ANALYSIS OF CLOTHING EFFECT FROM BLEVE FIREBALL IMPACT

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Abstract

This research is conducted to study the effect of BLEVE fireball impact to the human in the area. The research focus on the effect and severity from blast and radiation based on the fabrics they wear. The experiment starts with determining the relevant theory and equation needed. The parameter of the fireball from the BLEVE is then determined using the formulae for the duration, diameter height and the thermal radiation emitted from the BLEVE fireball. Then, using the quantitative value determined, the effect to the different type of fabrics is simulated using excel worksheet. Among the type of fabrics considered are wool, polyester, acrylic, nylon, etc. It is concluded that the wool is the most resistance material due to its high resistance to heat radiation. Mixture of 65% polyester and 30% cotton, 100% acrylic and 100% nylon are less effective for heat radiation resistance.

I. Introduction

Boiling Liquid Expanding Vapour Explosion or BLEVE is often the accident feared in oil and gas industry. As the name suggest, BLEVE happens when a failure of vessel containing an overheated liquid explode due to the vapour pressure [1]. Throughout the year, various BLEVE accident had been identified happening worldwide. Every accident varies from the cause of the accident such as from natural disaster, human error, etc and each with varies consequences. Most of the vessel in industry involved in BLEVE contained flammable liquid like liquified petroleum gas. It is reported that one third of BLEVE accident reported in industry is due to exposure of fire [2] the consequences of BLEVE will result with a fireball when the content of the vessel catch fire.

The fireball effect is what this research main focus is and also the effect of the fireball to the human based on the type of clothing they wear. In determining the parameters of the fireball, several formulae are used based on the literature review. The fireball formulae are as follow.

Table 1: List of formulae used

Parameters	Formulae
Duration of Fireball	$t_d = 0.9M_{FB}^{\frac{1}{4}}$
Diameter of Fireball	$D(t) = 8.664\, M_{FB}^{\frac{1}{4}} t^{\frac{1}{4}},$ $for\ 0 \le t \le \frac{1}{3}t_d$ $D_{max} = 5{,}8\, M_{FB}^{\frac{1}{3}},$ $for \frac{1}{3}t_d \le t \le t_d$
Height of Fireball	$H_{FB}(t) = \frac{D(t)}{2}$ $for\ 0 \le t \le \frac{1}{3}t_d$ $H_{FB}(t) = \frac{3D_{max}(t)}{2}$ $for \frac{1}{3}t_d \le t \le t_d$
Thermal Radiation Emitted	$E_{max} = 0.0133\, f\, H_c M_{FB}^{\frac{1}{12}}$

[3]

Then, from the fireball parameters required, the values are then used to simulate the effect on human within the radius of the fireball based on the type of clothing. The relation is calculated using the probit that relate the radiation effect

to the type of clothing. The clothing effect formula is

$$y = -37.23 + 2.56\, ln\, V \qquad [4]$$

where the value of the thermal load V is different based on the different clothing material.

In the analysis of this research, the data from a case study of previous BLEVE accident is acquired. The value needed to calculate the parameters is referred using the case study of the BLEVE accident at Tohoku, Japan in 2011. The accident is caused by an earthquake that in consequence caused the explosion of a vessel containing about 461 200 kg of propane [5]. All the information obtained from the case study has been used for simulation analysis using Excel.

II. Methodology

There are a few steps that need to be determined in order to calculate the fireball effect. The value that need to be determined include the duration of fireball, the diameter of fireball, the height of fireball and last but not least, the maximum thermal radiation emitted. Then, the clothing effect is determined based on the thermal radiation and the type of clothing material.

Analytical Method.

As the fireball effect of the BLEVE is a result from the flammable content inside the vessel, the duration of fireball is intercorrelated with the amount of the flammable liquid [6]. From the amount of flammable mass inside the vessel, the duration of fireball can be determined.

From the duration of fireball, its diameter can be calculated. This is because the diameter of the fireball is an equation of the duration with the mass of the flammable substance. The fireball can be separated into two parts which is the growing phase and the max phase. The growing phase take time in the first-third of the fireball duration.

A Height of the fireball is measured from the centre of the fireball to its maximum height. The height of the fireball also uses an equation involving the duration of the fireball. The centre of the fireball increases at constant rate during the first-third of the duration and the rest of the duration. Therefore, the formulae to determine the height of fireball is split into two formulae from the first-third duration of the fireball and the rest of the time.

