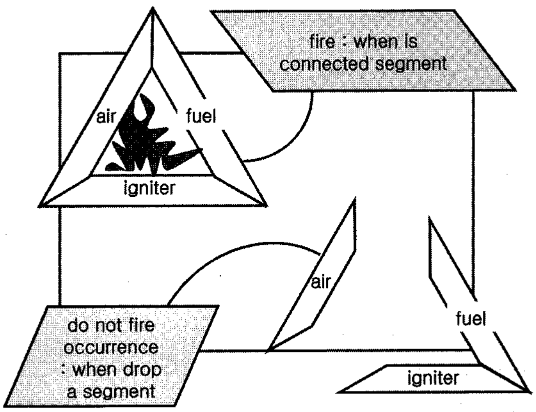

Fig. 1. 3 elements of fire.

Table 3. Classification of country fire

Grade of fire	Korea/Japan	America	Germany
A (General fire)	General combustibles of wood, paper, textile etc.	Such as left	Such as left
B (Oil fire)	Oil (combustibility liquid inclusion)	Such as left	Such as left
C (Electric fire)	Electric	Such as left	Gas (compression, liquid)
D (Metal fire)	Metal	-	Such as left
E (Gas fire)	Gas (compression, liquid)	Such as left	Electric

Also, the gas explosion accident turns into a fire, and the damage by this flame is very serious[21].

Like Fig. 1, a fire cannot occur although one of three elements is excluded as a triangle cannot be made without one side.

Classification of fire is very important for extinguishment. The level of fire is set based on the kind and nature of flammable materials of the elements that makes fire. Korea divides the level of fire into A, B, C, D and E like America and Japan. However it is classified roughly into A, B and C by the frequency of fire generation, and it is generally used. Table 3 is the classification of fire of Korea, America, Japan and German based on the flammable materials which make combustion at fire.

Korea usually follows the regulations of America. Proper extinguishing method should be chosen according to the above classification of fire. If it is not followed, more dangerous accident can be happened.

The damage of radiant heat by the fire is serious, and the formula of the radiant heat is as follows[22-25].

2.1. Calculating the amount of leakage

Domestic LPG pipe lines in the filling station consist of 50A in the size of liquid line and 25A in the size of gas lines. So, in order to figure out the accident damage up to the maximum, it was calculated by a scenario that seems to be leaked from the liquid line.

Incompressible fluid charges most of the leak in the liquid line and if energy changes in piping and pressure drop effects were ignored, the leakage rate can be expressed as follow by the energy balance equation[26,27].

$$Q = C\rho_L A\sqrt{\frac{2g(P_0 - P_{atm})}{\rho_L}} \quad (1)$$

Q : Velocity of leakage by mass(kg/s)
C : Friction Coefficient
- Sharp orifice 0.6, Round orifice 0.99

ρ_L : Liquid Density(kg/m^3)
A : Leakage area(m^2)
g : Gravity acceleration(9.81m/sec^2)
P_0 : Pressure of storage tank(Pa)
P_{atm} : Atmospheric pressure(Pa)

2.2. Calculating the size of fireball

$$D_{fireball} = 5.8 \times M_{fireball}^{1/3} \quad (2)$$

$D_{fireball}$: The largest diameter of fireball(m)
$M_{fireball}$: Early leaking amount of flammable liquid(kg)

2.3. Calculating the continuance time of a flame

$$t_{fireball} = 0.45 \times M_{fireball}^{1/3} \quad (3)$$

$t_{fireball}$ = Continuance time of a flame(second)

2.4. Calculating the height of the center of fireball

$$H_{fireball} = 0.75 \times D_{fireball} \quad (4)$$

$H_{fireball}$: The height of the center of fireball(m)

