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Severity Impact of a Vapour Cloud Explosion (VCE) – Liquefied Petroleum Gas (LPG) Road Tanker Accident

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An explosion accident from a road tanker while carrying hazardous materials can have a dangerous effect on road users and the surrounding area through which the road tanker passes. Based on the evidence of the accident case involving the road tanker reported, it shows that this accident case can cause death and destruction to the surrounding property. In Malaysia, several cases of accidents involving road tankers have also occurred. Among the methods used to determine the impact of a road tanker explosion is the use of the consequences analysis method. Currently, there is limited number of software that can be used to determine the impact of a road tanker explosion accident that carries explosive chemicals such as butadiene, Liquefied Petroleum Gas (LPG), etc. However, there are weaknesses in the display of the impact results plotted on the map. Where the impact of the explosion is only shown to the 3 main zones, namely building damage, serious injury, and glass breakage. In this paper, the enhanced contour profile method on the impact of an LPG road tanker explosion on human and structural damage is shown.

Keywords: Severity; VCE; Road tanker; Threat zone; Grid contour

I. INTRODUCTION

Chemical transportation is unavoidable in the manufacturing and delivery of products across regional and worldwide borders. The Department of Transportation (DOT) of the United States of America has identified more than 3,300 hazardous compounds that require regulation. Additionally, tens of thousands of nameless substances are classified for regulation based on attributes like explosive, flammable, corrosive, or contagious (RSPA 2003). According to the United States Department of Transportation, more than two-thirds of oil products are transported by tanker truck, make up roughly 40% of all hazardous material shipments in the country (Zulkifli *et al.,* 2007). Given Malaysia's and the rest of the world's increased industrialisation, the number of stationary installations (i.e., chemical process plants, oil and gas terminals, petrol stations, etc.) has increased significantly in recent years. Further with exploration of oil and gas in the country, the growth of chemical-related industries has been accelerated, and it is now one of the primary areas for expansion. As a result of this discovery, the percentage of Hazardous Materials (HAZMAT) transported from one stationary installation to another for further processing or product distribution has increased indirectly. Since 1982, several papers have been published by researchers concentrating on identifying a lower-risk route by road, sea, or combination of the two (Erkut & Ingolfsson, 2000; Huang & Cheu, 2004; Verma & Verter, 2007). At any point along its route, dangerous chemical transportation poses a risk to the surrounding people and environment. Previous studies on HAZMAT transportation accidents has revealed that

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accidents involving hazardous materials transportation may have additional consequences due to their physical and chemical properties (Rhyne, 1994; Carson & Mumford, 2003; Lisi *et al.,* 2001). The amount of destruction is expected to be greater if the accident occurs in a densely populated area (Bubbico *et al.,* 2001). The review of transportation risk analysis methodologies and consequences calculations for chemical transportation is mainly based on major TRA guidelines and risk assessment handbooks such as CCPS Guidelines of Chemical Process Quantitative Risk Analysis, (2000), Methods for the calculation of Physical Effects The 'Yellow Book', (2005), TNO Purple Book, (1999), CCPS Guidelines of Chemical Risk Transportation Risk Analysis, (1995), CCPS Guidelines of Characteristics of Vapour Cloud Explosions (1994), CCPS Vapour Cloud Dispersions (1987), (Rhyne,1994), CCPS Guidelines for Chemical Transportation Safety, Security, and Risk Management (2008), CCPS Guidelines for Vapour Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards (2010), CCPS Guidelines for Use of Vapour Cloud Dispersion Models (1996) and BUWAL methodology developed by Swiss Federal Institute of Technology. The results of the impact damage calculation for road tankers utilising risk simulation are presented in the contour profile. However, the explosion damage contour profile cannot distinguish the impact damage on objects that receive the same maximum from different locations. This is because the contour zone profile can only distinguish by three maximum pressures at a time. Although the difference in impact damage on objects exposed to an explosion can be plotted beyond or more than 3 maximum pressures on the graph, thus there are still shortcomings in terms of determining the contour of explosion impact damage on the topographic map. Therefore, this research aims to enhance the contour impact profile on the LPG road tanker explosion over human and structural damage.

II. MATERIALS AND METHODS

A. Methods

In this paper, the methodology used is to determine the threat zone from an explosion accident from a road tanker carrying LPG. ALOHA software will be used to determine the consequences of an iso tanker LPG truck explosion. The impact results of the explosion from the LPG tanker (ALOHA) are then exported to MARPLOT automatically to get more effective impact damage results on Google Maps. To increase the effectiveness of the impact damage results of LPG tanker explosion plotted on Google Maps, the additional number of plot grid damage contour profiles exceeding 3 contour explosion damage will be introduced. Below are the methods used to generate enhanced damage contour profile of LPG tanker explosion:-

1. Identification of the study area

The location of the incident was the LPG tanker explosion at Jln. Sungai Besi near Taman Billion, Cheras. During that accident, the road iso-tanker carried a load of 42000 litres of LPG.