During the fireball effect, one important aspect to be determine is the thermal radiation emitted by the fireball. Thermal radiation is calculated in term of how much power radiated per unit surface of the fireball. This amount is also related to the duration of the fireball. It is assumed to be constant in the growing phase and reach its maximum value after one-third of the duration of the fireball.

Simulation.

Last but not least, the effect of the fireball is then determined based on the clothing of the personnel. The effect is mostly come from the radiation from the fireball and different clothing material can have different effect in shielding the wearer from the thermal radiation. The clothing effect from radiation can be determined using the equation

III. Result and Discussion

Analysis of fireball size and its characteristic is important as to identify the relationship between the mass of LPG involve with the growth of the fireball from BLEVE. Duration of one fireball is depend on the mass of the LPG involve [7]. Larger quantity of LPG involves will resulting longer duration of fireball. The height and diameter of fireball is time-dependent where the longer the time duration, the larger will be for the fireball. The result obtained about the characteristic and growth of fireball is shown in Table below.

Table 2: Calculated result of the Fireball

Characteristic	Result
Duration of Fireball (t_d), s	23.454
Maximum Diameter (D_{max}), m	448.1
Flash Radius (R_{flash}), m	291.3
Surface thermal Flux Emitted (E_{max}), kW/m^2	617.97

Table 3: Growing phase of Fireball from BLEVE

	(Growing Phase) (0 ≤ t ≤ 1/3 td)			
	t (s)	D (m)	H (m)	(Emax)
T0	0	0	0	0
	1.1168	234.25	117.12	617.96
T1	51777	52223	76111	95286
	2.2337	295.14	147.57	617.96
T2	03553	30856	15428	95286
	3.3505	337.85	168.92	617.96
T3	5533	44936	72468	95286
	4.4674	371.85	185.92	617.96
T4	07106	69862	84931	95286
	5.5842	400.57	200.28	617.96
T5	58883	07954	53977	95286
	6.7011	425.66	212.83	617.96
T6	10659	99883	49942	95286
	(MaturedPhase) (1/3 td ≤ t ≤ td)			
	t (s)	D (m)	H (m)	(Emax)
	7.8179	448.11	224.05	617.96
T7	62436	66629	83314	95286
	8.9348	448.11	256.06	573.82
T8	14212	66629	66645	88479
	10.051	448.11	288.07	529.68
T9	66599	66629	49976	81673
	11.168	448.11	320.08	485.54
T10	51777	66629	33306	74867
	12.285	448.11	352.09	441.40
T11	36954	66629	16637	68061
	13.402	448.11	384.09	397.26
T12	22132	66629	99967	61255
	14.519	448.11	416.10	353.12
T13	07309	66629	83298	54449
	15.635	448.11	448.11	308.98
T14	92487	66629	66629	47643
	16.752	448.11	480.12	264.84
T15	77665	66629	49959	40837
	17.869	448.11	512.13	220.70
T16	62842	66629	3329	34031
	18.986	448.11	544.14	176.56
T17	4802	66629	1662	27224
	20.103	448.11	576.14	132.42
T18	33198	66629	99951	20418
	21.220	448.11	608.15	88.281
T19	18375	66629	83282	36122
	22.337	448.11	640.16	44.140
T20	03553	66629	66612	68061

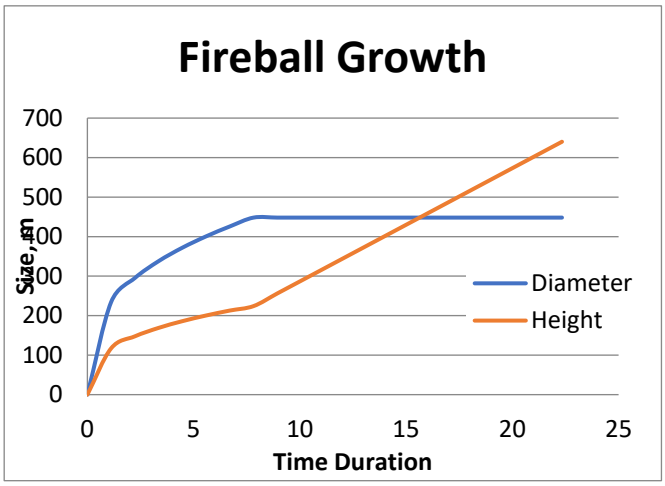

Figure 1: Pattern of growth of fireball from BLEVE

From the figure above, the diameter of the fireball increases rapidly in the first few second before it reaches the maximum growth of the diameter for the rest of the fireball duration. However, the height of fireball is seen to increase as the duration increase throughout the duration of the fireball.

