Integration of Boiling Liquid Expanding Vapour Explosion (BLEVE) Risk Model with Process Simulator for Inherent Safety Design

by

Sulaiman bin Sidek

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JULY 2005

Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Pn. Risza Rusli)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SULAIMAN BIN SIDEK

ABSTRACT

The aim of this project is to develop an interface that able to integrate process simulation (e.g. HYSYS) for estimating the risk owing to the phenomenon of Boiling Liquid Expanding Vapour Explosion (BLEVE). The overall integration network is divided into three stages – (1) HYSYS-ME Interface, (2) mathematical calculation under ME platform and (3) VB-ME Interface. Within HYSYS-ME interface, two models were programmed under steady state simulation. The first model was a storage tank applied for a given problem (Roberts M. W., 2000), while the second model correspond to case study on Vessel V-2408 of Malaysia LNG Dua Sdn. Bhd. For the second stage, three measures of the BLEVE consequences - blast, fireball and missile effect, have been considered. The blast effect is estimated based on the established relationship between overpressure and effects, the fireball effect estimated using the thermal intensity and the missile effect is estimated with respect to the distance travel. For the last stage, VB-ME Interface was used to display the BLEVE parameters and effects that were calculated in the previous stage. Overall, this project can be used to evaluation the BLEVE effects on the chemical process operation. Further improvements are necessary to commercialize and integrate this project with other risk effects estimation.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The word *safety* used to mean the older strategy of accident prevention through the use of hard hats, safety shoes and a variety of rules and regulations – mainly focus on worker safety (Crowl D. A. and Louvar J. F., 1990). The term is now incorporated with *loss prevention* to include hazards identification, technical evaluation and design of new engineering features to prevent accident.

Chemical plants contain a large variety of hazards and thus making the *safety* and *loss prevention* (SLP) is an important aspect in chemical process plant design (CPPD). CPPD is a quite complex activity which is carried out in stages over a period of time and involves people of many disciplines. An understanding of SLP during CPPD involves putting much greater stress on technological measures to control hazards and on trying to get things right first time.

Traditional approach to CPPD mostly concern of the detailed engineering phases that involves the use of procedural controls and the addition of safety devices at the end of the design process on the identified hazards. This approach is referred as external safety – or sometimes as extrinsic safety. The control devices added do not perform any fundamental operation rather to act in the event of sudden process upset.

Khan F. I. and Amyotte P. R. (2002) declared that "External safety is a cost intensive approach as the add-on control devices require continual staffing and maintenance as well as repetitive training and documentation upkeep throughout the life of the plant. It is favored by management that considers safety and environmental activities as a need rather than a requirement, thus ignoring the use of basic principles of science in eliminating or reducing operational safety control measures."

Consequently, another method was developed in order to overcome this design strategy and it is known as inherent safety. Inherent safety involves the elimination or reduction of process hazards through the use of inherent properties of materials or processes and process equipment. Having been formalized approximately 35 years ago, full exploration of inherent safety ensure safe processing of chemicals and prevention of industrial accidents which in turn minimizing human, financial and material losses. Crawley F. (1995) and Lutz W. K. (1997) stated that an inherent safety culture often achieves the lowest lifetime costs per unit mass of product in relation to safety and environmental concerns.

While the basic principle governing the inherent safety is generally accepted, this project presents the integration of Boiling Liquid Expanding Vapour Explosion (BLEVE) risk model with process simulator (HYSYS) as one of the elements for inherent safety in process design.

1.2 Problem Statement

In spite of the advanced technology employed in safeguarding chemical plants, industrial accidents continue to occur and there is a demand for remedial action and a permanent resolution (Frank W. L. and Arendt S., 2002). In other words, the aim should be to design the process and plant so that they are inherently safer and the provision of mean to control the hazard is very much the second solution.

Numbers of researchers have identified the need to assist designers applying concept of inherent safety during CPPD thus generating the term inherently safer design (ISD). Lees F. P. (1980) stated that ISD is particularly important for major hazard plants and the concept is a recurring theme in the three reports of the Advisory Committee on Major Hazards (ACMH) and receives more detailed treatment in the *Third Report* (Harvey, 1984). The main hurdles to adopting ISD are – absence of awareness on the concept; lack of understanding on the principles and guidelines; difficulty in securing time at the early stages of projects to consider safety aspects; the manner in which safety is addressed in feasibility studies; and the limited attention to inherent safety in regulations (Khan F. I. and Amyotte P. R., 2002).

Chan T. L. (2004) proposed that ISD can be implemented if the consequence analysis is included in the early stage especially during process simulation. The graphical representation of the concept is given in **Figure 1.1**.

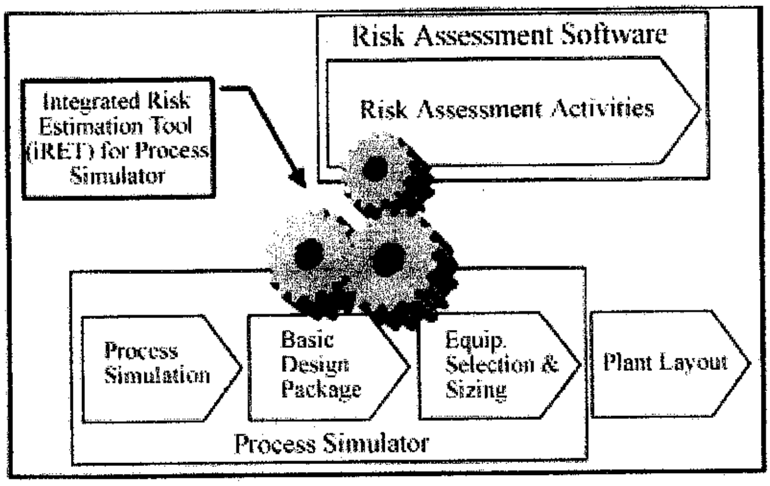


Figure 1.1: Graphical representation of ISD concept (Chan T. L., 2004)

One of the consequence analyses which present convincing arguments for ISD execution is BLEVE. DOSH (1999) reported that the second dangerous and destructive accidents in the chemical process industries (CPI) are BLEVE – as represented in **Figure 1.2**.

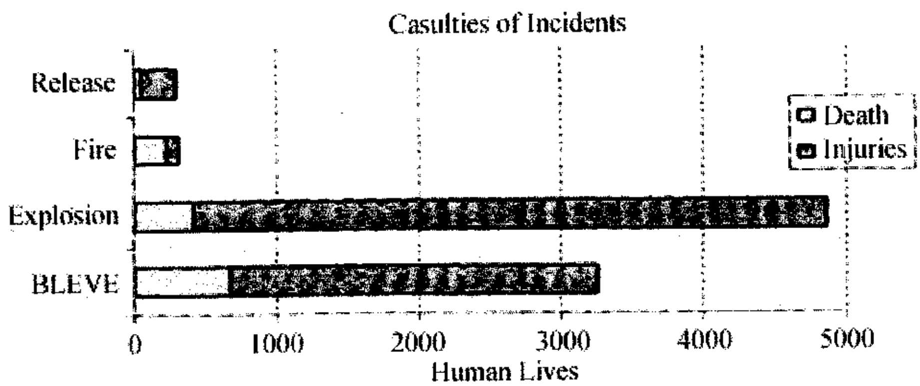


Figure 1.2: Causalities of incidents in Malaysia at year 1999 (DOSH, 1999)

The current tools for estimating the risk associated with BLEVE are lack of integration with process simulation (e.g. HYSYS). During CPPD, process simulator is widely used as it bales to provide the optimum condition of the process and reflect any changes immediately. Thus, development of tool for estimating the risk from BLEVE during CPPD will further promote the development of ISD.

1.3 Objectives and Scope of Study

Specifically, this project anticipated the development and improvement of the existing BLEVE risk model done by the previous student in Microsoft Excel (ME) application. It is expected to have HYSYS-Microsoft Excel (HYSYS-ME) Interface that able to assimilate the desirable data within HYSYS simulation case and ME platform for the mathematical calculation of the BLEVE effects. User friendly Visual Basic-Microsoft Excel (VB-ME) Interface should be design to display the calculation result.

The reliability of the project is appraised based upon two case studies. The first case study is conducted on a storage tank of a given problem (Roberts M. W., 2000) while the second case study is corresponds to Vessel V-2408, one of the major process equipment in Malaysia LNG Dua Sdn. Bhd. To further enhance the acceptability of the tools, it is benchmark with available risk assessment software, SAFETI, on the establish BLEVE effect (e.g. blast, thermal radiation, missile projectile etc.).

CHAPTER 2
LITERATURE REVIEW

2.1 Inherent Safety Principles and Indicators

An inherently safer plant is one that by virtue of it design generates little or no damage if an accident occurs (Khan F. I. and Amyotte P. R., 2002). Inherent safety concept was first proposed in the late 1970s by Kletz T. A. (1985, 1991) as a fundamental approach to hazard management.

The essence of the inherent safety is to avoid and remove hazards rather than to control them by add-on protective system. The four main principle and six key indicators incorporated with the inherent safety is describe subsequently.

2.1.1 Inherent Safety Principles

Minimize (intensification): Intensification strategy challenges the process designers to determine an optimum inventory of hazardous materials that compromises neither profitability nor the safety integrity of a process when the hazardous materials cannot be eliminates (Khan F. I. and Amyotte P. R., 2002). This strategy leads to the use of smaller and simpler equipment.

Substitute (substitution): Substitution can be achieved by replacing a chemical process route with one that avoids hazardous processing condition, substituting hazardous material with less hazardous material or replacement of process equipment. Substitution strives to eliminate material with highly hazardous inherent characteristics (e.g. flammability, reactivity and toxicity).

Moderate (attenuation and limitation of effects): Moderation entails for using hazardous materials in their less hazardous forms or the use of less severe processing conditions (Khan F. I. and Amyotte P. R., 2002). It is worth emphasizing that the overall objective of all moderation strategies is elimination or reduction of hazards.

Simplify (simplification/error tolerance): Simplification involves designing process to eliminate irrelevant complexities that minimizing the opportunities for errors to occur for better layout of plant equipment and elimination of passive structures.

2.1.2 Inherent Safety Indicators

Table 2.1: Inherent Safety Indicators (Khan F. I. and Amyotte P. R., 2002).

Term	Description
1. Inventory	The quantity of material in a process, wherein for potentially hazardous material a process becomes inherently less safe as the quantity of the material increase.
2. Pressure	Indicator of hazard level of a process. High pressure indicates high potential energy as it provides the needed momentum for materials to escape at high velocities from confinement.
3. Temperature	It is a necessary parameter for assessing the inherent safety of a process as molecules possess higher kinetic energy at higher temperature and vice versa. Systems operating at high temperature and pressure are more prone to fire and explosion hazards since the contents can easily flashed.
4. Flammability	It is generally regarded that the flash point of a material is an appropriate property for the determination of flammability hazard.
5. Reactivity	It is the ability of a material to react both with itself and with other materials.
6. Toxicity	It is a measure of the ability of a material to impair the health of living organism. Toxic material can be classified those that generate severe impact upon short exposure, and others that generate noticeable effect or permanent damage only on long-term. Thereby, minimizing their ability mitigate the severity of an incident.

2.2 Boiling Liquid Expanding Vapour Explosion (BLEVE)

Boiling Liquid Expanding Vapour Explosions (BLEVE) generally occurs when a pressure vessel containing a flammable liquid is exposed to fire so that the metal loses strength and ruptures (Lees F. P., 1996). Any process containing quantities of liquefied gases, volatile superheated liquid or high pressure and high temperature gases is also consider to be a good candidates for a BLEVE.