2. Specification of iso-tanker

Iso LPG tankers are made of stainless steel. The length of the iso tanker is 12 meters, and the diameter of the tanker is 2.6 meters. To ensure that the LPG in the iso-tanker is the liquid phase, the pressure in the tank is increased to a pressure of 9.8 bar, while the temperature of the LPG is the same as the ambient temperature of 30 degrees Celsius. There are 2 safety valves (15 bar) installed at the top of the iso tank.

3. Physical properties of LPG

The physical properties of LPG are as in Table 1 below.

Table 1. Properties of LPG

Properties	Values
CAS Number	74-98-6
Molecular Weight	44.10 g/mol
Ambient Boiling Point	42.3 °C
Vapour Pressure at Ambient Temperature	Greater than 1 atm (853.kPa)
Density (g/cm^3):	0.002 (0 °C) -0.493 (25 °C)
Heat of combustion	(46400 kJ/kg)
Specific heat capacity, C	(73.60 J K^{-1} mol^{-1})
Autoignition	470 °C

4. Weather conditions during the accident

The weather conditions during the accident are as per Table 2.

Table 2. Weather Conditions

Conditions	Values
Humidity	80%
Stability class (day):	B
Wind speed	2.57 m/s
Ambient temperature (day)	30 °C, atmospheric pressure

5. Model for determining Blast effect from Vapour Cloud Explosion (VCE)

For explosion studies from LPG road tankers, the model incorporated in ALOHA is the Baker Strehlow model (BST) model. The Baker-Strehlow-Tang (BST) model is the basis for the blast overpressure calculation (non-dimensional) which empirically derived the blast curves to predict the overpressure value (CCPS, 2000). The overpressure is based on the propagation speed of the flame front and the mass of fuel involved in the reaction. The leak/rupture/crack size of the hole used on the iso LPG tanker is 50mm for a small leak and 160mm for a catastrophic hole leak size.

6. Possible causes

A possible failure of the iso-tanker is a leak on the surface of the iso tanker, or a failure of the safety valve that prevents the release of LPG gas below 15 bar.

7. Damage area/ threat zone

Determining the damaged area or threat zone of a possible road tanker accident is done using MARPLOT. The damaged area in m^2 will be identified in length or radius.

8. Grid and damage area

The damaged area affected will be determined by length and width based on 2D dimensional area. Next, the damaged area is divided into smaller compartments or cells. Each small box or compartment should be the same size. Each compartment represents the maximum overpressure result resulting from the LPG tanker iso explosion source. The smaller the plot of the damaged area, the more accurate the maximum blast overpressure value represented by the VCE coordinates of the impact. This step is called the grid process on the ALOHA threat zone contour.

9. Plot a new damage contour profile

The blast overpressure effect results from all small and equal size squares (20C x 14R), integrated simultaneously as a new damage contour profile.

III. RESULTS AND DISCUSSION

Based on the above methodology, the impact of the 42000 litre LPG tanker explosion accident at Jln. Sungai Besi near Taman Billion, Cheras was successfully plotted using ALOHA software and installed using MARPLOT. Figure 1 shows the threat zone contour of the LPG iso tanker lorry that was released from the 50mm and 160mm hole size opening. The condition of the gas LPG does not burn when coming out of the hole in the wall of the iso tanker lorry surface. However, the potential for death to humans exposed to LPG gas around 65 meters radius from the source of the LPG iso tanker lorry leak is expected to occur. This is because a person who is exposed for 60 minutes to 33000 ppm of LPG (propane) can be categorised as experiencing exposure to Acute Exposure Guideline Levels level 3 (AEGL-3) which could experience life-threatening health effects or death.

