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A Study on the Estimation of Human Damage Caused by the LP Gas Flame in Enclosure using Probit Model

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Abstract - The energetic and environmental problems have been getting serious after the revolution of modern industry. Therefore, demand of gas as an eco-friendly energy source is increasing. With the demand of gas, the use of gas is also increased, so injury and loss of life by the fire have been increasing every year. Hence the influence on flame caused by Vapor Cloud Explosion in enclosure of experimental booth was calculated by using the API regulations. And the accident damage was estimated by applying the influence on the adjacent structures and people into the PROBIT model. According to the probit analysis, the spot which is 5meter away from the flame has nearly 100% of the damage probability by the first-degree burn, 27.8% of the damage probability by the second-degree burn and 14.5% of the death probability by the fire.

Key words : human damage, lpgas flame, estimation, probit analysis

Ⅰ. Introduction

The use of gas has dramatically increased in industry and in the home because the gas is an eco-friendly energy source, so it plays a pivotal role in industry. With the development of the industry, the desire for safety of humans has increased.

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.

Especially, the gas explosion accidents cause a severe loss in our society.

According to the Ministry of Economy of Japan, Nuclear and industrial safety agency, The high Pressure Gas Safety Institute of Gas, Japan LPgas Association, The Japan Gas Association, Agency for Natural Resources and Energy and British Petroleum, for the last five years, accidents, status and types of Korea, Japan and England are as below in Table 1 and Table 2.[1-8]

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The study on the damage range by the gas explosion such as flame behavior and safety of the gas fire was preceded, but it is insufficient to calculate the damage distance for provision of the accident which can be occurred by unsuitable treat of

Table 1. The present state of LPG accident.
(units : Ea)

Section	2005	2004	2003	2002	2001
Korea	88	82	92	84	92
Japan	99	105	120	90	87
England	174	153	116	130	161

Table 2. Accident by Explosion and Fire.
(units : Ea)

Section	2005	2004	2003	2002	2001
Korea	62	65	84	78	86
Japan	98	129	169	125	101
England	36	34	30	43	38

gas facility. Therefore, we want this study to be used as a basic data to set up the boundary for the explosion in enclosure of experimental booth (11.4㎥).[9,10]

II. The Equation and Theory

The gas explosion can be divided into the explosion in a closed space and the explosion in an open space, and the pressure which is made by the gas explosion can cause the damage to humans and structures. Also, the explosion can be advanced to a fire and an accident such as BLEVE.[11-14]

"BLEVE" is an acronym for boiling liquid, expanding vapor explosion.

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.[15-17]

Also, the gas explosion accident turns into a fire, and the damage by this flame is very serious.[18]

Table 3. Classification of country fire.

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

Table 3 is the classification of fire of Korea, America, Japan and German based on the flammable materials which make combustion at fire.

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.

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. [19-22]

2.1 Combustion theory

Combustion is a kind of oxidation reaction which combustibles are combined with oxygen, but it means 'chemical reaction' which has flames and heat(Tatyana et al., 1998).[23] According to Korea gas & Petroleum appliance association(1994)[24], the combustion equation of hydrocarbon is as follows.

$$C_mH_n + \left(m + \frac{n}{4}\right)O_2 \rightarrow mCO_2 + \frac{n}{2}H_2O \qquad (1)$$

This equation is called 'the theory air' which is the minimum air quantity for burning out 1㎥ of air of the normal status. So, for examples, that for propane gas(C_3H_8) can be by using the formula(1) and then got the formula(2).

$$C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 5(3.76N_2) + Energy \qquad (2)$$

The calculation of the quantity of theory air of LP gas is shown in Table 4.

It is known that the theory quantity of each gas is almost same as about 0.9~1.0 per 1000㎉/㎥ of the caloric value.

As a matter of fact, however, it cannot make

Table 4. Theoretical air demand of LPG combustion.

Ingredient	A Contain volume in 1Nm³	B Oxide equivalent	AB Oxide needed	Theory Air volume
C_2H_4 C_3H_8 C_4H_{10}	0.008 0.989 0.003	3 5 6.5	0.024 4.945 0.019	4.988/0.21 =23.75
Total	1.000		4.988	

perfect combustion with the theory air quantity because air and the gas are not fully mixed during the combustion. It leaves the gas ingredient which was not burned out or makes imperfectly chemical reaction. Therefore, it comes to need about 20~50% of excess air.

2.2 The equation

2.2.1 Calculating the size of fireball[25]

$$D_{fireball} = 5.8 \times M_{fireball}^{1/3} \tag{3}$$

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

2.2.2 Calculating the continuance time of a flame

$$t_{fireball} = 0.45 \times M_{fireball}^{1/3} \tag{4}$$

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

2.2.3 Calculating the height of the center of fireball

$$H_{fireball} = 0.75 \times D_{fireball} \tag{5}$$

$H_{fireball}$: The Height of the cente of fireball(m)

2.2.4 Calculating atmospheric transmissivity

$$\tau_a = 2.02(Pp_{water} \times X_s)^{-0.09} \tag{6}$$

$$Pp_{water} = RH \times P_{water} \tag{7}$$

$$P_{water} = 0.0060298 \times P_a \times \exp\left\{5407\left(\frac{1}{273.15} - \frac{1}{T_a}\right)\right\} \tag{8}$$