The development of BLEVE is illustrated by Lees F. P. (1996) in **Figure 2.1** and the describes of the overall event can be summarized as follow;

> "Exposed fire acting on a vessel containing pressurized liquid gives rise to the vapour pressure and the pressure in the vessel as the liquid is heats up. It should be noted that liquid is effective in cooling that part of the vessel wall which is in contact with it but the vapour is not. As the vapour is released to the atmosphere, the liquid level and the portion of the vessel wall which has the benefit of liquid cooling falls. The exposed metal becomes hot, weakens and ruptures. Consequently for flammable fluid, often involves with formation of vapour cloud that contribute for fireball effect."

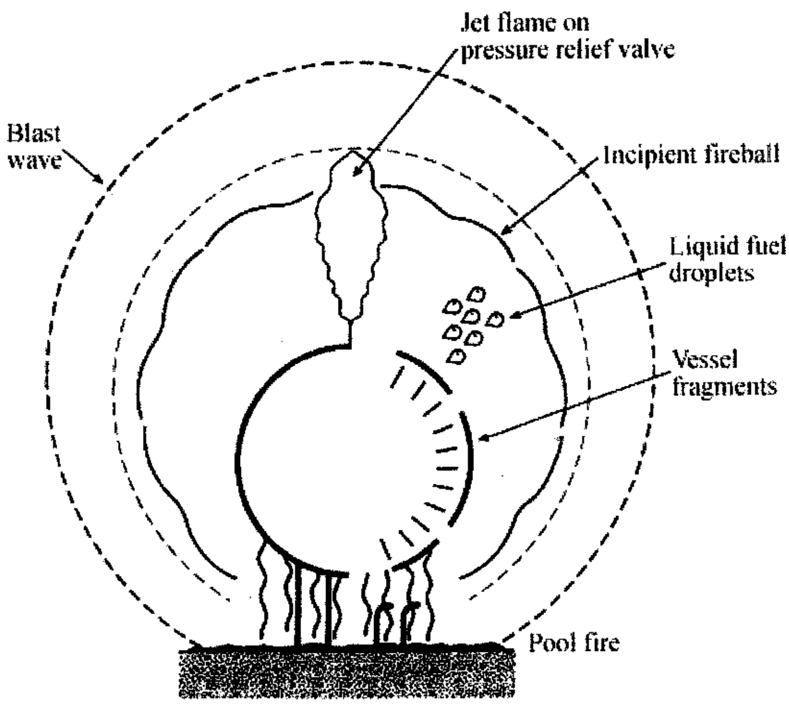


Figure 2.1: A BLEVE event (Lees F. P., 1996)

Essential features of a BLEVE event are (1) blast effect, (2) fragments and, for flammable fluids, (3) a fireball. The blast effect is associated with vapour expansion, flash vaporization and for flammable fluids, the combustion of the vapour. Fragments created by the rupture event and also the body of the vessel itself generate missile as the pressure at the instant of burst is high and the reaction force is often large enough to cause the fragments to rocket. For a vessel containing flammable fluids, fire engulfment of the vessel gives rises to fireball (Lees F. P., 1996).

2.3 Available Simulation Tools

2.3.1 ADORA

Source: http://www.blazetech.com

Atmospheric Dispersion of Reactive Agent (ADORA) was developed by COTR Maj. Becky Wagner in 1998. It is premier Environmental and Safety Offsite Consequence Analysis tool available for use by organizations involved with environmental impact assessment for intentional or incidental discharge of hazardous chemicals that react with air, fire or each other. This software mainly focuses on the characterization and dispersion model for extremely hazardous chemicals in the atmosphere.

2.3.2 BIS

Source: http://www.thermdyne.com

BLEVE Incident Simulator (BIS) was developed by Professor A. M. Birk in 1997. It is an interactive computer program to study the effect of different tank sizes, different fire types and different tank protection on BLEVE. BIS used tank thermal model to estimate the critical tank behavior in a fire and to develop an understanding of how pressure tanks are affected by fire impingement. This software is intended as a response planning tool and training simulator.

2.3.3 SAFETI

Source: http://www.dnv.com

Software for Assessment of Flammable, Explosive and Toxic Impact (SAFETI) was developed by DNV Software Risk Management Solution in 1995. It combines the consequences and frequencies of the hazards to determine the risk. SAFETI uses built-in chemical and parameter data, along with scenario, meteorological, population and ignition data supplied by the user to predict the risk. SAFETI analyses complex consequences from accident scenarios, taking account of local population and weather conditions, to quantify the risks associated with the release of hazardous chemicals. It is by far the most comprehensive quantitative tool available for assessing process plant risks. However, this software is too general in term of estimating the BLEVE effect as it considers the estimation of the BLEVE was just a minor part.

2.3.4 SEVEX View

Source: http://www.weblakes.com

SEVEX View developed in 1995 from the collaboration of Lakes Environmental Software, ATM-Pro, the Walloon Region of Belgium, the Faculty Polytechnique de Mons, the University Catholique de Louvain, the Universiti de Liège and SOLVAY. It is an advanced 3D complex terrain gas model designed that estimate risks zones around hazardous materials handling and storage facilities like chemical activities, railway yards, ports area or pipe-line terminals. This software did not integrate with process simulator although posses good database on estimating BLEVE.

CHAPTER 3
THEORY

3.1 Case Study

3.1.1 Storage Tank Model

As a case study, consider a 10 000 gal. (37.85 m^3) capacity propane storage tank with a safety relief valve set at 250 psig (1723.7 kPa) and to be filled with 80% of volume capacity. The storage tank is assumed to be engulfed in flames, resulting in BLEVE event (Roberts M. W., 2000).

The initial condition of the tank is defines by assuming that the tank fail at an internal pressure of 1.21 times the setpoint of the relief valve, 320 psig (2206.3 kPa), with the approximate saturation temperature of 144°F (61.7°C). The final condition of the tank are atmospheric pressure of 14.7 psia (101.4 kPa) with the normal boiling point of propane at - 44°F (- 42.18°C).

3.1.2 Vessel Model

Figure B.1 in Appendix B illustrates the Process Flow Diagram (PFD) of the cryogenic process of LPG processing (Malaysia LNG Dua Sdn. Bhd., 2004). The case study was conducted on the Vessel V-2408.

The vessel is assumed to be engulfed in flames and fail at its operation condition, resulting in BLEVE event. The initial condition of the vessel is defines by operating pressure of 1299 kPa, approximate saturation temperature of 37.63°C and to be filled with 80% volume capacity of liquid propane. The final condition is assumed to be at atmospheric pressure of 101.4 kPa with the normal boiling point of propane at - 42.18°C.

3.2 Blast Effect

3.2.1 Liquid Superheat Limit

In particular, under certain condition, explosive flashing of the superheated liquid can occur, giving a large released of energy. Hence, if a liquid has a sufficient degree of superheat and the pressure on it is suddenly removed, microscopic vapour bubbles form and a large fraction flashes off within milliseconds (Lees F. P., 1996).

The energy of the explosion of a BLEVE event depends on the condition in the vessel. It is vital to obtained first whether the liquid temperature is greater than the superheat limit as it determine the degree of superheat limit necessary for explosion of a BLEVE event to occur. Using Redlich-Kwong equation, Reid (1976) obtained;

$$T_{sl} = 0.895T_c$$

where T_c is the critical temperature (K) and T_{sl} is the superheat limit temperature (K).

CCPS *Fire and Explosion Model Guidelines* (1994/15) outlined that if the superheat limit temperature is not exceeded, estimation of the explosion energy is made of the ideal gas condition, whilst if it is, use is made of the non-ideal gas condition.

3.2.2 Vessel Burst Energy: Ideal Gas

Taking the ideal gas case, the treatment given by Brode (1959) consider the energy of explosion is the energy required to raise the pressure of the gas at constant volume from atmospheric pressure to the initial, or burst, pressure. Brode's equation is;

$$E = \frac{(P_1 - P_0)V}{\gamma - 1}$$

where E is the energy of the explosion, P is the absolute pressure, V is the volume of the vessel, γ is the ratio of the specific heat and the subscripts 1 and 0 denote initial and atmospheric, respectively.

3.2.3 Vessel Burst Energy: Non-Ideal Gas

For non-ideal gas condition, the energy of explosion is obtained as the different in the internal energy between the initial and the final state, assuming an isentropic expansion, using the following equation (Lees F. P., 1996);

$$E = n(u_1 - u_2)$$

where n is the number of mole, u is the internal energy and the subscripts 1 and 0 denote initial and final state, respectively.

Lees F. P. (1996) considered that, for the expansion of vapour there are several different cases which may arise with the fluid – (1) a superheated vapour in both states, (2) wet vapour in both states or (3) a superheated vapour in state 1 but wet vapour in state 2. thus the wetness of the vapour may be expresses as;

$$x = \frac{\phi - \phi_f}{\phi_g - \phi_f}$$

where x is the wetness of the vapour, subscripts f and g denote saturated liquid and saturated vapour, respectively, and ϕ is a variable that may be replace by v, s, u or h.

3.2.4 Correlation of Blast Effect

In the absence of models for vessel burst explosion, it has been frequently practice to model the explosion by estimating the energy of the explosion corresponds to the TNT equivalent. Work on the correlation of blast parameters which is frequently utilized is that of Baker W. E. et al. (1983). The scaled distance is expressed as;

$$z = \frac{R}{W^{\frac{1}{3}}}$$

where R is the distance (m) and W is the mass of explosive (kg).

Graph of scaled peak overpressure and scaled impulse for the explosion is plots against the scaled distance based on the equation develop by Kinney and Graham (1985).

For the scaled peak overpressure;

$$p_s = \frac{808\left[1+(z/4.50)^2\right]}{\left[1+(z/0.048)^2\right]^{\frac{1}{2}}\left[1+(z/0.32)^2\right]^{\frac{1}{2}}\left[1+(z/1.35)^2\right]^{\frac{1}{2}}}$$

for the impulse;

$$i_p = \frac{0.067\left[1+(z/0.23)^4\right]^{\frac{1}{2}}}{z^2\left[1+(z/1.55)^3\right]^{\frac{1}{3}}}$$

with the scaled impulse derives by Lees F. P. (1996) as;

$$i_s = i_p / W^{\frac{1}{3}}$$

where p_s is the scaled peak overpressure, i_p is the impulse (barms), i_s is the scaled impulse (Pas/kg$^{1/3}$), W is the mass of explosive (kg) and z is the scaled distance (m/kg$^{1/3}$).

Damage caused by blast waves from explosions has traditionally been correlated in terms of peak overpressure of the explosion (Lees F. P., 1996). **Table A.1 in Appendix A** shows damage table given by Clancey V. J. (1972) in the context of accident investigation. It is used to estimates the damage level produced by the blast wave of the calculated explosion.

3.3 Missile Effect

Lees F. P. (1996) stated that, "Missiles are generally classified as primary and secondary. Primary missiles are those resulting from the bursting of containment so that the energy is imparted to the fragments which become missiles. Secondary missiles occur due to the passage of blast wave which impart energy to objects in its path thus turning them into missile".

