부탄 캔 파열로 인한 인체피해예측에 관한 연구

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A Study on Estimation of Human Damage Caused by Rupture of Butane Can

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Abstract : As the industrial society is highly developing, human need in daily life has also changed drastically. With the introduction of 40 hour working week system, more households enjoy picnics on weekends. More gas accidents take place on Saturdays and on Sundays than any other days of week. In this context, the Institute of Gas Technology Training in Korea Gas Safety Corporation carries out explosion experiment to make trainees to take all possible measure to ensure safe management of gas in the field by fully recognizing the hazards of gas explosion accidents. In this study, the influence of explosion over-pressure caused by the rupture of butane can thrown away after use was calculated by using the Hopkinson's Scaling Law and the accident damage was estimated by applying the influence on the adjacent people into the Probit model. The value of those away from 50 meters from the explosion site was 1.35kPa and the peak overpressure to thoes away from 25 meters directly was 3.2kPa. Those value was input to the PROBIT model, the estimation showed the same result 0 percent of damage possibility.

요 약 : 산업사회의 발전과 더불어 인간의 삶에 대한 욕구도 날로 급변하고 있으며, 주40시간제가 도입되면서 피크닉을 즐기는 세대가 늘어나고 있는 실정이다. 또한 가스에 의한 사고는 토요일과 일요일에 가장 많이 발생하고 있다. 따라서 가스안전교육원에서는 이러한 가스의 폭발사고에 대한 영향이 매우 위험하다는 것을 교육생에게 알려 현장에서 가스안전관리에 만전을 기하도록 하고자 폭발실험을 실시하고 있다. 본 논문에서는 이러한 폭발실험으로 교육에 참관하는 교육생에게 미치는 영향을 알아보고자 폭발로 인한 과압은 Hopkinson의 삼승근법을 이용하여 계산하고, 인간에게 미치는 영향은 Probit 모델에 적용하여 사고피해예측을 평가하였다. 폭발위치에서 50m 떨어진 곳에서의 피크과압은 1.35kPa이고, 25m 떨어진 곳에서는 3.2kPa이다. 이 값은 Probit 모델에 적용하면 손상가능성이 0%로 나타났다.
Key Words : human damage, explosion, GEN(gas explosion noise), over-pressure

1. Introduction

This study is for the emergency management which is the legal professional training performed at Gas Safety Education and for guarantee the safety of students from GEN(Gas Explosion Noise) and overpressure by the explosion experiment.

The students participate in this experiment directly or indirectly, and their damage is observed by dividing into two groups - active students participating in the experiment and passive students not participating but being trained at a classroom.

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There have been 58 accidents of portable butane burners and joining containers(this study proposed to call it butane cans to the following) and 20 accidents (34.5%) of keeping and handling of butane cans during these five years.

Also, the explosion and fire caused by a gas leak by poor setting of butane cans were 10 cases(26.3%) and 16 cases(80%) of careless keeping and handling were explosion by rising of inner pressure, which were occurred by heating container to use the gas left with neglecting the butane cans placed around fires including keeping butane cans in portable butane burners[1,2].

Therefore, the explosion experiment performed by this Education Center is used for the training data to guarantee safety from these kinds of accidents.

Also, we wish it will be used as basic data to ensure the safety distance for experiment of gas explosion.

2. Experimentals and Formula

2.1. Experiment

The damage prediction by the explosion of butane cans is predicted by the predicting method of accident damage, but this study wants to predict the damage by GEN and overpressure. Therefore, we want to measure the noise of the students' place(active students) 25meter far from the explosion place and of the classroom(passive students) 50meter far from. Also we want to compare that result with the theory formula. Besides, we want to predict the accident damage to human beings by using these measured values. Probit analysis is applied to have the effect value for human beings.

Fig.1 is an arrangement plan for the place of explosion experiment. As the picture shows, the explosion place is 25meter far from the watching place of active students. We thought there would be little damage by noise and overpressure to other places because this education center is surrounded by mountains, so we didn't make an evaluation for the circumstance of the explosion place[3-5].