2.5. Calculating atmospheric transmissivity

$$\tau_a = 2.02(P_{P_{water}} \times X_S)^{-0.09} \quad (5)$$

$$P_{P_{water}} = RH \times P_{water} \quad (6)$$

$$P_{water} = 0.0060298 \times P_a \times \exp\left\{5407\left(\frac{1}{273.15} - \frac{1}{T_a}\right)\right\} \quad (7)$$

τ_a : Permeation degree(Dimensionless)
X_s : The distance from the surface of fireball to

the damaged point(m)

$$X_S = \sqrt{(H_{fireball}{}^2 + L_{fireball}{}^2)} - \frac{D_{fireball}}{2} \tag{8}$$

P_{water} : Steam pressure of water(Pa)
T_a : Temperature of atmosphere(K)
RH : Relative humidity(%)
P_a : Pressure of atmosphere(Pa)
$L_{fireball}$: The horizontal distance from the center of fireball to the damaged point(m)

2.6. Calculating radiation energy of surface

$$E = \frac{R \times M_{fireball} \times H_C}{3.14 \times D_{fireball}{}^2 \times t_{fireball}} \tag{9}$$

E : Radiation energy of surface(kJ/m^2 · s)
R : Radiation ratio of combustion heat (Dimensionless) 0.4(The case that a container or a pipe breaks at over the set pressure of pressure radiation equipment)
H_c : Genuine combustion calory(kJ/kg)

2.7. Calculating view factor

$$F_V = \frac{L_{fireball} \times \left(\frac{D_{fireball}}{2}\right)^2}{(L_{fireball}^2 + H_{fireball}^2)^{\frac{3}{2}}} \tag{10}$$

2.8. Calculating radiation

$$Q_{fireball} = \tau_a \times E \times F_V \tag{11}$$

$Q_{fireball}$: Radiation at a certain point(kW/m^2)

2.9. Probit analyze

The human injury degree by the heat radiation is calculated with the exposure time to the flame, the size of the radiant heat and the probit analyze model formula[28-30].

$$P = \frac{1}{(2\pi)^{\frac{1}{2}}} \int_{-\infty}^{Y=5} \exp\left(-\frac{u^2}{2}\right) du$$

$$Y = k_1 + k_2 \ln V$$

(1) In the case of first-degree burn

$$P_r = -39.83 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{4}{3}}\right)\right] \tag{12}$$

(2) In the case of second degree burn

$$P_r = -43.14 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{4}{3}}\right)\right] \tag{13}$$

(3) In case of death caused fire

$$P_r = -36.38 + 2.56\left[\mathrm{Ln}\left(tQ^{\frac{4}{3}}\right)\right] \tag{14}$$

P_r = Probability value(Probit value)
t = The time of exposure[sec]
Q = Intensity of radiant heat[W/m^2]

3. Estimate of damage and Results

20tons and 30tons of storage tanks correspond to the 80% of domestic LPG filling stations. In this paper, the leakage from the liquid line of facility is targeted to maximize the scale of accident damage.

The result calculated by equation (1) is about 1,995 kg, assuming that the crisis response time is 1'30" including blocking time of emergency shut-off valve. This value is 10% of the storage capacity 20tons, therefore, leakage amount is selected into 2,000kg.

According to API521 and World bank, the criterion of the effect of radiant heat is as Table 4, 5.

To predict the damage to humans, the numerical value which comes out from the probit analyze formula is applied to the formula (1), (2), (3), and (4) like

Table 4. Time of feeling an ache(API521)

Intensity of radiant heat		Time that begin to sting(sec)
(Btu/ft^{2}hr)	(kW/m^2)	
500	1.6	60
740	2.3	40
920	2.9	30
1500	4.7	16
2200	6.9	9
3000	9.5	6
3700	11.7	4
6300	19.9	2

Table 5. The effect of radiant heat(Word bank)

Intensity of radiant heat (Btu/ft²hr)	Intensity of radiant heat (kW/m²)	Effect
11900	37.5	Equipment and facilities are damaged.
7900	25	If it is exposed for a long time, a wood is caught fire by the minimum energy.
4000	12.5	The minimum energy which is enough for ignition of a wood or a plastic tube.
3000	9.5	Feel a severe pain 8 seconds later and got burnt of the second degree 20 seconds later.
1300	4	If it is not protected in 20 seconds, an ache is felt and the skin is swollen.
500	1.6	If it is exposed for a long time, discomfort is felt.