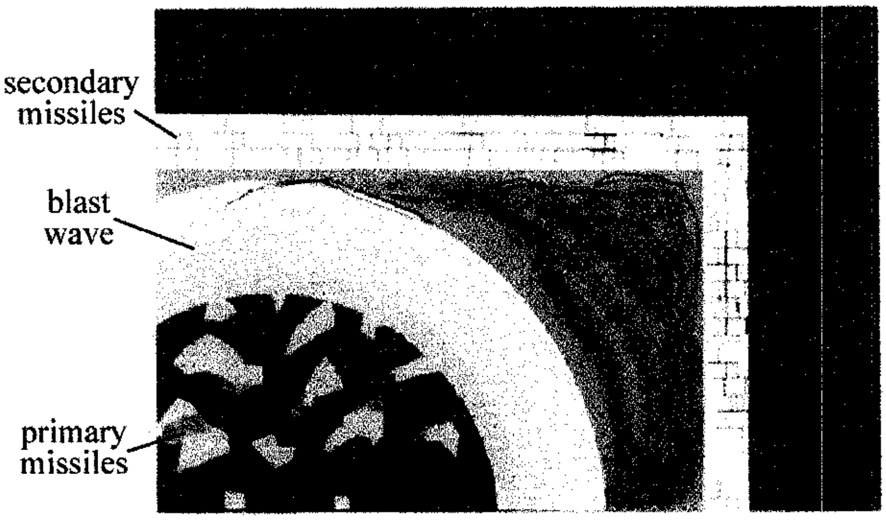


Figure 3.1: Illustration of primary and secondary missile (Jagger R. E., 1984)

The fragments associated with a BLEVE event are generally not evenly distribute owing to the fact that the fragments can be launched in any direction and the trajectory of propelled fragments can be changed by bouncing off terrain or structures (Robert M. W., 2000).

Possible projectile range of the generated fragments is used to correlate the missile effect resulting from the BLEVE explosion. Birk A. M. (1995) suggested approximate guidelines of the projectile ranges related to the fireball radius as follows – (1) 80% to 90% of rocketing fragments fall within 4 times the fireball radius, (2) severe rocketing fragments may travel up to 15 to 30 times the fireball radius and (3) very severe, rare case, rocketing fragments may travel up to 30 times the fireballs radius.

3.4 Fireball Effect

Fireballs mostly related to liquefied gas and are distinct into several type depend upon the event which give rise to it – (1) bursting of pressure vessel which may occur under fire condition and be part of a BLEVE or may occur in the absence of fire, (2) formation of vapour cloud that predominate by the buoyancy forces, (3) ignition of a release on a liquefied gas pipeline where the jet flame is preceded by a fire ball in which unignited gas is burned, (4) an eruption in hot oil that giving rise to a release of burning vapour, and (5) congested fireball from the rupture and release of flammable contents of a reactor (Lees F. P., 1996).

The type of fireball of particular interest, however, is that which occurs as part of a BLEVE. They usually take place when a vessel ruptures and are predominate by the momentum forces.

Based on a frame-by-frame analysis of the National Fire Protection Association (NFPA) film on BLEVE, as illustrate in **Figure 3.2**, Crawley (1982) stated that;

> "The fireball development passes through three phases – (1) growth, (2) steady burning and (3) burnout. The growth phase may be divided into two intervals with each about 1 second duration. In the first interval the flame boundary is bright with yellowish-white flames indicating a flame temperature of about 1300°C. The fireball grows to about half its final diameter and calculation indicates that fuel droplets of less than 4 to 5 mm diameter would vaporize. This would give good mixing with air at the droplet scale and would also be good bulk mixing. In the second interval of the growth phase, which last some 10 seconds, the fireball is now roughly spherical and is no longer growing. At the start of this phase it begins to lift off, rise and changes to the familiar mushroom shape. The estimated effective flame temperature is 1100 to 1200°C. In the third phase, which last for 5 seconds, the fireball remains the same size but the flame become less sooty and more translucent."

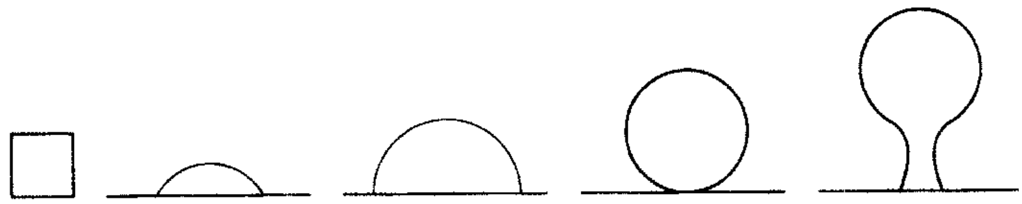


Figure 3.2: Typical development of a fireball (Lees F. P., 1996)

3.4.1 Mass of Fuel

The mass of fuel in the fireball depends on the fraction of fuel which flashed and on the further fraction which forms liquid spray (Lees F. P., 1996). Hasegawa and Sato (1977) found that when the theoretical adiabatic flash fraction reach 35% virtually all the liquid released burns as a fireball.

From the above hypothesis, Robert A. F. (1982) derives that;

$$f = \frac{M}{M_r} = 0 \quad \phi = 0$$

$$f = 1 \quad \phi \geq 0.35$$

by linear interpolation;

$$f = \frac{\phi}{0.35} \quad 0 < \phi < 0.35$$

where f is the faction of fuel released entering the fireball, M is the mass of the fuel in the fireball (kg), M_r is the mass of liquid released (kg) and ϕ is the traction of liquid vaporized. The method used by CCPS (1994/15) outlined that the mass of fuel participates in the fireball is three time the flash fraction or, if this figure exceeds unity, the mass released.

3.4.2 Diameter and Duration of the Fireball

The basic correlation for the diameter of the resulting fireball are provide as a function of the mass involved in the combustion through an equation of the form;

$$D = k_1 M^{n_1}$$

where D is the diameter of the fireball (m), M is the mass of the fuel in the fireball (kg), k_1 is a constant and n_1 is an index.

The empirical relationships of the duration time are of the form;

$$t_d = k_2 M^{n_2}$$

where t_d is the duration time of the fireball (s), M is the mass of the fuel in the fireball (kg), k_2 is a constant and n_2 is an index. Data for parameters k_1, k_2, n_1 and n_2 are given in **Table A.2 in Appendix A.**

3.4.3 Solid Flame Model

The thermal radiation estimated using this model assumes the fireball is a spherical ball that rises into the air as the flammable material is burned (Roberts M. W., 2000). An important assumption made by those using this model is that the emissive power is constant and does not depend on the mass of the fuel participate in the combustion. A surface emissive power commonly used for solid flame model is 350kW/m^2.

Lees F. P. (1996) derives the intensity of thermal radiation at a target for a solid flame model as follows;

$$I = \alpha \tau F E$$

where τ is the atmospheric transmissivity, α is the absorptivity of the target, F is the view factor and E is the surface emissive power of the fireball (kW/m^2).

View factor is the radiating surface that can be viewed by a receptor. Sets of view factors for fireballs covering different situation have been given by CCPS (1994/15). The simplest and most conservative approach is when the surface is vertical, not directly beneath the fireball, to the line between the receptor and the centre of the fireball.

According to Papazoglou I. A. and Aneziris O. N. (1999), the view factor can be estimated by the following equation;

$$F = \frac{D^2}{4l^2}$$

where D is the diameter of the fireball and l is the distance between the centre of the fireball and the target.

3.4.4 Point Source Model

Papazoglou I. A. and Aneziris O. N. (1999) stated that "Point source model used a selected fraction of the heat combustion emitted as radiation in all direction with the heat radiated at a constant rate and the emissive power is a function of the fuel mass, of the radius and of the duration of the fireball".

Based on the statement, the emissive power of point source model can be estimated by the following equation;

$$E = \frac{M \Delta H_c F_r}{\pi D^2 t_d}$$

where M is the mass of the fuel in the fireball (kg), ΔH is the heat of combustion (kJ/kg), F_r is the fraction of the heat radiated, D is diameter of the fireball (m) and t_d is the duration time of the fireball (s).

For the fraction of heat radiated, Robert A. F. (1982) proposed the following relation based on the works done by Hasegawa and Sato (1977);

$$F_r = 0.27P^{0.32}$$

where P is the burst pressure of the vessel (MPa).

The heat received by the target can be estimated using the equation develop by Hymes (1983 SRD R275) as follows;

$$I = \frac{2.2\alpha\tau F_r \Delta H_c M^{0.67}}{4\pi l^2}$$

where M is the mass of the fuel in the fireball (kg), ΔH is the heat of combustion (kJ/kg), F_r is the fraction of the heat radiated, τ is the atmospheric transmissivity and α is the absorptivity of the target.

3.4.5 Correlation of Fireball Effect

Fire causes damage to property and injury to people. Prediction of hazards result from the fireball is made in terms of thermal radiation intensity based on **Table A.3 and Table A.4 in Appendix A.**

CHAPTER 4
METHODOLOGY

4.1 Algorithm

The algorithm for integration of consequence assessment is given in **Figure 4.1**;

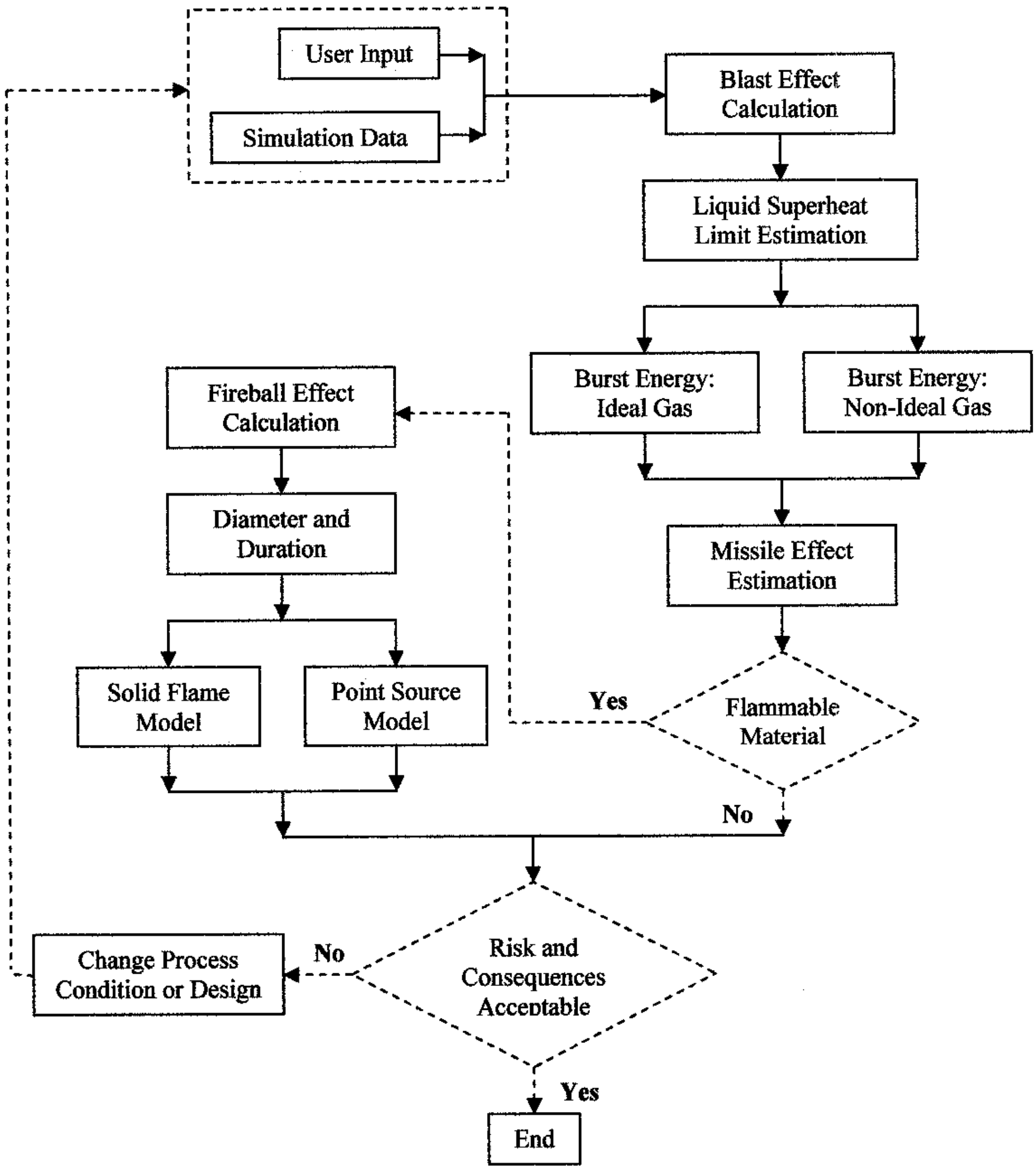


Figure 4.1: Project's methodology

4.2 HYSYS-Microsoft Excel Interface

4.2.1 HYSYS Steady State Simulation Model

As apparent by now, two HYSYS steady state simulation model have been develop – (1) vessel and (2) storage tank. In order to virtually simulate BLEVE effect in HYSYS simulation case, some modification is required for both models.

