Analyze on Heat Radiation Effect from Feyzin Domino Accident Scenario

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***Abstract*— This research was carried out with three objectives which were to analyze the impact of the heat radiation happened during the incident at Feyzin, to assess accuracy of the mathematical models on explosion and fire occur at Feyzin disaster area and to recommend on uncertainty of the heat radiation models that has been used. This research had been carried out by using the data obtained from the explosion and fire occurred at Feyzin in from previous research by ARIA (2008) entitled BLEVE in PLG storage Facility at refinery Feyzin and also data recorded by T. Zoltán (2010) entitiled Quantitive and Qualitative Risk Analyses in the Chemical. The data were analyzed and extracted to obtained probability of domino accident, time for the propane tank to fail and the fragments distribution ranges. Results obtained from the research proved that, the models used to determine the probability of domino accident shows that the tank will damage and explode leading to continuous accident. based on the results, the predicted time to failure using models give a good agreement between real Feyzin accident scenario and correlated data for the T 61443 tank and the results on fragments distribution shows that the model used need further advances development.**

Keywords*— *Heat radiation; Feyzin accident; BLEVE; Domino; Fragments distribution

I. INTRODUCTION

Fire and explosion are the commonly events that commonly occurring in major accidents involving chemical process plant [15]. Usually BLEVE refers to the combination of these two phenomena, BLEVE and fireball. The sudden release of superheated flammable liquid from a process vessel or storage tank is the starting of a disastrous event that often leads in the formation of a fire ball [14]. There are several chemical industry disasters that ever recorded in history involving BLEVE phenomena. In November 1984, BLEVE phenomena have occurred at the Petroleos Mexicanos (PEMEX) PLG terminal in San Juan Ixhuatepec, Mexico City started with a pressure drop in a pipeline due to the rupture of the pipe that cause gas to escape and formed 2 m high cloud [12].

Based on previous study by ARIA [2], it starts with a small human error where the operators opened the valves to take samples which were mounted in series at the bottom of a propane spherical tank. The propane cloud increased thus spread to the nearby highway. By accidently, the escaped gas caught fire by a car passing through the local road and the fire flashed back to the tank which the PLG first leaked and explosive destruction, called BLEVE occurred.

Due to the disastrous accidents that had been occurred widely in chemical industry, a wide variety of models have been proposed and developed on the concept of association of BLEVE phenomena. Various types of model regarding the fire and explosions like pool fire, flash fire and BLEVE incidents have been compiled and discussed by the pioneer researchers in this field [11].

Due to the blast of the explosion and the heat radiation involves before and after the first BLEVE, this significant event contributes to the domino effects to the accident. When an accident in one of the facilities occurred and causes failure in one or more of the other units, this is called a domino effect even though it setting off secondary or higher-order accidents [16]. Also, Kardell [8] stated that domino effects can be observed as the cumulative effect from a chain unwanted events comes with severe consequences. The heat radiation cause primary damage to the people and property [16]. Not only affect the industrial sites, but consequences of the damage also affect the people, environment and economy at various levels [7].

According to Lisi et al. [9], there are basically three types of factors that could triggered or lead to a domino effect in an fire and explosion accidents which are overpressures, thermal radiation and projections of fragments. Major Hazard Incident Data Service (MHIDAS) recorded over 100 domino accidents and have been analysed to conclude that overpressure, heat radiation and fragment projection are the main escalation vectors for the accidents [10]. Thus this research is carried out to study and analyse the effect of the heat radiation on the domino accident scenario that occur in Feyzin accident.

II. METHODOLOGY

The methods are divided into several parts to fulfil the purpose and to reach the objective of this research. Fig 1 shows the flowchart of the methodology.

A. Review Domino Accident Theory

In previous studies, several accidents have been discussed on the causes and effect of the catastrophic accidents. Some of it leads to domino accident such as at Chiba refinery near Tokyo, 2011 [3] and Sydney, Australia Distribution Depot, 1990 [4]. The review on the domino accident theory was to understand the concept of domino propagation for the research.

B. Feyzin Case Study

The data of the Feyzin accident was obtained from previous study by ARIA [2] entitled BLEVE in LPG storage Facility at refinery Feyzin and also by Zoltán [18] entitled Quantitive and Qualitative Risk Analyses in the Chemical. The data analysis on the Feyzin incident was carried out to extract the data required.

C. Simplified the Best Domino Effect Route

From the review on the previous study on the Feyzin case, the best domino effect route for the scenario can be constructed based on the chronology and factors of the accidents occurred in Feyzin.