Table 6. Related value of fireball

M(kg)	D(m)	t(s)	H(m)
2000	73.075	5.67	54.81

Table 7. Related value of C_3H_8+C_4H_{10}

C_3H_8+C_4H_{10}	kcal/kg	kJ/kg
10%+90%	12341.88	51656.94

Table 6. Also, Table 7 is combustion energy of LPG.

According to Liquefied Petroleum Gas Safety Control and Business Law, the separated distance between storage capacity of 20tons and 30tons is 30m.

For the calculation of the radiant heat of Table 8, the numerical value which comes out from the formula (2), (3) and (4) is applied to the formula (8), and then we can get the distance from the surface of the fuel intake to the damage spot.

At first, the temperature, air pressure and humidity of the time when the fire occurs are applied to the formula (7), and the result is applied to formula (6), and the final value is applied to the formula (8) and (5). Then, we can get the Permeation degree.

To get the surface radiant energy, the values of the formula (2), (3), (4) and of the Table 7 are applied to the formula (9).

And the value of visual factor is calculated by applying the formula (2), (3) and (4) to the formula (10).

Also, the human injury degree by the heat radiation can get by applying the Permeation degree, the radiant energy and the visual factor which come out from the above to the formula (11) like Table 8.

The relationship between the probability value and the percentage of the human injury degree by the heat radiation is like Fig. 2[31], and the calculated values

Table 8. Calculated value of radiant heat

L(m)	X_s(m)	P_{water}	$P_{P_{water}}$	τ_a	E (kJ/m² · s)	Fv	Q (kW/m²)
8.5	18.93	2357.95	35.369	1.1247	434.678	0.0665	32.51
11.5	19.47	2357.95	35.369	1.1218	434.678	0.0874	42.62
12	19.57	2357.95	35.369	1.1213	434.678	0.0907	44.21
13.5	19.91	2357.95	35.369	1.1196	434.678	0.1002	48.76
15	20.29	2357.95	35.369	1.1177	434.678	0.1091	53.02
17	20.85	2357.95	35.369	1.1149	434.678	0.1201	58.20
21	22.16	2357.95	35.369	1.1089	434.678	0.1386	66.82
24	23.29	2357.95	35.369	1.1039	434.678	0.1496	71.77
27	24.56	2357.95	35.369	1.0986	434.678	0.1580	75.47
30	25.95	2357.95	35.369	1.0932	434.678	0.1642	78.02
50	37.65	2357.95	35.369	1.0572	434.678	0.1635	75.12
75	56.36	2357.95	35.369	1.0195	434.678	0.1249	55.35
100	77.49	2357.95	35.369	0.9907	434.678	0.0900	38.77
150	123.16	2357.95	35.369	0.9502	434.678	0.0492	20.31
200	170.84	2357.95	35.369	0.9227	434.678	0.0299	12.01

*temperature: 20.0, humidity: 15%, atmosphere: 760.0

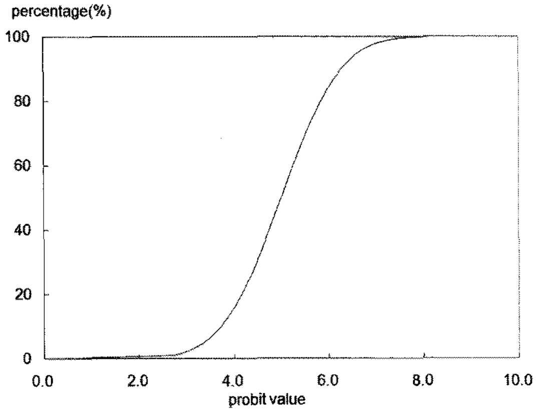

Fig. 2. Relationship with probability value and percentage.

by using the formula (12), (13) and (14) to apply to that are like Table 9.