For the second phase of the research, the probability is used to estimate the percentage of injury for the population surrounding the BLEVE event. For the simulation, it is considered that every victim whose expose to the BLEVE Fireball impact are at the same distance from the explosion. The sample size is assumed 100 people where all receive the impact at the same duration. For example, a result a result with 29% people receiving 1st degree burn means that 29 out 100 people

exposed to the explosion resulting in a 1st degree burn due to the fireball radiation.

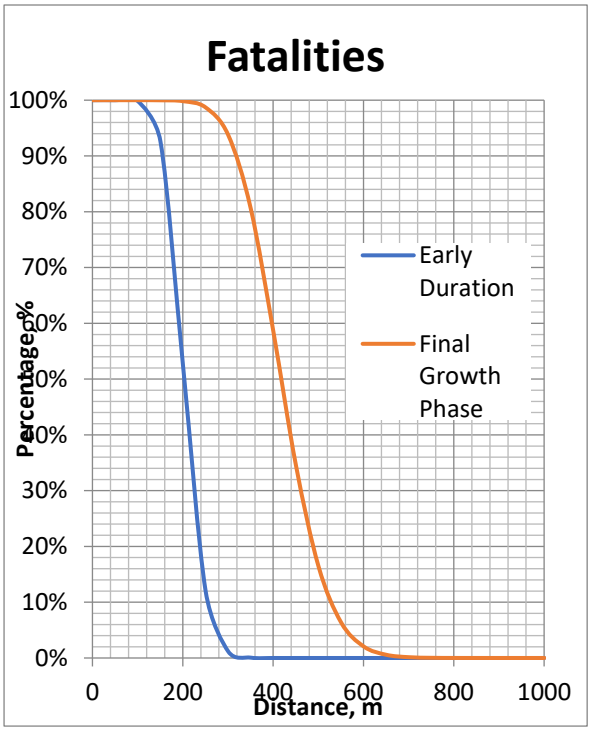

Figure 2: Percentage of Fatality at early, growth and matured fireball phase.

From the figure, it is estimated that for the distance of 550 meter from explosion, only one person escaped from any injury while 3 fatalities happen. The distance between subject and the explosion point weaken as the distance increase due to the increase of resistance of air. As the subject move closer to the explosion source, the percentage of fatalities increase significantly.

Protective Clothing

Protective clothing plays important role in order to minimize the impact of blast radiation from fireball explosion. As for the results obtained before that show the number of fatalities for a BLEVE event to a population, the data is based on the assumption of people whose are not protected by clothing. This explains that cloth factor is not taken into account.

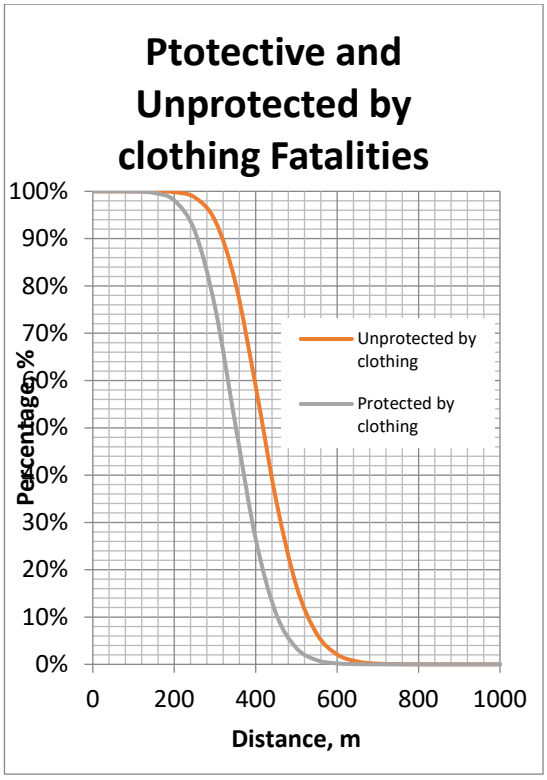

Figure 3: Percentage of Fatality for protected and unprotected by cloth

From the figure 3, at the 400 meters from an explosion, the finding shows protective clothing is able to minimize the percentage probability of fatalities for 30%. If 100 people are expose to the radiation heat fluxes, for normal wear, 60 people are expected for fatalities while with protective clothing, the estimation can be reduced to 30 people only