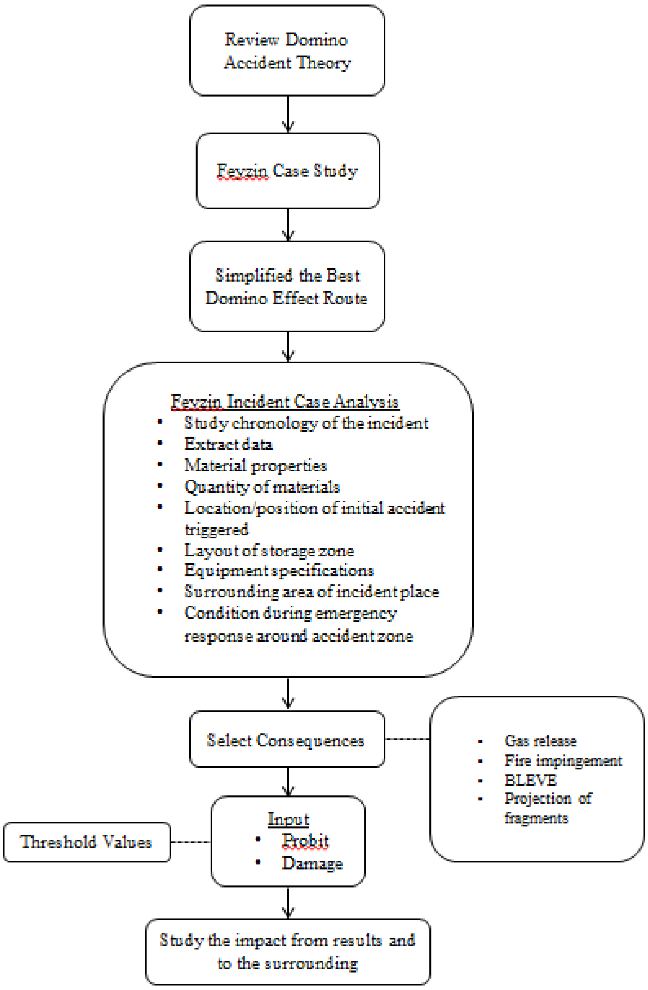

Fig 1: Flowchart of the methodology

D. *Feyzin Incident Case Analysis*

From the chronology of the incident from previous study, the data were extracted to obtain the properties and quantity of the materials. The specifications on the equipment also was determined and analysed. These data was used to determine the time for the sphere to fail and explode. Also, the exact location of initial accident triggered was determined by analysing the layout of the storage zone. From the analysis of the Feyzin case, the condition and facilities of the surrounding area of incident place also can be identified.

E. *Select Consequences*

From the data obtained from previous studies on the gas release, fire impingement, BLEVE, projection of fragments in Feyzin accidents were used in calculating the probits by obtaining the threshold values first. From the probits value, the domino accident probability can be determined. Cozzani et al proposed a probabilistic model of damaged the equipment due to thermal radiation [16].

$$Y = 12.54 - 1.84\ln(t) \qquad \text{(Eq. 1)}$$

Where, Y is initial scene expanding effect probit, t is the failure time, I is the radiation intensity of the target object (kW/m^2) and V is the volume of the device. The data extracted becomes the input to determine the fragments distribution which can be calculated by using Eq. 2 [1]:

$$R = \frac{\upsilon_i^2 \sin(2\alpha_i)}{g} \qquad \text{(Eq. 2)}$$

Where R is range distribute (m), υ_i is vertical range (m), α_i initial trajectory angle (rad) and g is the gravitational acceleration (m/s^2). Thus, the study on the mathematical models on explosion and fire occur at Feyzin disaster area can be carried out.

F. *Study the results*

From the results obtained, the studies on the impact and to the surrounding were carried out.

III. RESULTS AND DISCUSSION

A. *Domino Accident Probability*

From the data obtained from previous study by ARIA [2] entitled BLEVE in an LPG storage Facility at refinery Feyzin, France and also Zoltán [18] entitled Quantitive and Qualitative Risk Analyses in the Chemical, the results on domino accident probability for the Feyzin accident were obtained. The probabilistic model of damaged the equipment due to thermal radiation was proposed by Cozzani et al [16] is used. Table 1 shows the domino accident probability.

Table 1: The domino accident probability

Accident Pattern	Radiation Intensity (kW/m^2)	Probit, Y	Probability of Damage, P
1st tank - T 61443 (Pool Fire)	181.82	9.142	1
2nd tank – T 61442 (BLEVE)	51, 670.62	12.52	1

From the data in Table 1, thermal radiation models are applied to find the radiation intensity of the fire that exposed to the surrounding. The radiation intensity obtained by using the pool fire simulation model proposed by R. Merrified (1992) shows that the heat flux that was exposed to the T 61443 is 181.82kW/m^2. API 521 states that pool fires can have heat fluxes of 100-250 kW/m^2 [3]. From the radiation intensity value obtained, it will be used in the calculation of initial scene expanding effect probit, Y. By using the probit value, the probability of the damage of the propane spheres is determined. Based on the results, the value of the probability of damage of T 61443 tank is 1 means that the damage on the equipment will occur.