If the values of Table 9 are applied to Fig. 2, we can get the damage type by the radiant heat.

This study researched the damage using the probit model and the value which we got from the probit model was 30m like Table 9. So we judged that the burn by the explosion of gas would be serious.

The probit model in about 30m of radius distance between the storage tank which is used to charge gases in the filling station and the field workers was calculated with the interpolation, and then we applied the result to Fig. 2, so the damage probability by the

Table 9. Probit value by distance of LPG 2,000kg

Z(m)	Possibility with a first degree burn	Possibility with second degree burn	Possibility with burnt to death
8.5	7.22270864	3.912709	3.524238
11.5	8.31252745	5.002527	4.448487
12	8.45994533	5.149945	4.573508
13.5	8.85421191	5.544212	4.907876
15	9.19132472	5.881325	5.193773
17	9.56650109	6.256501	5.511951
21	10.1223947	6.812395	5.98339
24	10.4100235	7.100024	6.227321
27	10.6123449	7.302345	6.398905
30	10.7460889	7.436089	6.51233
50	10.593636	7.283636	6.383039
75	9.36442114	6.054421	5.340572
100	7.93147196	4.621472	4.125323
150	5.32930443	2.019304	1.918489
200	3.2147802	-0.09522	0.125213

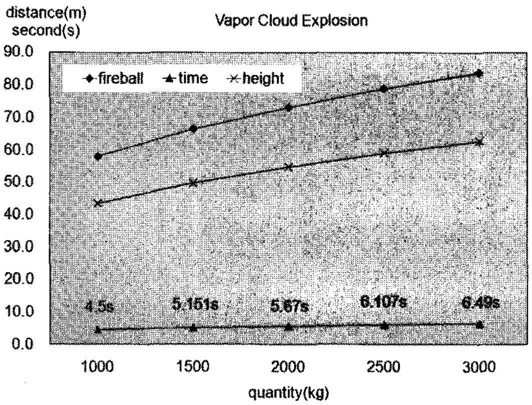

Fig. 3. Value for fireball.

first-degree burn was 100%, the second-degree burn was 99.2% and the death probability by the fire was 93.4%.

We got the size of the fuel intake and the lasting hour of the flame caused by the vapor cloud explosion in filling station by using the formula (2), (3) and (4), and the result is like Fig. 3. According to Fig. 3, every value goes up when the volume is increased.

Fig. 4 is about the amount of the heat radiation by the temperature and the humidity in the field of summer, and what we can see there is little effect by the pressure of the atmosphere by Fig. 5, but the radiant heat goes up when the temperature and the humidity decrease.

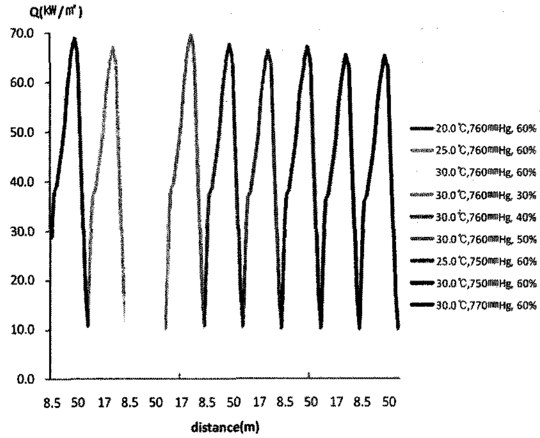

Fig. 4. State with temperature and humidity.