From the simulation study, the results prove that the protective clothing is able to reduce the effect of high radiation blast from fireball of BLEVE event. The protective clothing data is collected based on the type of fabric wore by worker as the typical industrial setting nowadays. Clothing effects can be beneficial of detrimental depending on whether the blast radiation heat fluxes are high enough to ignite the clothing. According to [4], if the cloth is ignited completely, the victim is considered 100% chance of death, but this statement has been argued from other research since it does not take account the seriousness for the injury suffered. However other research indicates that only 20% of patients whose clothing caught on fire died [8].

Impact of BLEVE Fireball based on different fabrics.

The protective clothing effect is dependent on various factors. In the cases of good material of fabrics, the heat can only penetrate to a minor extend and cause minor injury but depends on the total heat radiation received and the exposure time.

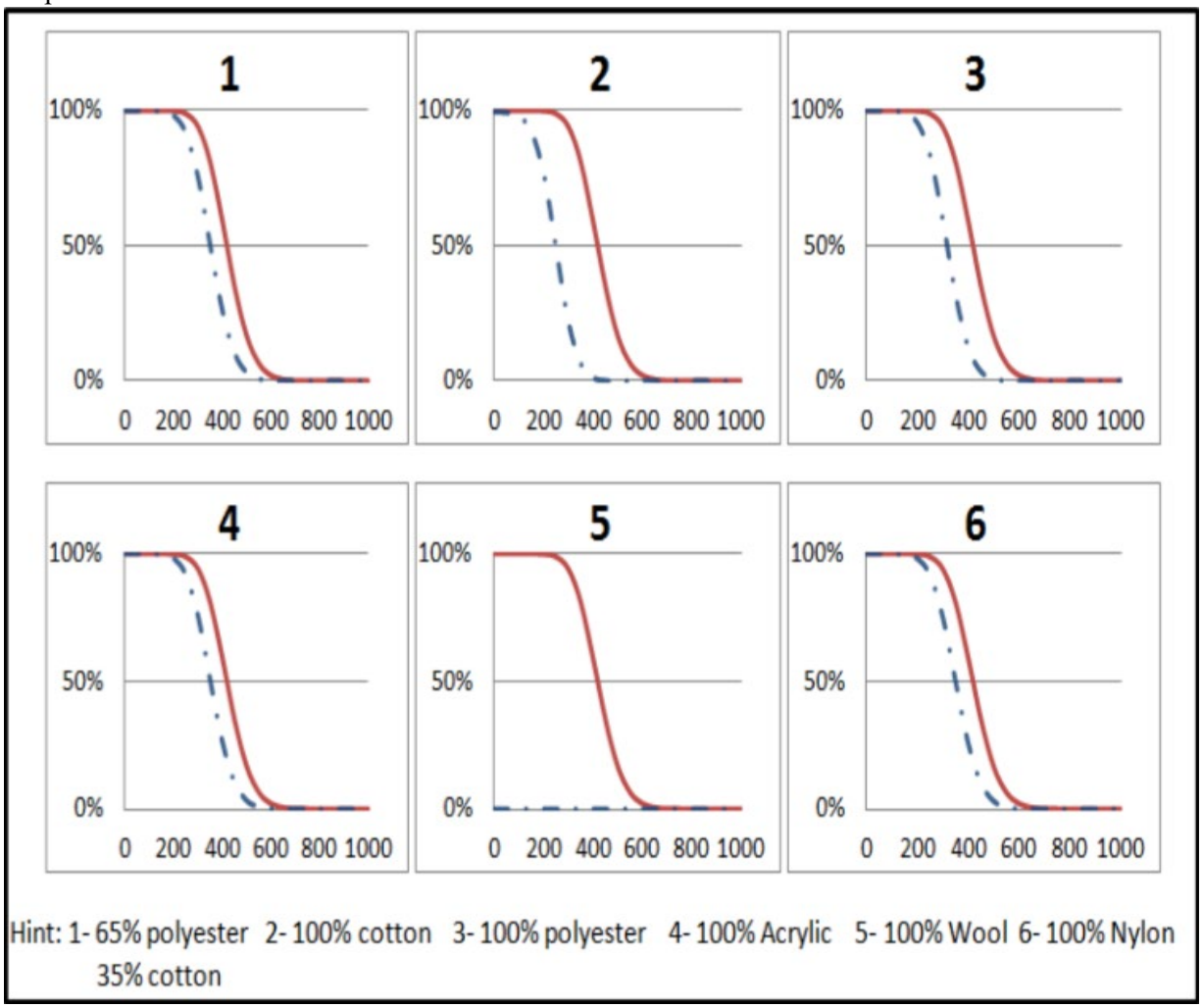

Figure 4: Percentage of Fatality for different type of fabrics material

Figure 4 shows the difference of probability of fatalities between 6 types of fibre of cloth. The 5th graph shows there is no fatality might happen if a person wears 100% wool of material clothing when the explosion occur. Wool has known as a fabric that capable to resist the heat radiation well with high ignition of temperature. 100% of cotton fabric also can endure high heat radiation and reduce the amount of blast to bare skin. On average, fabrics have the capability to reflect 50% of heat radiation and 20% of the radiation is absorbed by the cloth. The remaining 30% will penetrate to bare skin and cause either severe injury like fatality and 2nd degree injury or minor injury like 1st degree burn [9].

Table 4: Statistic of death for type of cloth and their fabrics.

Clothing	Fabrics	Total population	400 meter (20 people)		550 meter (50 people)		650 meter (30 people)		Total	
			Fatality	Survive	Fatality	Survive	Fatality	Survive	Fatality	Survive
Unprotected	-	100	12	8	3	47	1	29	16	84
Woven Blouse	100% polyester	100	1	19	0	50	0	30	1	99
Double Knit	100% polyester	100	3	17	0	50	0	30	3	97
Denim	100% cotton	100	1	19	0	50	0	30	1	99
Jersey T-shirt	100% cotton	100	5	15	0	30	0	30	5	95
Slack	65% Polyester 35% cotton	100	5	15	1	49	0	30	6	94
Jersey Tube Knit	100% acrylic	100	5	15	1	49	0	30	6	94
Jersey T-shirt	65% Polyester 35% cotton	100	2	18	0	50	0	30	2	98