Figure 4.2 illustrates the modified steady state simulation model of Vessel V-2408 in HYSYS. Under normal operating condition, there are three inlet streams to the Vessel V-2408 – from Heat Exchanger E-2415A, Heat Exchanger E-2415B and Heat Exchanger E-2415C. A mixer is added in between the inlet steams and the vessel to gives a single inlet stream, labeled as *feed stream,* as to simulate the initial condition of the vessel. Another additional stream is used to retrieve the desired data for the final condition of the vessel, which is labeled as *final stream.*

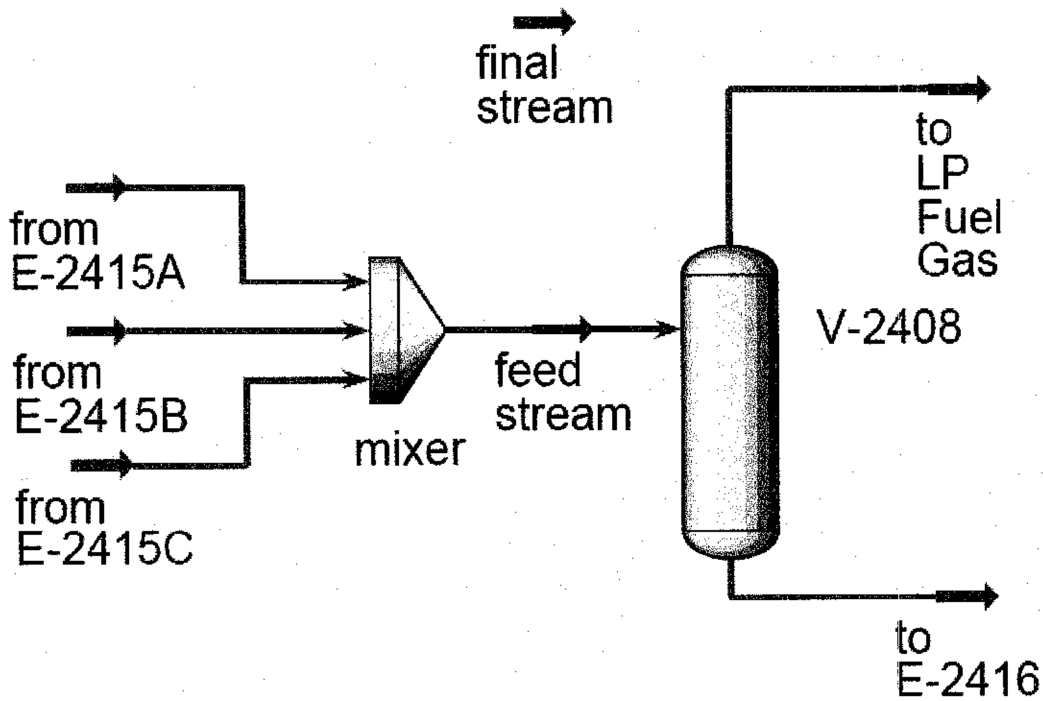


Figure 4.2: HYSYS steady state simulation of Vessel V-2408

Figure 4.3 illustrates the steady state simulation model of storage tank in HYSYS applied to a given problem used by Roberts M. W. (2000). The initial condition of tank will be based on the *feed stream,* while the final condition of the tank is retrieve from the additional stream labeled as *final stream.*

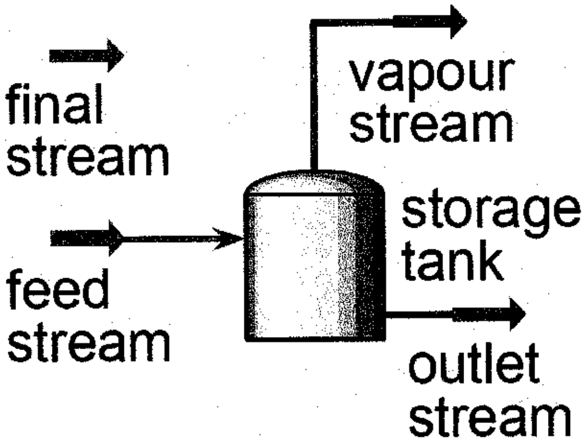


Figure 4.3: HYSYS steady state simulation of storage tank

Nevertheless, the modification of the process does not change any of the original process parameter for both models.

4.2.2 Functions of Interface

Figure 4.4 and **Figure 4.5** below illustrate the main interface appearance in Microsoft Excel for storage tank and Vessel V-2408 simulation, respectively.

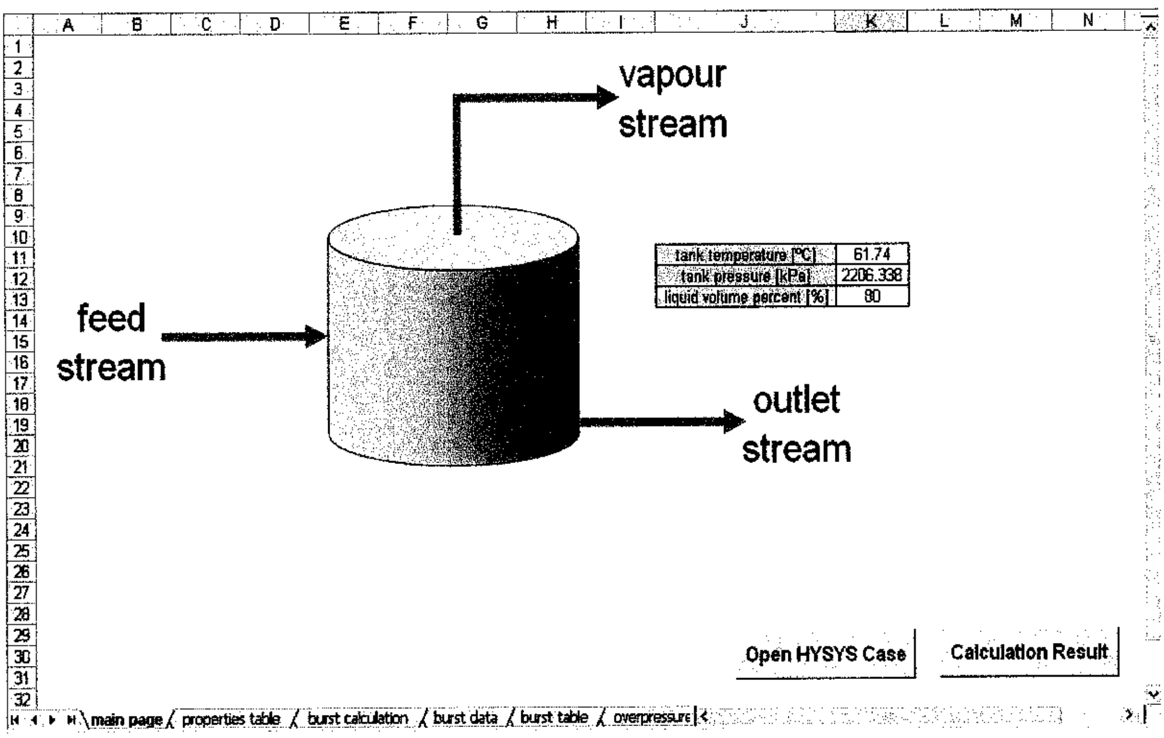


Figure 4.4: Main Interface appearance in Microsoft Excel for storage tank

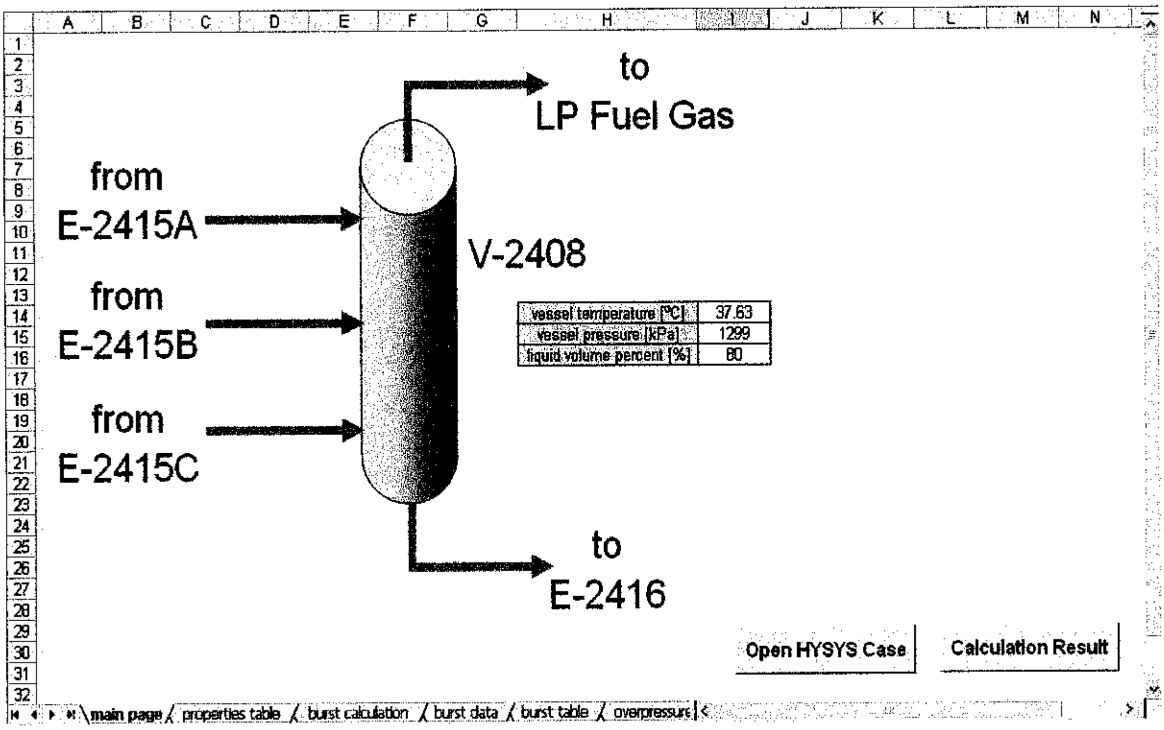


Figure 4.5: Main Interface appearance in Microsoft Excel for Vessel V-2408

Two command buttons was set for both simulations. The functions of these command buttons were explained in **Table 4.1** below;

Table 4.1: Functions of Main Interface command buttons

Buttons	Descriptions
Open HYSYS Case	This button is used to select the desire HYSYS simulation file. Once the file is opened, the desired data will be either extracted from HYSYS to Microsoft Excel or vice versa. Calculation then will be conducted under Microsoft Excel worksheet.
Calculation Result	This button is used to display all the calculated result under Visual Basic-Microsoft Excel Interface.