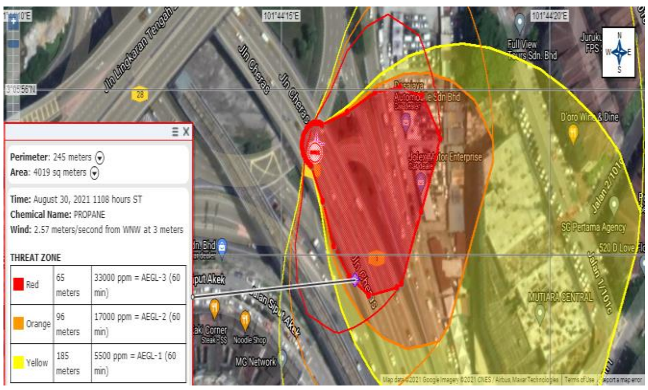

Figure 1. Non-burning LPG gas escapes from a 50mm hole size leak at the top surface of the LPG iso-tanker (42000L)

Figure 2. A local area of flame can occur even the average concentration is below the lower explosive limit (LEL) from LPG tanker (42000L)

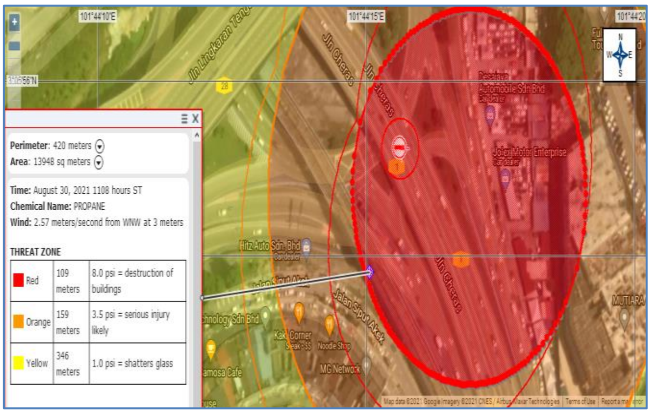

Figure 4. Overpressure (blast force) from vapour cloud explosion due to detonation impact LPG tanker (42000L)

Figure 2 shows that the risk of fire is high if the ignition source or spark is located within a radius of 115 meters from the LPG tanker. A thick contour red line indicates a hazardous zone area if exposed to a fire source. The LEL zone area was found to be further away from the toxic vapour cloud effect area as in Figure 1 (red zone 96 meters). This shows that while flash fire does not occur as in Figure 1, the potential for a flash fire remains if there is a fire source ignited by shop buildings, vehicles, and others located within a radius of 115 meters. Figure 3 is the impact of a vapour cloud explosion that occurs if the flammable zone is triggered by a spark or flame (ignition source). However, impact lethality can only occur around a 10-meter radius from the LPG tanker. Meanwhile, people who are within a 77 -meter radius of the LPG tanker will suffer serious injuries.

Figure 4 shows the scale of damage to buildings within a radius of 109 meters from the LPG tanker, as well as the potential for people who will experience serious injuries approaching 159 meters. Serious injury may be caused by blast overpressure or the impact of a flying object and debris the effect of VCE detonation (less than I minute). Based on Department of Defense data from Glasstone and Dolan (1977) and Sartori (1983), it summarises the effects of increasing blast pressure on various structures and the human body. According to Glasstone and Dolan (1977), Finney (1971), Lobato *et al.* (2006) and Sartori (1983) the human body can survive relatively high blast overpressure. There also found that at 35-45 psi overpressure, may cause 1% fatalities, and 55 - 65 psi blast overpressure may cause 99% fatalities.

Figure 3. Overpressure (blast force) from vapour cloud explosion and ignited by spark or flame and propagate back LPG tanker (42000L)

Figure 5. Overpressure (blast force) from vapour cloud explosion due to detonation impact LPG tanker (42000L) at maximum overpressure 30 psi

Based on Figure 5, it is found that the potential of the impact would not be shown since the software would plot the maximum overpressure up to 30 psi only. According to Glasstone and Dolan (1977), a 5 psi blast overpressure would rupture the eardrums an average of 1% and a 15 psi blast would damage the lung. Meanwhile, 35-45 psi overpressure might cause 1% fatalities, and 55 to 65 psi overpressure might cause 99% fatalities. However, Marplot and ALOHA could not differentiate the severity of damage to VCE for blast pressure of more than 30 psi. Figure 6 shows the gridding of 20 columns x 20 rows on the threat zone explosion LPG iso tanker.

Figure 6. grid 20 x 20 to LPG explosion threat zone

The contour pressure map as in Figure 7, shows the blast overpressure plotted on the contour map exceeding 3 impact zones. A total of 9 threat zones are shown in Figure 7, from 3 psi to 55 psi and above. Between 74 to 80m from the source of the explosion, people who are exposed to blast overpressure measure 35 to 45psi. which has the potential to result in 1 % of fatalities, as well as can result in a serious eardrum rupture injury of 99 %. At 19.25 psi to 22 psi between a distance of 80 and 85m, the new contour plot shows that the row of buildings around the radius will be heavily built concrete damaged. Moderate damage to houses at a distance of 114m. Figure 8 shows a distance between 6 to 65m below the LPG iso tanker (52.0) will be exposed to a blast pressure of 48-291 psi according to the Y axis direction between (52.6) m to (52, 65) m. If the blast overpressure exposure takes into account the change in distance from the source of the explosion (0.52) m in the X axis direction, Figure 9 shows that the value of the blast overpressure curve is between 105 to 291 psi at a distance between (0, 52) m to (65.52) m.