According to ARIA [2], the T 61443 tank explodes and cause fireball. The heat radiation from the explosion was exposed to the T 61442 tank which was only 19 m away from T 61443 propane tank. For the second propane sphere, fireball point source radiation was used to obtained the radiation intensity that received by the tank wall. Thus, the radiation intensity hit the tank wall is obtained which is 51, 670.62 kW/m^2 and probability of damage of the propane vessel is 1. From the results obtained shows that when the first tank, T 61443 occurs fire explosion accident, regardless of the pool fire or BLEVE fireballs, its thermal radiation will destroy the second tank, T 61442, leading to secondary accidents. When the fire explosion accident occurs, its thermal radiation will destroy tanks nearby [16].

B. *Time to Failure*

The volume of propane filled in the tank recorded in Feyzin accident was about 693 m^3 (400 tonnes) while the tank volume was 1218 m^3 [2]. The radiation intensity is 181.82 kW/m^2. Table 4.2 shows the time predicted to failure of T 61443 tank in Feyzin accident.

Table 2: Time to failure of the first tank

Fill (Linear Scale)	**Evaporate rate (Mass)**	**Time (min)**
About 693m^3 (400 tonnes) of propane was filled in the tank during that time Scale: 0.6 of tank	0.1 (40 t)	56
	0.2 (80 t)	66
	0.3 (120 t)	76
	0.4 (160 t)	86
	0.5 (200 t)	97

As can be seen from Table 4.2, as time increase, the propane contained in the vessel also keep on evaporated. The result for the time of failure stop at 97 min because at that this moment, the vessel temperature rises to 700°C in which case the steel tensile strength falls to 150 MN/m^2, the maximum membrane stress, then the vessel will rupture even with the safety valve open. Based on previous study by Yi & Wang [17] states that one of the experiments on the LPG tank or storage to fail under engulfing fires shows a 2000 m^3 sphere tank with 0.5 full of liquefied propane was failed after heated by a 181 kW/m^2 engulfing fire for 89 min.

In Feyzin accidents, a car enters the cloud at 7.15 am and a minute later, the liquefied propane leak ignites. Around 8.45 am, about 90 minutes from the first ignition, sphere 443 explodes resulting fireball forms [2]. Based on the result obtained Table 4.2, the time recorded in ARIA is between 0.4 to 0.5 evaporated rates of the propane mass. Comparing with Table 2, the time difference between times recorded in ARIA was only about 7 minutes of time for the tank to fail and explodes. The relative error between actual and predicted time to failure is 7.78%. This is probably due to difference in value of the heat flux or the mass of propane used in the calculation. The time failure of a pressure vessel in a fire is driven by the fire heat flux and the vessel fill level [3].

C. *Fragments Distribution*

Due to high intensity of heat flux on the wall of the propane tank wall, at certain point it cause the propane spheres, T 16443 and T 16442 exploded violently causing fragments propelled to the surrounding area. In Feyzin accidents, the fragments of propane spheres T 16443 and T 16442 of all sizes were found in a radius exceeding 800 m [2]. The determination of ranges of the fragments distribution should involve with their masses as well as velocities and energy of the explosion [15]. The parameters for the fragments distribution is given in Table 3.

Table 3: The parameters for the fragments distribution

Fill (%)	**Internal energy (MJ)**	**Initial Fragment Velocity, ν_i (m/s)**
80	2170	68.144
60	1566.4	62.83
40	1085	57.705
20	542.5	46.108
10	271.24	35.125

It is important to determine the total energy of a vessel's contents because it is a measure of the strength of the explosion following rupture [6]. From the Table 4.3, the results show that the internal energy in tank is decreasing as the amount of tank filled with propane is decrease. Thus, it will affect the initial velocity, υ_i of the flying fragments. This value of initial fragment velocity is used to calculate either range of fragment travel or if collision with an obstacle occurs before maximum range is reached [13]. With the value of the initial velocity is obtained, the ranges of the fragments distribute can be determined as shown in Table 4.4.

Table 4: Ranges for various initial trajectory angles

Fill (%)	v_i (m/s)	Ranges (m)		
		5°	10°	45°
80	68.14	82.19	161.88	473.299
60	62.83	69.88	137.63	402.41
40	57.71	58.95	116.114	339.49
20	46.11	37.63	74.126	216.73
10	35.13	21.84	43.015	125.766

The initial trajectory will be low for large fragments with horizontal axis travel which are typically 5° or 10° and to obtained maximum range of fragments 45° propelled at an angle of, the fluid-dynamic forces are neglected [13]. Taking these forces into account can reduce maximum ranges significantly.