4.3 Mathematical Calculation

4.3.1 Liquid Superheat Limit Estimation

The liquid superheat limit estimation is essential in order to determine the method for calculating the burst energy and will be based on the liquid saturation temperature just before the explosion. **Table 4.2** and **Table 4.3** show the calculated liquid superheat limit for storage tank and Vessel V-2408 models, respectively;

Table 4.2: Liquid superheat limit for storage tank model

Properties	Result
Saturation Temperature	61.74°C
Critical Temperature	96.75°C
Superheat Limit Temperature	57.9105°C

Table 4.3: Liquid superheat limit for Vessel V-2408 model

Properties	Result
Saturation Temperature	37.63
Critical Temperature	96.75
Superheat Limit Temperature	57.9105

4.3.2 Burst Energy

As stated earlier, the burst energy will be estimated by two condition – (1) ideal gas condition and (2) non-ideal gas condition. **Table 4.4** below shows the calculated burst energy of ideal gas and non-ideal gas condition for both models;

Table 4.4: Vessel burst energy for storage tank and Vessel V-2408 models

Model	Vessel Burst Energy: Ideal Gas Condition	Vessel Burst Energy: Ideal Gas Condition
Storage Tank	995920.8578 kJ	548573.3195 kJ
Vessel V-2408	12475483.75 kJ	1832708.698 kJ

4.3.3 Explosion Parameters

The explosion parameters were calculated in order to estimates the correspond hazard of the explosion. Those parameters are scaled distance, scaled peak overpressure and scaled impulse. **Table 4.5** and **Table 4.6** below show the explosion parameters, while **Table A.1 in Appendix A** shows the damage table given by Clancey V. J. (1972).

Table 4.5: Explosion parameters for storage tank model

Distance (m)	Scaled Distance ($mkg^{-1/3}$)	Scaled Peak Overpressure	Scaled Impulse ($kPaskg^{-1/3}$)
287.9603484	12.16882934	0.076792318	0.681270069
1079.851306	45.63311003	0.018299248	0.181794692
2159.702613	91.26622006	0.009086687	0.090898385

Table 4.6: Explosion parameters for Vessel V-2408 model

Distance (m)	Scaled Distance ($mkg^{-1/3}$)	Scaled Peak Overpressure	Scaled Impulse ($kPaskg^{-1/3}$)
553.1292001	12.0888566	0.077417163	0.354665913
2074.2345	45.33321224	0.018422547	0.094642715
4148.469	90.66642447	0.009147079	0.047321909

4.3.4 Diameter and Duration

The diameter and duration of the explosion will be computed based on four references stated in previous chapter. **Table 4.7** and **Table 4.8** below shows the respective value of the diameter and duration calculated together with the references used;

Table 4.7: Diameter and duration of the explosion for storage tank model

References	Diameter (m)	Duration (s)
Roberts A. F.	132.9753201	10.3170507
Pietersen, TNO	141.6794292	9.732835486
Moorhouse and Pritchard	118.7691108	24.2886174
Fay and Lewis	143.9801742	12.70291245

Table 4.8: Diameter and duration of the explosion for Vessel V-2408 model

References	Diameter (m)	Duration (s)
Roberts A. F.	255.4259045	19.81752707
Pietersen, TNO	269.4668415	16.27789375
Moorhouse and Pritchard	226.7880585	46.37879621
Fay and Lewis	276.5646	17.78056736

4.3.5 Intensity and Emissive Power

The thermal intensity is calculated based on two models – solid flame model and point source model, with the emissive calculated under point source model. **Table 4.9** and **Table 4.10** below show the calculated thermal intensity using solid flame model for storage tank and Vessel V-2408 models;

Table 4.9: Thermal intensity for storage tank model

Distance (m)	265.9506402	997.3149008	1994.629802
View Factor	0.073272889	0.005210517	0.001302629
Thermal Intensity (kWm^{-2})	25.6455113	1.823680803	0.455920201

Table 4.10: Thermal intensity for Vessel V-2408 model

Distance (m)	265.9506402	997.3149008	1994.629802
View Factor	0.073272889	0.005210517	0.001302629
Thermal Intensity (kWm^{-2})	25.6455113	1.823680803	0.455920201

Table 4.11 and **Table 4.12** below show the calculated thermal intensity and emissive power of the explosion using point source model with their respective references;

Table 4.11: Thermal intensity and emissive power for storage tank model

References	**Thermal Intensity (kWm^{-2})**			**Emissive Power (kWm^{-2})**
Roberts A. F.	230.7346981	16.40780075	4.101950189	372.9045626
Pietersen, TNO	203.2550764	14.45369432	3.61342358	348.2109077
Moorhouse and Pritchard	289.2330972	20.56768691	5.141921728	198.5571576
Fay and Lewis	196.8111091	13.99545665	3.498864161	258.3370265

Table 4.12: Thermal intensity and emissive power for Vessel V-2408 model

References	**Thermal Intensity (kWm^{-2})**			**Emissive Power (kWm^{-2})**
Roberts A. F.	198.6476787	14.12605715	3.531514288	321.0467535
Pietersen, TNO	178.4854057	12.69229552	3.173073879	351.1872575
Moorhouse and Pritchard	251.9840246	17.91886397	4.479715993	174.0154401
Fay and Lewis	169.4416587	12.04918462	3.012296155	305.2170761

4.4 Visual Basic-Microsoft Excel Interface

This VB-ME Interface is programmed to display all the calculated result. The overall VB-ME Interface is divided into five subsections – (1) introduction page, (2) properties table, (3) blast effect, (4) missile effect and (5) fireball effect, where users can browse through all the calculated results and graphs together with the hazard estimation tables.

4.4.1 Introduction Page

The Introduction Page will appear once the *Calculation Result* button, in the Microsoft Excel main interface, is activated by the users and will prompt the users to choose either entering storage tank simulation or entering vessel simulation.

The result for the first case study and the second case study will be displayed under the storage tank simulation and under the vessel simulation of the VB-ME Interface, respectively. **Figure 4.6** shows the Introduction Page of the VB-ME Interface;

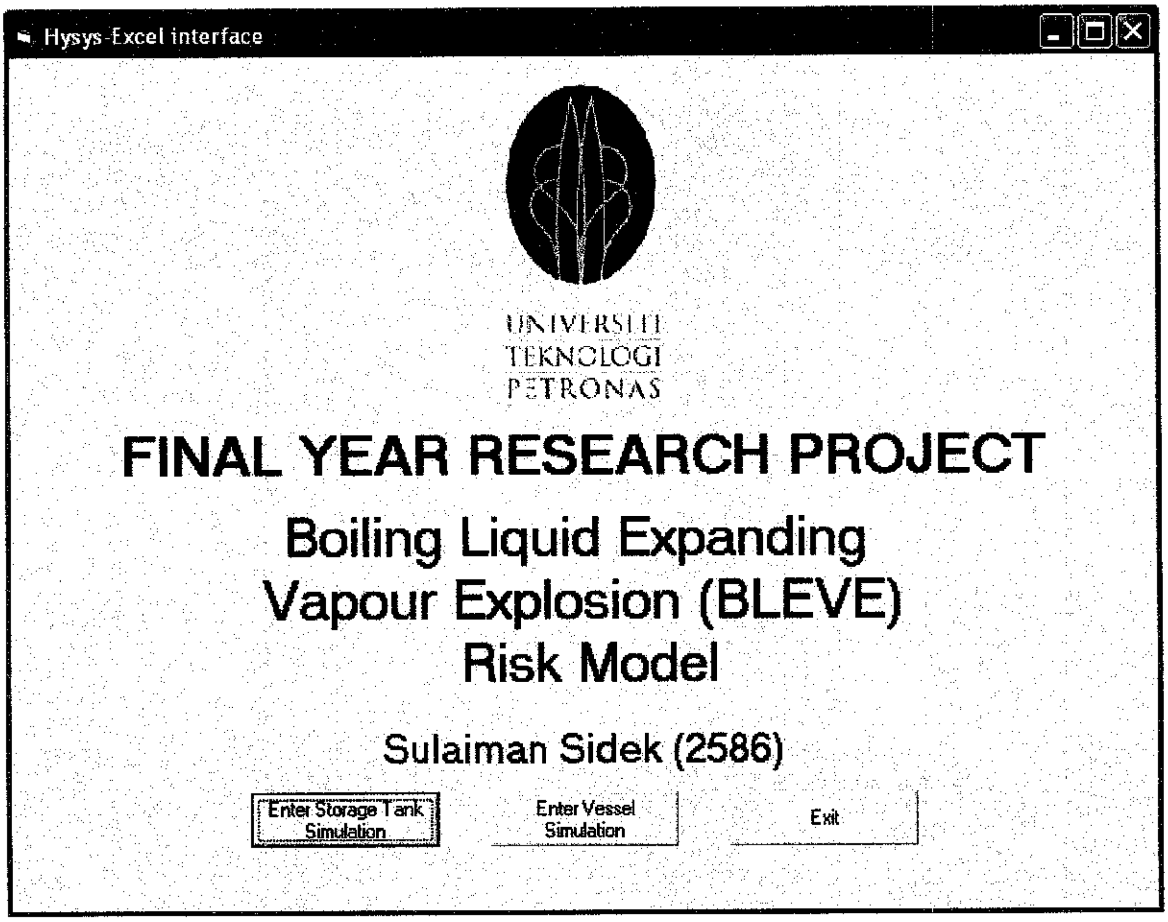


Figure 4.6: Introduction Page of the VB-ME Interface

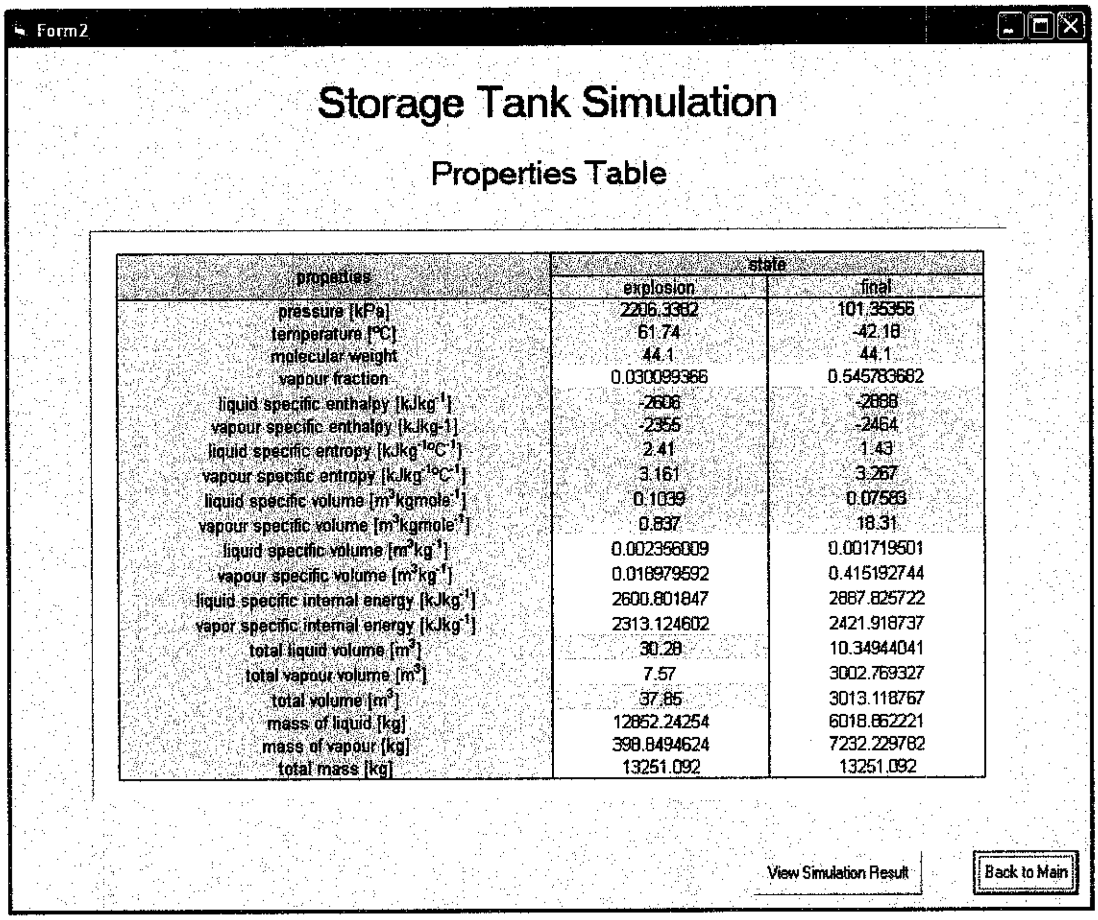
Three command buttons was set for this page. The function of these command buttons were explained in **Table 4.13**;

Table 4.13: Function of Introduction Page command buttons

Buttons	Descriptions
Enter Storage Tank Simulation	This button will trigger the exit function of the Introduction Page while simultaneously activate the next subsection.
Enter Vessel Simulation	This button is will trigger the exit function of the Introduction Page while simultaneously activate the next subsection.
Exit	This button is used to trigger the exit function of the VB-ME Interface.