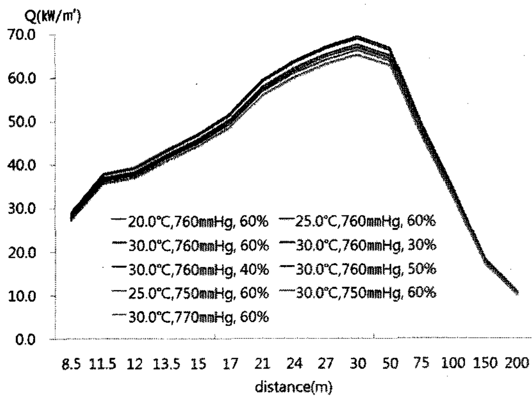

Fig. 5. Radiant heat by distance.

Table 10. Possibility of damage effect about distance of LP gas 2,000kg

Z(m)	Possibility with a first degree burn	Possibility with second degree burn	Possibility with burnt to death
8.5	98.60%	13.80%	7.10%
11.5	100%	50.00%	28.90%
12	100%	55.90%	33.40%
13.5	100%	70.80%	46.40%
15	100%	81.00%	57.70%
17	100%	89.50%	69.60%
21	100%	96.50%	81.10%
24	100%	98.20%	88.90%
27	100%	98.90%	91.80%
30	100%	99.20%	93.40%
50	100%	98.80%	91.60%
75	100%	85.30%	63.40%
100	99.80%	35.40%	19.10%
150	62.90%	0.80%	0.70%
200	3.70%	0%	0%

Finally, Table 10 displays the human injury possibility by the heat radiation, it can get by applying the Table 9 to the Fig. 2.

4. Conclusions and discussion

This study calculated the accident occurrence probability for the damage by the radiant heat by using the probit analyze.

The following conclusion is come out through this study.

1) 78kW/m^2, the calculated value on the damage to the human body by the radiant heat is shown as 30m from the heat of fire, and even though the lasting hour of the flame is so short, we judge that it may be dangerous.

2) According to the probit analyze, the spot which is 30m away from the flame has 100% of the damage probability by the first-degree burn, 99.2% of the damage probability by the second-degree burn and 93.4% of the death probability by the fire.

Therefore, we think the minimum distance length should be maintained to reduce the damage by the heat of fire through the result of this study. Also, we want to continue our research and find out the damage range of safety accident by the flame based on the gas concentration and by the splinters of the explosion through the experiments.