Terry cloth	100% cotton	100	4	16	0	50	0	30	4	94
Batiste	100% cotton	100	6	14	1	49	0	30	7	93
Tricot	80% acetate 20% nylon	100	0	20	0	50	0	30	0	100
Tricot	100% nylon	100	0	20	0	50	0	30	0	100
Tafeta	100% nylon	100	5	15	1	49	0	30	6	94
Shirt	50% Polyester 50% cotton	100	6	14	1	49	0	0	7	93
Batiste	65% Polyester 35% cotton	100	6	14	1	49	0	30	7	93
Flannel	100% cotton	100	5	15	1	49	0	30	6	94
Flannel	100% wool	100	0	20	0	50	0	30	0	100

Table 4 above shows the result obtained to analyse the effect of radiation heat blast among 15 types of cloths and their specific fabric used. Among 15 fabrics, tricot made by 100% nylon and mixture of 80% acetate and 20 % nylon show the best heat radiation resistance together with flannel with 100% wool with no fatality occur from heat radiation blast of BLEVE fireball. This might be because of their lower heat conduction, material thickness and the capability to absorbed and reflect heat radiation.

Woven blouse and denim clothing made by 100% polyester and 100% cotton also can reduce the impact of radiation blast effectively with average material thickness and high ability to reflect the heat radiation [10]. Based on the result, the poorest heat radiation among the 15 clothing is batiste with 100% cotton and with the mixture of 65% polyester and 35% cotton and the other one is a normal shirt made by 50% polyester and 50% cotton. It is because of their small materials thickness, poor reflection and absorption ability and high heat conduction

IV. Conclusion

Among the materials of fabrics, wool is the material that has the best heat resistance, follow by 100% cotton and 100% polyester. Mixture of 65% polyester and 30% cotton, 100% acrylic and 100% nylon is less effective for heat radiation resistance but still show the positive influence.

As the conclusion, the BLEVE fireball is able to give serious injury and death to people at surrounding. The impact of from the fireball is depend on the amount of the mass of LPG involve and the distance between the victims and the explosion location. Longer distance from explosion will produce higher chances to reduce BLEVE impact. Furthermore, to increase the probability of survive from BLEVE event, a good cloth needed as to resist the heat radiation from penetrate into the bare skin. Large thickness material, poor heat conductor, higher specific heat capacity and ability to reflect and absorb heat radiation are needed to produce a good heatproof clothing.

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