In case of before study, the noise influence research was applied effect to the house and the school around explosion place. This study guaranteed the safety of the students participating in this experiment directly or indirectly.

Also, the intensity of gas explosion by accidents has been calculated as TNT equivalent or TNT efficiency comparing with TNT explosion because there is little experiment on gas explosion.

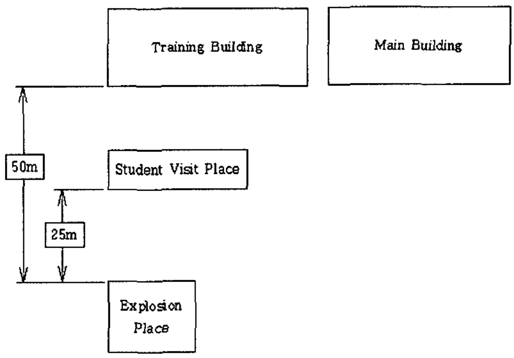

Fig. 1. Arrangement plan.

TNT efficiency shows how many percentage of TNT equivalent contributes to real gas explosion accidents because there are big differences between the generation speed and the space of an explosive and gas even the generation amount of their energy is the same.

That is, Theoretical explosion energy = total mass * combustion heat.(The combustion heat assumes complete combustion.) Also, Explosion to fire transition phenomena is affected by the explosion characteristics[6].

2.2. Formula

The sound source of GEN by the explosion of butane cans is a dot sound source generally. When the sound is spread in free sound field, the decrement is decided by the distance from a sound source and shape[7,8].

The strength of sound I d(m) far from a dot sound source is as following formula.

$$I = \frac{w}{4\pi d^2} \tag{1}$$

When a sound source is marked with sound power level, sound pressure level from the distance d is calculated as follows.

Sound pressure level, SPL = 10 log(I/10^{-12}), PWL = 10log(W/Wo)

$$SPL = 10\log(\frac{w}{\pi d^2 \cdot 10^{-12}})$$
$$= 10\log(\frac{w}{10^{-12}}) - 20\log d - 11 \quad (2)$$

10 log(I/10^{-12}) is a power level by w of original sound energy, and it is marked as PWL.

$$SPL = PWL - 20\log d - 11$$

Also, Calculating the explosion effect range is

1) explosion efficiency

$$\eta = \frac{Real\ energy}{Therotical\ energy} \times 100 \quad (3)$$

Table 1 is the recent CCPS data and is used as explosion efficiency for each material on operating the research program of general accident damage prediction[9,10].

2) Scaling law : a typical law using for assumption how far and how much TNT can make damage when a certain mass of TNT is exploded[11,12].

Table 1. Explosion efficiency for explosiveness vapor

η	Material	
$\eta = 0.03$	Acetone **Benzene** 1,3-Butadiene **Butene-1** Carbon Monoxide Dimethyl Ether Ethane Ethanol Ethyl Benzene Furfural Alcohol **Hydrogen** Iso-Butyl Alcohol Isobutylene Iso-Octane	**Methane** Methanol 3-Methyl-Butene-1 Methyl Mercaptan Naphthalene N-Butane N-Pentane **Petroleum Ether** Phthalic Anhydride **Propane** Proprionaldehyde Propylene **Toluene** Water Gas
$\eta = 0.06$	Acrolein Carbon Disulphide Cyclohexane Ethyl Nitrate	Diethyl Ether Divinyl Ether Ethylene Propylene Oxide
$\eta = 0.19$	Acetylene Ethylene Oxide Ethyl Nitrate Vinyl Acetylene	Hydrazine Isopropyl Nitrate Methyl Acetylene Nitromethane

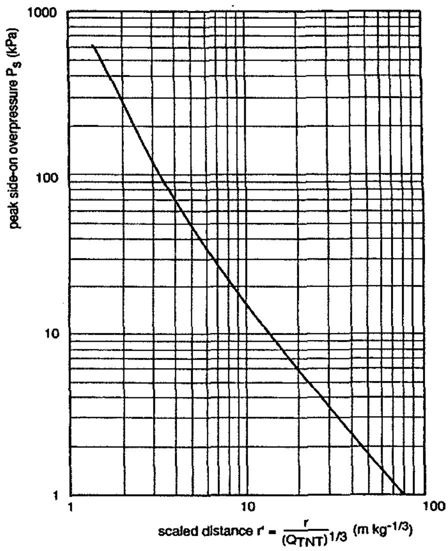

Fig. 2. Peak overpressure by TNT explosion.