4.4.2 Properties Table

Figure 4.7 below shows the Properties Table of the storage tank simulation. The coloured boxes indicate the parameters extracted from HYSYS while the white boxes indicate the calculated parameters.



properties	state	
	explosion	final
pressure [kPa]	2206.3382	101.35356
temperature [°C]	61.74	-42.18
molecular weight	44.1	44.1
vapour fraction	0.030099366	0.545783682
liquid specific enthalpy [$kJkg^{-1}$]	-2606	-2888
vapour specific enthalpy [kJkg-1]	-2355	-2464
liquid specific entropy [$kJkg^{-1}{}^{o}C^{-1}$]	2.41	1.43
vapour specific entropy [$kJkg^{-1}{}^{o}C^{-1}$]	3.161	3.267
liquid specific volume [$m^3kgmole^{-1}$]	0.1039	0.07583
vapour specific volume [$m^3kgmole^{-1}$]	0.837	18.31
liquid specific volume [m^3kg^{-1}]	0.002356009	0.001719501
vapour specific volume [m^3kg^{-1}]	0.018979592	0.415192744
liquid specific internal energy [$kJkg^{-1}$]	2600.801847	2887.825722
vapor specific internal energy [$kJkg^{-1}$]	2313.124602	2421.918737
total liquid volume [m^3]	30.28	10.34944041
total vapour volume [m^3]	7.57	3002.769327
total volume [m^3]	37.85	3013.118767
mass of liquid [kg]	12852.24254	6018.862221
mass of vapour [kg]	398.8494624	7232.229782
total mass [kg]	13251.092	13251.092

Figure 4.7: Properties Table for Storage Tank Simulation

Table 4.14 below shows the functions of the two command buttons set this subsection;

Table 4.14: Function of Properties Table command buttons

Buttons	Descriptions
View Simulation Result	This button is will trigger the exit function of the Properties Table and simultaneously activate the next subsection, Blast Effect.
Back to Main	This button will reload the previous subsection, the Introduction Page, while closing the existing subsection.

4.4.3 Blast Effect

The main function of this subsection is to enable the users to analyze the damage level produced by the blast wave. It displayed the calculated result for the scaled distance, scaled overpressure, scaled impulse and the respective energy of explosion together with the equivalent mass of TNT. The **Table A.1 in Appendix A** will appear together with the scaled peak overpressure or scaled impulse graph.

Figure 4.8 illustrates the Blast Effect subsection of the VB-ME Interface while **Table 4.15** describes the command buttons for this subsection;

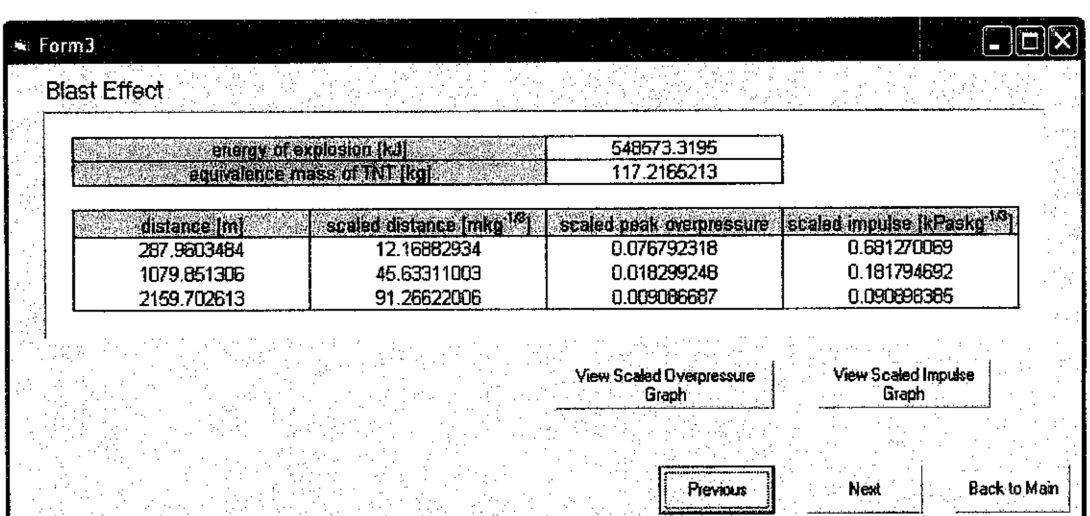


Figure 4.8: Blast Effect of the VB-ME Interface

Table 4.15: Function of Blast Effect command buttons

Buttons	Descriptions
View Scaled Overpressure Graph	This button is will display the calculated scaled peak overpressure plotted versus the scaled distance.
View Scaled Impulse Graph	This button is will display the calculated scaled impulse plotted versus the scaled distance.
Previous	This button will reload the previous subsection, the Properties Table, while closing the existing subsection.
Next	This button is will trigger the exit function of the Blast Effect and activate the next subsection, Missile Effect.
Back to Main	This button will reload the Introduction Page while simultaneously closing the existing subsection.

4.4.4 Missile Effect

Figure 4.9 shows the Missile Effect subsection of the VB-ME interface while **Table 4.16** shows the descriptions of the command buttons;

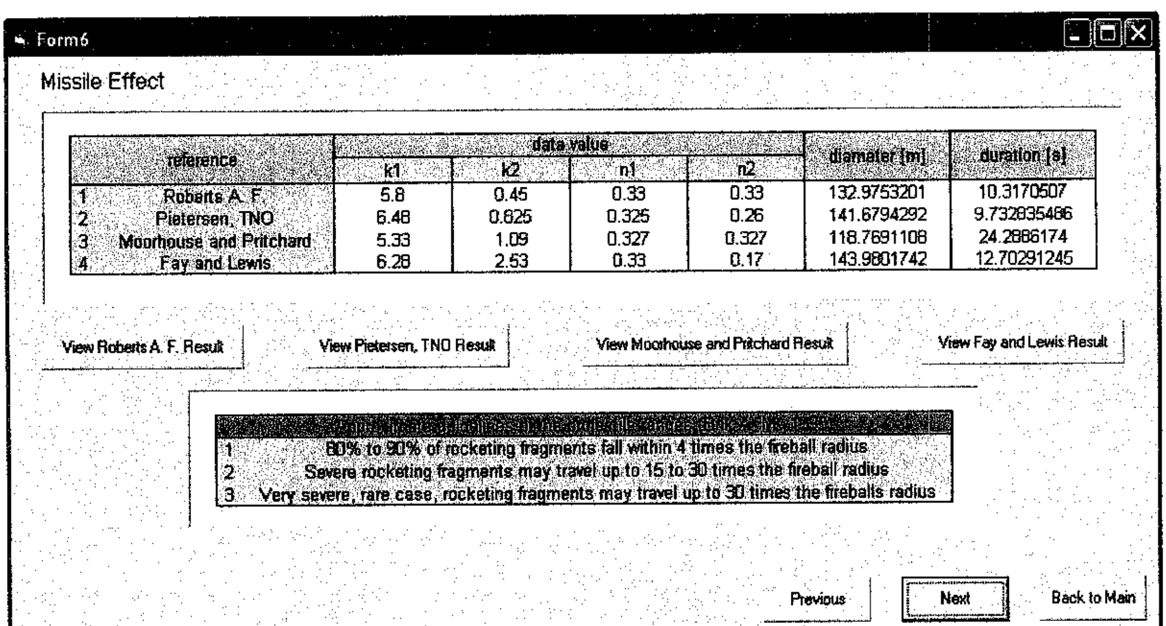


Figure 4.9: Missile Effect of the VB-ME Interface

Table 4.16: Function of Missile Effect command buttons

Buttons	Descriptions
View Roberts A. F. Result	This button is used to display the approximate projectile range for Roberts A. F. (1982) model.
View Pietersen, TNO Result	This button is used to display the approximate projectile range for Pietersen, TNO (1985) model.
View Moorhouse and Pritchard Result	This button is used to display the approximate projectile range for Moorhouse and Pritchard (1982) model.
View Fay and Lewis Result	This button is used to display the approximate projectile range for Fay and Lewis (1977) model.
Previous	This button will reload the previous subsection, the Blast Effect, while closing the existing subsection.
Next	This button is used to trigger the exit function of the Missile Effect and activate the next subsection, Fireball Effect.
Back to Main	This button will reload the Introduction Page while simultaneously closing the existing subsection.

Missile Effect subsection displays the correlation result for the diameter and duration of the resulting fireball together with the data for parameters k_1, k_2, n_1 and n_2 given in **Table A.2 in Appendix A**. Graph for the approximate projectile ranges can be display with respect to the model references. The approximate guidelines of the projectile ranges, related to the fireball radius, produce by Birk A. M (1995) are also included in this subsection for further understanding of the plotted graph.

4.4.5 Fireball Effect

Fireball Effect subsection display the calculated result for thermal radiation intensity and the correlation of fireball hazard based on **Table A.3 and Table A.4 in Appendix A**. Emphasis on flammable material, this subsection can be used to the estimate the thermal radiation intensity at a target for solid flame model or point source model. This subsection can also be used to show the difference of the emissive power with respect to the reference model used.