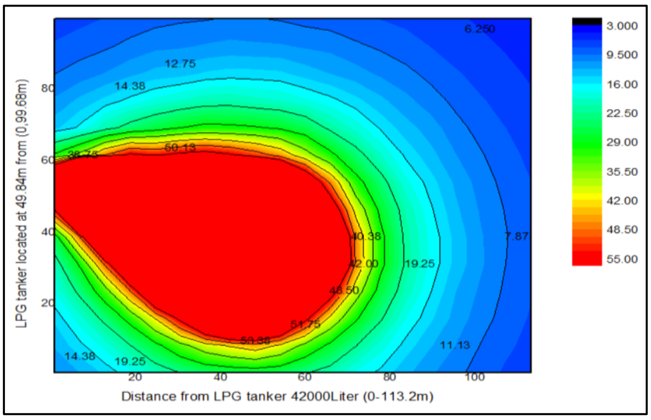

Figure 7. impact contour from LPG explosion damage

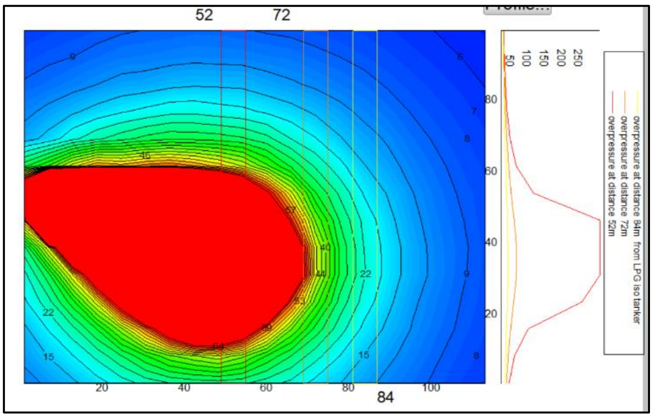

Figure 8. Contour impact of LPG explosion between 52 to 84 m with peak overpressure

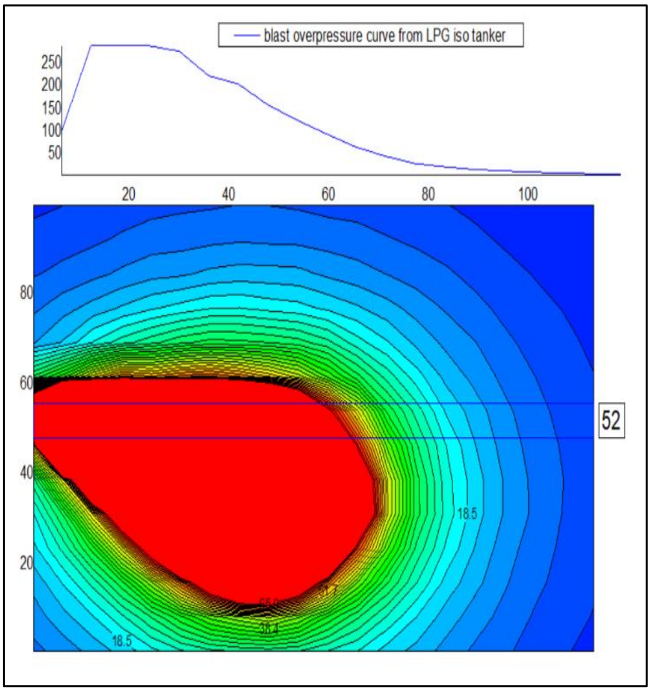

Figure 9. contour of the red zone at a distance 52m from point (0,0) of the contour

IV. CONCLUSION

Damage explosion impact on human and building structures are depending on the absorbed amount of maximum overpressure of the blast object. The results of ALOHA software are restricted to only the destruction of buildings, serious injuries and shattered glass. According to the literature, at 35-45 psi overpressure might cause 1% of fatalities, and at 55 to 65 psi overpressure might cause 99% of fatalities. However, the mapping result of ALOHA in MARPLOT is only limited to 30 psi and below.

Therefore, by implementing the smaller overpressure grid point in the MARPLOT threat zone area, the unknown severity impact contour profile of the LPG iso tanker explosion accident toward structure and humans in the MARPLOT can be plotted effectively and minimise the uncertainty to predict vulnerability damage at the study site when applied.

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