3) TNT weight which emit the same energy with a certain gas explosion.

$$W_{TNT} = \frac{\eta \times H_C \times W_C}{H_{TNT}} \quad (4)$$

Fig. 2 is calculated the overpressure from the explosion place to a settled distance.

4) Conversion distance at overpressure

$$Z = \frac{R}{W_{TNT}{}^{1/3}} \quad (5)$$

5) The distance which a given overpressure reaches at(m)

$$X = 0.3967 \times W_{TNT}{}^{(1/3)} \exp[3.5031 - 0.7241\ln(O_P) + 0.0398(\ln O_P)^2] \quad (6)$$

Table 2 is the damage type based on the peak overpressure.

6) Effect of the overpressure of explosion

Ejsenberg(1975) and others presented Probit model on direct effect of blast wave based on the data of a nuclear explosion[13,14]. Eisenber's calculating formula

Table 2. Blast damage by overpressure

over pressure(kPa)	form of damage
0.14	disagreeable noise by low frequency (10~15Hz)
0.21	partial damage of window made of glass
0.28	big noise and glass is broken
0.69	small transformed window made of glass is broken
1.03	glass bursting pressure
2.07	10% of glass window is broken
2.76	Small damage limitation of building
3.45	big and small window fracture
4.83	house small breakage
6.89	house portion breakage
8.96	building steel frame flexure
13.79	weak concrete wall fracture
15.86	serious structural damage lowlevel
20.68	steel frame building flexure
27.58	oil storage tank explosion
34.47	wood pillar is crash and explosion of tympanum
41.37	house whole breakage
48.26	overthrow of freight car
62.05	whole destruction of freight car
68.95	whole destruction of building
2068	death probability of 100%

on a building and a human being is as follows.(Only it is 150pounds(0.45359237*150 = 68kg) mass of an individual aim and standing position. Also, it isn't placed around a vertical surface)[15].

A) Death of hemorrhage from the lungs

$$Probit = -77.1 + 6.91 \ln (Ps) \quad (7)$$

B) The case of eardrum rupture

$$Probit = -15.6 + 1.93 \ln (Ps) \quad (8)$$

3. Results and Discussion

3.1. Effect of Noise

Noise measurement was done with the measuring method of construction noise by KS A ISO 1996-1 (indication of environmental noise and measuring method)[16].

1) Measuring place

(1)Explosion place (Point A) : Measured within a 2-meter radius of explosion place of butane cans

Table 3. Noise measure value

units : dB(A)

date	point	background noise(dB)		noise(dB)
		A level	C level	A level
5.19	A	43.5	53.5	96.9
7.06	B	41.0	52.8	68.8
7.14	C	41.7	53.6	59.5

* A level : generally standard of noise
* C level : the analysis recording or frequency

Measuring place of a noise meter : Measured above 150cm high from GL to the upper part

(2) Active students' place (Point B) : Measured at 25m far from the explosion place

(3) Passive students' place (Point C) : Measured at 50m far from the explosion place

The noise level measured at each point is as Table 1.

2) Measuring date

(1) Date - Point A : 11:25, May 19
Point B : 11:24, July 06
Point C : 11:26, July 14

(2) Weather - on measuring point A : clear
Wind speed : 1.8m/s,
Wind direction : the south wind
on measuring point B : clear
on measuring point C : clear

3) Analysis

The amount of decrease is calculated as follows by the theory of noise decrease with the measured value at point A as a noise source.