Figure 4.10 below, shows the Fireball Effect subsection of the VB-ME interface while **Table 4.17** shows the descriptions of the command buttons;

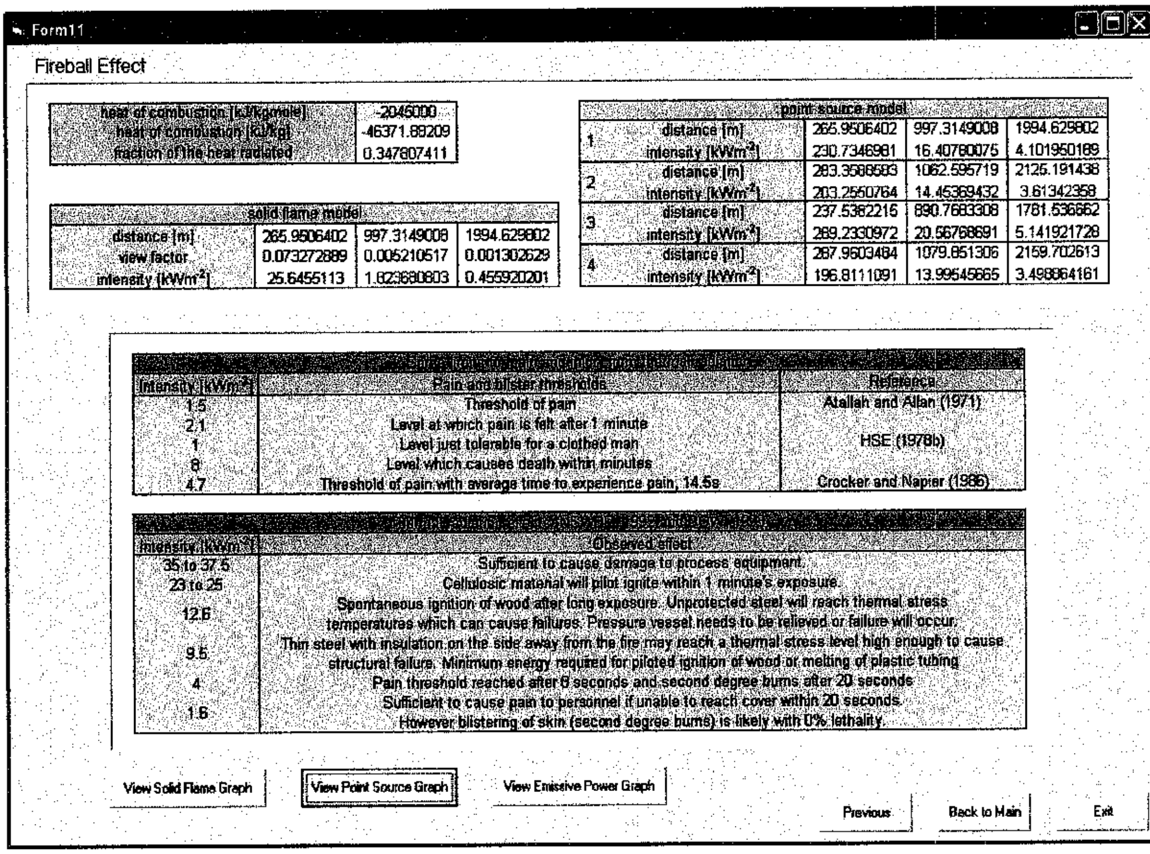


Figure 4.10: Fireball Effect of the VB-ME Interface

Table 4.17: Function of Fireball Effect command buttons

Buttons	Descriptions
View Solid Flame Graph	This button is used to display the plot of the thermal radiation intensity of the target for solid flame model.
View Point Source Graph	This button is used to display the plot of the thermal radiation intensity of the target for point source model.
View Emissive Power Graph	This button is used to display the emissive power with respect to reference model used.
Previous	This button will reload the previous subsection, the Missile Effect, while closing the existing subsection.
Back to Main	This button will reload the Introduction Page while simultaneously closing the existing subsection.
Exit	This button triggers the exit function of VB-ME Interface.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Blast Effect

5.1.1 Scaled Peak Overpressure versus Scaled Distance

Figure 5.1 and **Figure 5.2** below show the relationship of scaled peak overpressure versus scaled distance for storage tank model and Vessel V-2408, respectively.

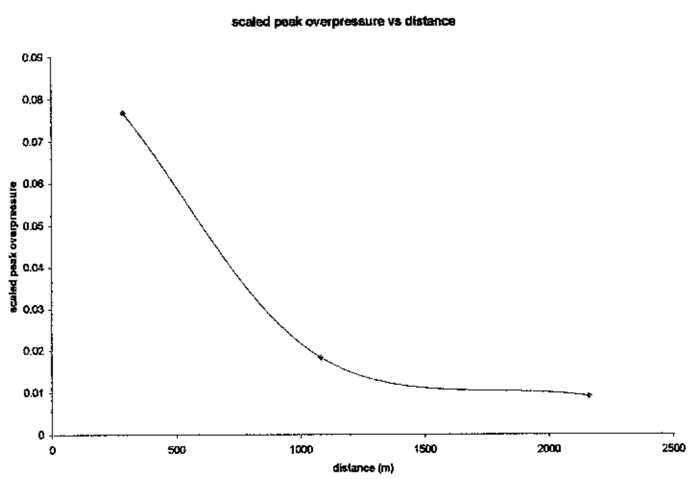


Figure 5.1: Graph scaled peak overpressure for storage tank model

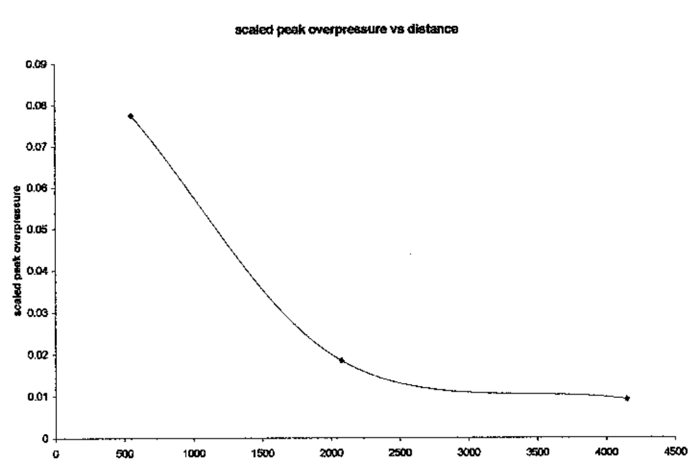


Figure 5.2: Graph scaled peak overpressure for Vessel V-2408 model

Both trends show that scaled peak overpressure dramatically decreases with the increasing of radius. This type of relation was proven to be correct as referred to **Figure B.2 in Appendix B** (Kingery and Bulmash, 1985).

5.1.2 Scaled Impulse versus Scaled Distance

Figure 5.3 and **Figure 5.4** below show the relationship of scaled impulse versus scaled distance for storage tank model and Vessel V-2408, respectively. Nevertheless, it was observed that scaled impulse dramatically decreases with the increasing of radius. This type of relationship was proven to be correct as referred to **Figure B.2 in Appendix B** (Kingery and Bulmash, 1985).

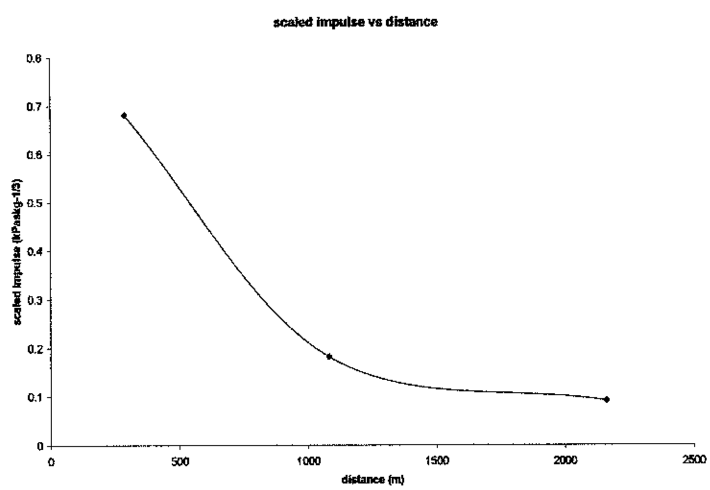


Figure 5.3: Scaled impulse versus distance for storage tank model

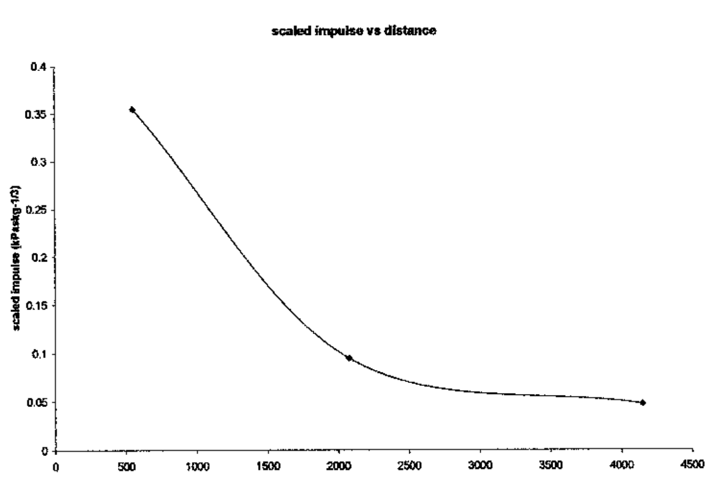


Figure 5.4: Scaled impulse versus distance for Vessel V-2408 model

5.2 Missile Effect

The graphs for approximate projectile range is plotted with correspond to the reference model used. For both storage tank and Vessel V-2408 model, all graphs show the same trend. Thus, one representative figure was select, from each simulation model, instead of displaying the entire figure.

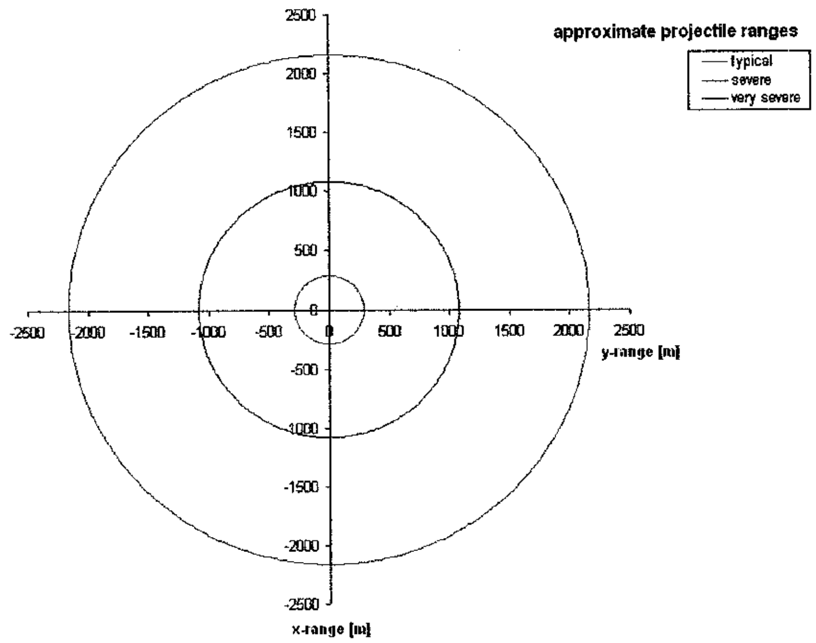


Figure 5.5: Approximate projectile range or storage tank model

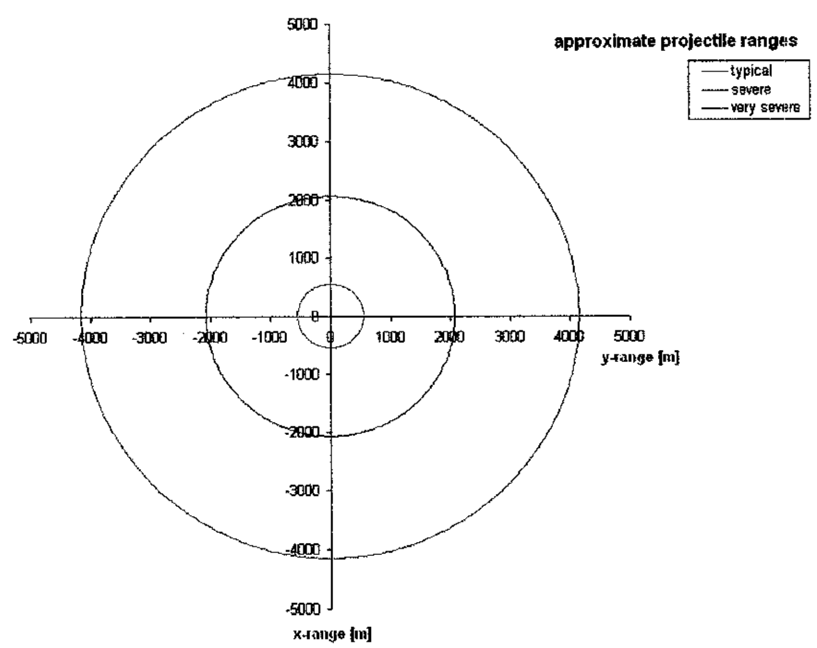


Figure 5.6: Approximate projectile range or Vessel V-2408 model

Figure 5.5 and **Figure 5.6** illustrate the approximate projectile range for storage tank and Vessel V-2408, respectively. In each of the graphs, the blue coloured graph shows the typical ranges, the red coloured graph shows the severe range and the green coloured graph show the very severe range of the missile effect.