Evaluating Table 4, it appears that the results of the ranges are basically depending on the initial velocity and the trajectory angle of the propelled fragments. For the fragments with the highest initial velocity which is 68.14 m/s shows that the ranges obtained for each trajectory angles are the farthest ranges for the fragments to propel to the surrounding. While the fragments with low initial velocity with 35.13 m/s shows the shortest ranges obtain for each trajectory angles of fragments.

Based on previous study by ARIA [2], about 693 m^3 (400 tonnes) of propane was filled in the tank during the Feyzin accident which 0.6 of the propane tank. The recorded ranges of the projected elements were 82 m to 325 m resulting from the explosion of the two spheres. Compared to the models used for fragments distribution with 60% filled propane tank, the result shows that the ranges is between 69.88 m to 402.41 m. Fig 1 shows comparison between data recorded by actual and calculated ranges of the fragments projected resulting from the T 61443 and T 61442 spheres.

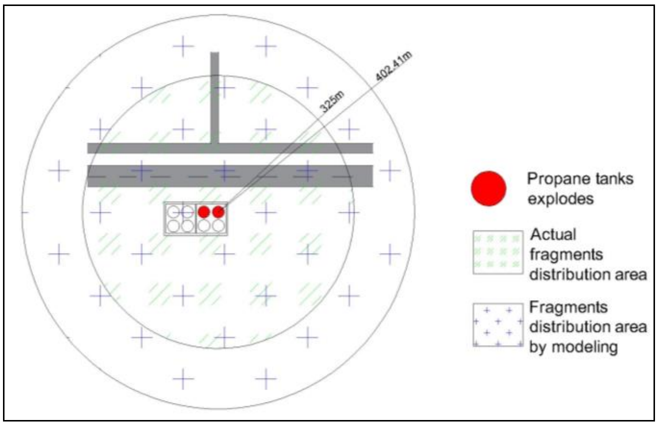

Fig. 2: Comparison between data recorded by actual and calculated ranges of the fragments projected resulting from the T 61443 and T 61442 spheres

From the result shown in Table 4 and Fig 1, the relative error determined between the actual and calculated fragments distribution area is 23.82%. This is probably because these models give almost no information on the number of fragments to be expected and only provide the means to calculate velocity value [1]. Also, the sizes of the fragments have different weight that could affect the velocity of the fragments projected thus resulting in different ranges. According to Wang et al. [16], it appears that the maximum range depends not only on initial velocity but also on fragment mass and shape. Besides that, the data recorded by ARIA did not include with angle of the projectile while the calculate data have various initial trajectory angles. The trajectory angle has a great influence on the range [1].

In BLEVE explosions phenomenon, there are models described with using different of parameters to improve the efficiency and accuracy in determine the results. Some models describe the overpressure phenomenon while other models describe the phenomenon's dynamics and calculate the heat radiation [18]. Blast wave overpressure included as one of the possible consequences of explosions on humans and structures or equipment other than impact from fragments generated by the explosion and heat effects from subsequent fire balls. Yi & Wang [17] gives relatively complete data of pool fire with different 13 types of fuels, and each fuel is grouped by fuel type and pool fire size separately. In the study, they show that the pool fire diameter also gives great influence in heat intensity on the wall of the tank to fail.

According to American Institute of Chemical Engineers [1], various models have been developed for calculating fragment's initial velocities and ranges but however these models are incomplete. In this research also have stated that the number, size and masses of the fragments are some of data that needed to obtain more precise results in determine the actual fragments distribution ranges by using mathematical modeling. The limitations of mathematical modeling described increase the importance of statistical analysis of accidental explosions [1]. Thus, further advances are needed to develop a common model to fit the different categories of fires, explosions and the domino phenomenon in accidents scenarios.

IV. Conclusion

In this research, analyzing of heat radiation effect from Feyzin domino accident scenario was successfully carried out. The probability of domino accident was calculated by using mathematical modeling proposed by Cozzani et al on the probabilistic model of damaged the equipment due to thermal radiation. The result shows that the probability of damage is proven to occur by using the data recorded by ARIA from the Feyzin accident. It shows that the heat radiation intensity hit the wall of propane storage way above the limit of the sphere tank can hold thus causing the tank slowly rupture and explode leading to continuous accident. New incidents are generated from a single initiating incident is identified as domino issue [5].

Apart from that, the predicted time to failure using models give a good agreement between real Feyzin accident scenario and correlated data for the T 61443 tank to rupture and explodes resulting a fireball form. It was found that the relative error for the comparison between the calculated and the actual time to failure in Feyzin accident indicates the data fits very well. Meanwhile the comparison for the fragments distribution ranges between the data obtained from actual accident and from the model have proven that the needs of more data instead of initial fragment velocity and amount of propane contained in the tank such as number, size and masses of the fragments and also the actual trajectory angle of the fragments as well.

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