(1) In case of a dot sound source

Point B

$SPL = PWL - 20\log d - 11$

$= 96.9 - 20 \log 25 - 11 = 57.94(dB)$

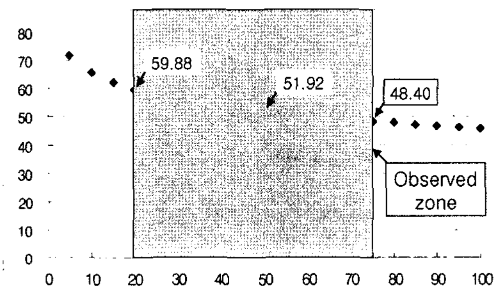

Fig. 3. Figures by Weber-Fechner's law.

Table 4. Calculation and a difference of measure

point	calculation	measure	difference
B	57.94	68.8	+10.86
C	51.92	59.5	+7.58

Point C

$SPL = PWL - 20\log d - 11$

$= 96.9 - 20 \log 50 - 11 = 51.92(dB)$

Explosion is calculated to 57.94(dB) and 51.92 (dB).

(2)Valuation by Rating Sound level

Lr = La± Revised value(-20dB)

Point B = 68.8 - 20 = 48.8dB

Point C = 59.5 - 20 = 39.5dB

On the estimate by the Rating Sound level, the permitted value is all lower than 50dB of regulation value, and exclude effect is not applied to the calculation because of geographical condition and the shape of a fence.

Table 4 is the comparison of calculation value with actual survey of the noise level of point B and C.

3.2. Effect of Overpressure

This study calculates equal to TNT by applying the formula (4) of chapter 2 to find the explosion pressure by the break of butane cans.

The effect of explosion applying to the explosion of C_3H_8 and C_4H_{10} is generally calculated by using the formula (3). As Table 1 shows, 0.03 is applied and 0.5 for sealed system.

This study calculates the effect of explosion by applying 1.

W_{TNT} equivalent is calculated by applying the effect of explosion 1 to the formula (4), and conversion distance Z is calculated by applying to the formula (5).

By using it, the overpressure from the explosion place to a settled distance is calculated from Fig. 2.

Fig. 4 is diagraming of the relation of probability value(Probit value) and percentage.

By using it, the accident damage of a human is predicted.

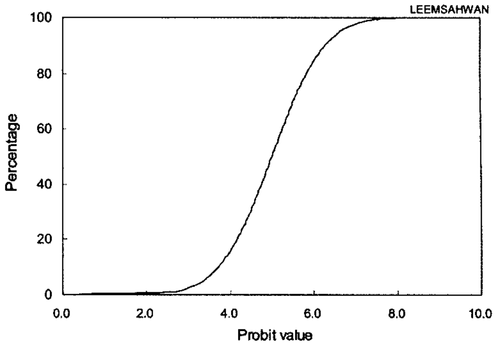

Fig. 4. Relation with probability value.

Table 2 shows the damage type based on the peak overpressure which is calculated by Fig. 4.

Also this study calculated the effect distance which the given overpressure reaches by applying to the formula (4) with these values.

This study is to search the damage effect based on the formula of Probit analysis, so Table 2 is used for comparing with the value of the formula of Probit analysis.

Table 5 is the value of conversion distance corresponding to TNT equivalent applied the formula (5) by using TNT equivalent calculated with the formula (4) of chapter 2 that the value of the peak overpressure by the distance far from the explosion place with applying it to figure 2.