References

1) Ministry of environment, http://me.go.kr/kor
2) U.S. EPA, Green Vehicle Guide (http://www.epa.gov/autoemissions/about.html), 2002.
3) So-Young Park, "German gas market trends - LPG gas increasing popularity of alternative fuels", The Gas Safety Journal, Vol.35, pp. 77～80, 2009.
4) AEGPL, AEGPL Strategy Paper - LPG Heavy Duty Vehicles, p. 3, 1999.
5) Korea Gas Safety Corporation, Technical Inspection & Advisory Service Division, "High-pressure Gas Statistics", 2009.
6) Korea Statistical Information System Consumption data of Energy source. http://kosis.nso.go.kr
7) Korea Gas Safety Corporation, "2008 Gas Accident Yearbook", Taein, 2006.
8) In-Tae Kim, In-Won Kim, Hee-Oeul Song, "A Study on the Overpressure Estination of BLEVE", Journal of the Korean Institute of Gas, Vol. 4, No. 1, March, pp. 69～76, 2000.
9) Seung-Lim Lee and Young-Soon Lee, "A Study on the Probability of BLEVE of Above-ground LP Gas Storage Tanks Exposed to External Fire", Journal of the Korean Institute of Gas, Vol. 7, No. 1, March, pp. 19～23, 2003.
10) Reid, R. C., "Some Theories on Boiling Liquid Expanding Vapor Explosions", Fire, March, pp. 525～526, 1980.
11) Korea Gas Safety Corporation, "Liquefied Petroleum Gas Safety Control and Business Law", 2007.
12) Sang-Hwa Jin, Tae-Woo Kim, In-Tae Kim, In-Won Kim and Yeong-Koo Yeo, "A Study on Reliability Analysis and Quantitative Risk Analysis for Liquefied Petroleum Gas Station", Journal of the Korean Institute of Gas, Vol. 5, No. 4, December, 40～48, 2001.
13) Seung-Lim Lee, "A Syudy on the Probability of BLEVE of Aboveground LP Gas Storage Tanks Exposed to External Fire", Seoul National University of Technology, Thesis for Master's Degree, 2001.
14) CCPS, "Guidelines for Evaluating the Characteristics of Vapor Cloud Explosion, Flash Fire, and BLEVEs", Center for Chemical Process Safety, AIChE, New York, USA, 1994.
15) Wiekema, B. J., "Vapour Cloud Explosion Model", J. of Hazardous Materials, Vol. 3, pp. 221～232, 1980.
16) Baker, Q. A., Tang, M. J., Scheier, E. A., and Silva, G. J., "Vapour Cloud Explosion Analysis", 28th Loss Prev. Symp., AIChE, April, 1994.
17) Dag Bjerketvedt, Kees Van Wingerden, Jan Roar Bakke, "Gas Explosion Handbook", Elsevier Science, pp. 40～65, 1997.
18) Kyu-hyung Oh, "A Study on the Explosion Relief Venting in the Gas Explosion", Journal of The Korean Society of Safety, Vol. 20, No. 3, pp. 71～77, 2005.
19) Crowl, D A. and J. F. Louvar, "Chemical Process Safety: Fundamentals with Applications", Prentice Hall, New Jersey, pp. 82～151, 1990.
20) Young-Soon Lee, Soo-Hyun Chae and Soo-Il Jung, "A Experimental Study on the Characteristics of Gas Explosion due to Vent Shape and Size", Journal of the Korean Society of Safety, Vol. 21, No. 3, pp. 38～44,

2006.

21) Kyu-Hyung Oh, Sung-Eun Lee and Kwang-Won Rhie, "A Study on the Transition of Hydrogen-Air and LPG-Air Explosion to Fire", Journal of the Korean Society of Safety, Vol. 19, No. 4, pp. 150～154, 2004.
22) M. Hattwing and H. Steen, "Handbook of Explosion Prevention and Protection", Wiley-VCH Verlag GmbH & Co. KGaA, 2004.
23) Van Dolah, R. W. and Burgess, D. S., "Explosion Problems in the Chemical Industry", The American Chemical Society, 1970.
24) Van Buijtenen, C. J. P., "Calculation of Amount of Gas in the Explosive Resion of a Vapour Cloud Released in the Atmosphere", J. Hazardous Materials, 3, pp. 201～220, 1980.
25) Sa-Hwan Leem and Yong-Jeong Huh, "A Study on the Damage of Fireball by the Butane-can Explosion", Journal of the Korean Society of Safety, Vol. 22, No. 4, pp. 110～116, 2007.
26) Frank, P.L., "Loss Prevention in the Process Industries", 2nd edition, Butterworth-Heinemann, 15/1, 1996.
27) Yonng-Do Jo, "A Study on the Minimum Safe Separation Distance from LPG Filling Station", Journal of the Korean Institute of Gas, Vol. 3, No. 2, July, 1999.
28) W. K. Crowl, Structure to Resist the Effects of Accidental Explosion, Technical Manual TM 5-1300, U. S. Army, Navy and Air Force, U. S. Government Printing Office, Washington D.C., 1969.
29) R. J. Harris, M. R. Marshall and D. J. Moppett, "The Response of Glass Windows to Explosion Pressure", Symp. Series No. 49, ICJemE, 1977.
30) Frank P and Less, M. I. Ang, "Safety Cases", Butterworth & Co. Ltd., 1989.
31) D. J. Finney, Probit Analysis, 3rd Ed., 1971, p.23, Reprinted by permission of Cambridge University Press, London.