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

$$X_s = \sqrt{\left(H_{fireball}^2 + L_{fireball}^2\right)} - \frac{D_{fireball}}{2} \tag{9}$$

P_{water} : Stream pressure of water(Pa)
T_a : Temperature of asmosphere(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)

2.2.5 Calculating radiation energy of surface

$$E = \frac{R \times M_{fireball} \times H_c}{3.14 \times D_{fireball}^2 \times t_{fireball}} \tag{10}$$

E : Radiation energy of surface(kJ/m²·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)

2.2.6 Calculating view factor

$$F_\nu = \frac{L_{fireball} \times \left(\frac{D_{fireball}^2}{2}\right)^2}{\left(2L_{fireball} + 2H_{fireball}\right)^{\frac{2}{3}}} \tag{11}$$

2.2.7 Calculating radiation

$$Q_{fireball} = \tau_a \times E \times F_\nu \tag{12}$$

$Q_{fireball}$: Radiation at a certain point(kW/m²)

2.3 Probit analysis

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 analysis formula.[26-28]

2.3.1 In the case of first-degree burn

$$P_r = -39.83 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (13)$$

2.3.2 In the case of second degree burn

$$P_r = -43.14 + 3.0186\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (14)$$

2.3.3 In case of death caused fire

$$P_r = -36.38 + 2.56\left[\mathrm{Ln}\left(tQ^{\frac{3}{4}}\right)\right] \quad (15)$$

P_r : Probability value(Probit value)
T : The time of exposure(sec)
Q : Intensity of radiant heat(W/㎡)

III. The Calculating Results and Consideration

According to API521, the criterion of the effect of radiant heat is as Table 5.

To predict the damage to humans, the numerical value which comes out from the probit analysis formula is applied to the formula (3), (4) and (5) like Table 6.

Table 7 is the calculation of the quantity of theory air of LP gas.

According to World bank, the criterion of the effect of radiant heat is as Table 8.

For the calculation of the radiant heat of Table 9, the numerical value which comes out from the formula (3), (4) and (5) is applied to the formula (9), 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 (8), and the result is applied to formula (7), and the final value is applied to the formula (9) and (6). Then, we can get the permeation degree.

Table 5. Time of feeling an ache(API521).

Intensity of radiant heat		Time that begin to sting(sec)
(Btu/hr/ft^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 6. Relate value of fireball in C_3H_8+C_4H_{10}.

M(kg)	D(m)	T(s)	H(m)
0.97	5.74	0.45	4.31

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

C_3H_8+C_4H_{10}	㎉/kg	kJ/kg
90%+10%	12539	52482

Table 8. The effect of radiant heat(World bank).

Intensity of radiant heat		Effect
(Btu/hr/ft^2)	(㎾/㎡)	
11900	37.5	Equipment and facilities are damage
7900	25.0	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 bunt of the second degree 20 seconds later.
1300	4.0	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 9. Calculated value of radiant heat.

L(m)	X_s(m)	E(kJ/㎡s)	F_v	Q(㎾/㎡)
3	2.38	441.64	0.44	222.63
5	3.73		0.51	247.87
10	8.02		0.54	242.78
20	17.59		0.49	204.30
50	47.31		0.36	139.90
62	59.28		0.33	126.00
100	97.22		0.27	98.52
110	107.2		0.26	93.64
200	197.2		0.20	67.45
475	472.1		0.13	41.21

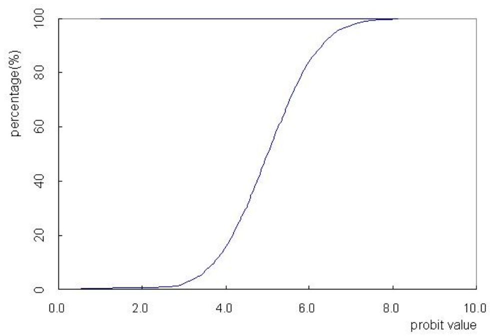

Fig. 1. Relation with probability value(probit) and percentage.

To get the surface radiant energy, the value of the formula (3), (4), (5) and of the Table 6 are applied to the formula (10).

Also, the value of visual factor is calculated by applying the formula (3), (4) and (5) to the formula (11).

Finally, 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 (12) like Table 9.

The relationship between the probability value and the percentage of the human injury degree by the heat radiation is like Fig. 1, and the calculated values by using the formula (13), (14) and (15) to apply to that are like Table 10.

Table 10 Probit value about distance of LPgas flame in enclosure (ingredient of 10% propane and 90% butane).

L(m)	possibility with a first degree burn	possibility with second degree burn	possibility with burnt to death
3	98.8	25.8	12.5
5	99.7	27.8	14.5
10	99.5	25	13.1
20	97.4	8.5	4.3
50	66.2	0.6	0.5
62	50	0.4	0.4
100	16	0.1	0.1
110	11.5	0	0
200	0.8	-	-
475	0	-	-

If the values of Table 10 are applied to Fig. 1, we can get the damage type by the radiant heat. This study researched the damage by the probit analysis.

Ⅳ. Conclusions

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

According to the probit analysis, the spot which is 5meter away from the flame has nearly 100% of the damage probability by the first-degree burn, 27.8% of the damage probability by the second-degree burn and 14.5% 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.

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