Table 5. Overpressure about distance of butane can weight 34g(10% propane and 90% butane ingredient)

Z(m)	R(m)	W_{TNT}(kg)	Overpressure(kPa)	X(m)
1.34	1.00	0.4196	740.00	0.80
2.67	2.00		175.00	1.44
4.01	3.00		69.00	2.30
5.34	4.00		42.50	3.02
6.68	5.00		31.00	3.64
8.01	6.00		22.00	4.49
9.35	7.00		17.50	5.20
10.69	8.00		16.00	5.52
12.02	9.00		13.50	6.18
13.36	10.00		12.00	6.69
20.04	15.00		5.90	11.06
26.71	20.00		4.25	14.14
33.39	25.00		3.20	17.61
40.07	30.00		2.40	22.15
53.43	40.00		1.75	28.70
66.79	50.00		1.35	35.73

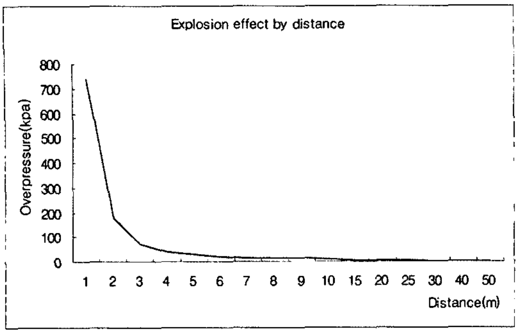

Fig. 5. Explosion effect by distance.

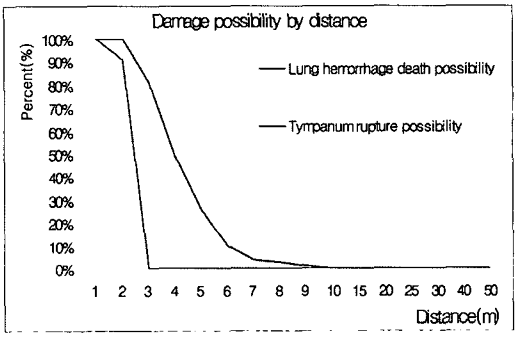

Fig. 6. Damage possibility by distance.

Table 6. Damage possibility about distance of butane can weight 34g(10% propane and 90% butane ingredient)

Z(m)	Lung hemorrhage death	Tympanum rupture
1	100.0%	100.0%
2	90.7%	99.8%
3	0.0%	81.6%
4	0.0%	48.9%
5	0.0%	26.0%
6	0.0%	9.6%
7	0.0%	4.0%
8	0.0%	2.8%
9	0.0%	1.3%
10	0.0%	0.0%

Also this study calculated the effect distance which the given overpressure reaches by applying to the formula (6) with these values.

Fig. 5 is diagraming of the calculation of overpressure by settled distance from the explosion place by repeating calculation with changing settled distance.

By using this, the effect of overpressure by distance from the explosion place can be predicted, so it can be reference for safety supervision.

4. Conclusion

This study got the following conclusion with the calculation by theory and the result of measuring noise.

1) The real noise to 25m of the interested distance is 68.8dB(A), and it shows some difference from 57.94dB(A) gotten by the theory value. However, both of these values are smaller than 90dB of environmental permitted value, so they are judged that there is no problem.

2) The real noise to 50m of the interested distance is 59.5dB(A), and it shows some difference from 51.92 dB(A) gotten by the theory value. However, both of these values are smaller than 65dB of environmental permitted value, so they are judged that there is no problem.

3) The overpressure caused by the explosion was calculated by using the Hopkinson's Scaling Law and accident damage was estimated by applying the PROBIT model which simulates the influence of TNT explosion on the adjacent the applicants(aspirants) participate in this experiment directly or indirectly. The value of those away from 50 meters from the explosion site was 1.35kPa and the peak overpressure to thoes away from 25 meters directly was 3.2kPa. Those value was input to the PROBIT model, the estimation showed the same result 0 percent of damage possibility.

There is no damage for a human from 10m far.

In calculating the peak overpressure of gas explosion, the explosion efficiency of 10 percent is generally applied. However, in this study, the explosion efficiency of 100 percent was applied in calculating the peak overpressure. As a result of this, the actual damage influenced by the rupture of butane can would be lower than the value calculated in this study and expected to be safer.

Damage effect evaluation of overpressure and flame from bursting by various amount of butane cans and other data should by surveyed and studied from now on. With the data, the effect to the circumstance should be observed. Also, we will calculate the damage effect distance by explosion and study on the plan to minimize the damage to human beings with it.

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