The trend for approximate projectile range increases with the increasing of the severity of the missile effect. This type of relationship was proven to be correct as referred to the suggested guideline by Birk A. M. (1995).

5.3 Fireball Effect

5.3.1 Thermal Radiation Intensity of Solid Flame Model

The important assumption made by those using this model is that the emissive power is constant and does not depend on the mass of the flammable substance involved in the combustion (Papazoglou I. A. and Aneziris O. N., 1995). The statement can be used verify the observation that both trending for storage tank and Vessel V-2408 give the same value, regardless of the references model used to compute the diameter and duration of the fireball. **Figure 5.7** and **Figure 5.8** below illustrate the thermal radiation intensity of solid flame model versus distance for storage tank and Vessel V-2408;

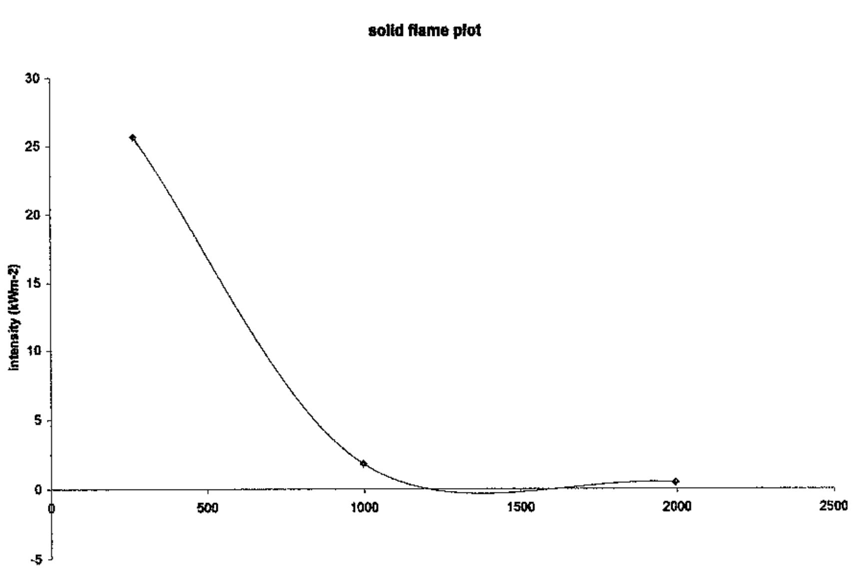


Figure 5.7: Thermal radiation intensity of solid flame model for storage tank model

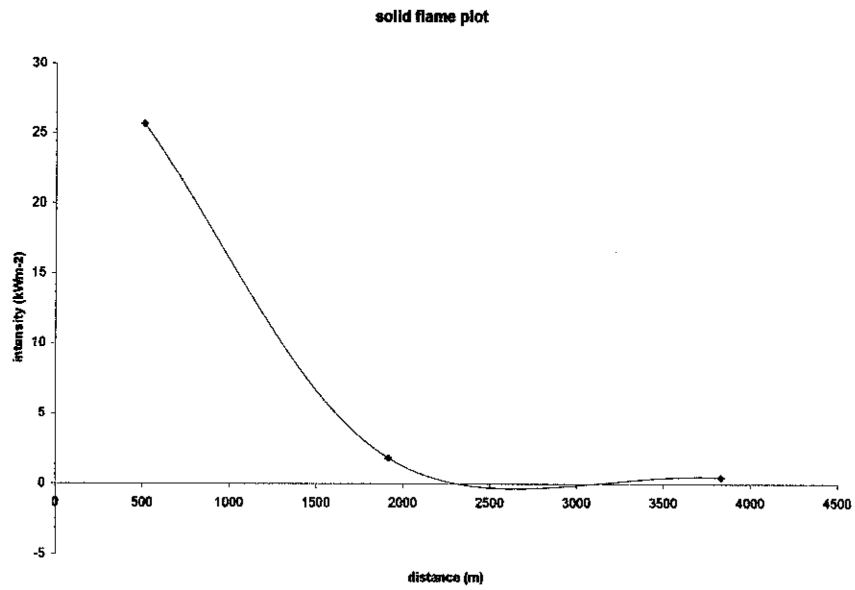


Figure 5.8: Thermal radiation intensity of solid flame model for Vessel V-2408 model

From the trends, it is observed that the thermal radiation intensity significantly decreases as the distance increases. As stated earlier in Chapter 3.4.3, Lees F. P. (1996) derives the intensity of thermal radiation at a target for a solid flame model as follows;

$$I = \alpha\tau FE$$

and according to Papazoglou I. A. and Aneziris O. N. (1995), the view factor can be estimated by the following equation;

$$F = \frac{D^2}{4l^2}$$

where τ is the atmospheric transmissivity, α is the absorptivity of the target, D is the diameter of the fireball, E is the surface emissive power of the fireball (kW/m^2) and l is the distance between the centre of the fireball and the target. The atmospheric transmissivity, τ and the absorptivity of the target, α used in the equation is constant. This shows that the thermal radiation intensity is inversely proportional with that of distance between the centre of the fireball and the target l. Hence, the relationship predicted from the trends is proven to be valid.

CHAPTER 6
PROBLEMS AND RECOMMENDATIONS

During the earlier stages of the project, the overall network of the simulation is divided into two stages – (1) mathematical calculation in Microsoft Excel platform and (2) HYSIS-VB-ME interface.

For the first stage, although the process seems to be easy but still there some errors occur. The value for the variable chosen for the missile effect is not readily available. Re-evaluation of the equation used and all the result obtained has to be done and the HYSIS-VB-ME interface has to be rebuilt. While, the result for manual calculation of blast and fireball effect shows that it needs further evaluation based on all of the expected conditions involve.

Earlier attempt on interfacing the HYSIS simulation to Microsoft Excel application using Visual Basic as a base platform causing lots of problems. Some of which involved with transfer of parameters and variables from the HYSIS to Microsoft Excel application. To reduce the complexness of the interface, the HYSIS-VB-ME interface is thus brake in to two stages – (1) HYSIS-ME interface and (2) VB-ME interface. HYSIS-ME interface will be the platform for all the modeling and calculation of the simulation while VB-ME interface will be use to display all the calculated result to the user.

Nonetheless, there are still flaws in the HYSYS-ME Interface. Due to lack of experience in developing HYSYS-ME Interface, errors seem to occur during the construction of the interface. The transfer of data between the two applications still can not be done automatically. There are also error occurs in the VB-ME Interface, where in the run time for the interface is still in the manual mode. The users had to manually update the result into the interface to views all the desired result.

Thus reevaluation of the sources code use in the HYSYS-ME Interface and VB-ME Interface had to be done in order to counter the problems stated above. To further enhance the acceptability of the project it recommended that it is benchmark with available risk assessment software (i.e. SAFETI) on the establish BLEVE effects.

CHAPTER 7
CONCLUSION

As a conclusion, this project can be used to calculate the risk owing to the phenomenon of Boiling Liquid Expanding Vapour Explosion (BLEVE) - blast, fireball and missile effect. Based upon two case studies conducted, this project successfully estimates the desired parameters for the BLEVE effects. More efforts and further developments in the overall integration network, mainly in the HYSYS-ME Interface, and the run time of the VB-ME Interface is highly recommended.

Overall, the project has a great potential in becoming a commercial tool that present the integration of Boiling Liquid Expanding Vapour Explosion (BLEVE) risk model with process simulator, as one of the element for Inherent Safety (IS) in Chemical Process Plant Design (CPPD).

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APPENDIX A

Table A.1: Damage estimates based on overpressure (Clancey V. J., 1972)

Pressure (kPa)	Observed effect
0.2	Annoying noise (137dB), if of low frequency (1Hz to 15Hz) Occasional breaking of large glass windows already under strain Loud noise (143dB). Sonic boom glass failure.
0.7	Breakage of windows, small, under strain
1	Typical pressure for glass failure
2	"Safe distance' (probability 0.95 no serious damage beyond this value) Missile limit Some damage to house ceilings; 10% window glass broken
2.8	Limited minor structural damage
3.5 to 6.9	Large an small windows usually shattered; occasional damage to window frames
4.8	Minor damage to house structures
6.9	Partial demolition of houses, made uninhabitable
6.9 to 13.8	Corrugated asbestos shattered Corrugated steel or aluminum panels, fastenings fail, followed by buckling Wood panels (standard housing), fastenings fail, panel blown in
9	Steel frame of clad building slightly distorted
13.8	Partial collapse of walls and roofs of houses
13.8 to 20.7	Concrete or cinder block walls, not reinforced, shattered
15.9	Lower limit of serious structural damage
17.3	50% destruction of brickwork of house
20.7	Heavy machines (3000lb) in industrial building suffer little damage
20.7 to 27.6	Steel frame building distorted and pulled away from foundations Frameless, self-framing steel panel building demolished Rupture of oil storage tanks
27.6	Cladding of light industrial buildings ruptured
34.5	Wooden utilities poles snapped
34.5 to 48.3	Tall hydraulic press (40 000lb) in building slightly damaged Nearly complete destruction of houses
48.3	Loaded train wagons overturned
48.3 to 55.2	Brick panels, 8 to 12in. thick, not reinforced, fail by shearing or flexure
62.1	Loaded train boxcars completely demolished
69	Probable total destruction of buildings

2000	Heavy (7000lb) machine tools moved and badly damaged Very heavy (12 000lb) machine tool survived Limit of crater lip

Table A.2: Data for parameters k_1, k_2, n_1 and n_2

Reference	k_1	k_2	n_1	n_2
DATA VALUES				
Roberts A. F.	5.8	0.45	0.33	0.33
Pietersen, TNO	6.48	0.825	0.325	0.26
Moorhouse and Pritchard	5.33	1.09	0.327	0.327
Fay and Lewis	6.28	2.53	0.33	0.17

Table A.3: Some limits for pain and injury from thermal radiation

Intensity (kWm^{-2})	Pain and blister thresholds	Reference
1.5	Threshold of pain	Atallah and Allan (1971)
2.1	Level at which pain is felt after 1 minute	HSE (1978b)
1	Level just tolerable for a clothed man	
8	Level which causes death within minutes	
4.7	Threshold of pain with average time to experience pain, 14.5s	Crocker and Napier (1986)

Table A.4: Thermal radiation effects (NSWDP, 1992 and DOW, 1993)

Intensity (kWm-2)	Observed effect
35 to 37.5	Sufficient to cause damage to process equipment.
23 to 25	Cellulosic material will pilot ignite within 1 minute's exposure.
12.6	Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress
	Temperatures which can cause failures. Pressure vessel needs to be relieved or failure will occur.
9.5	Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause
	Structural failure. Minimum energy required for piloted ignition of wood or melting of plastic tubing
4	Pain threshold reached after 8 seconds and second degree burns after 20 seconds
1.6	Sufficient to cause pain to personnel if unable to reach cover within 20 seconds.
	However blistering of skin (second degree burns) is likely with 0% lethality.

APPENDIX B

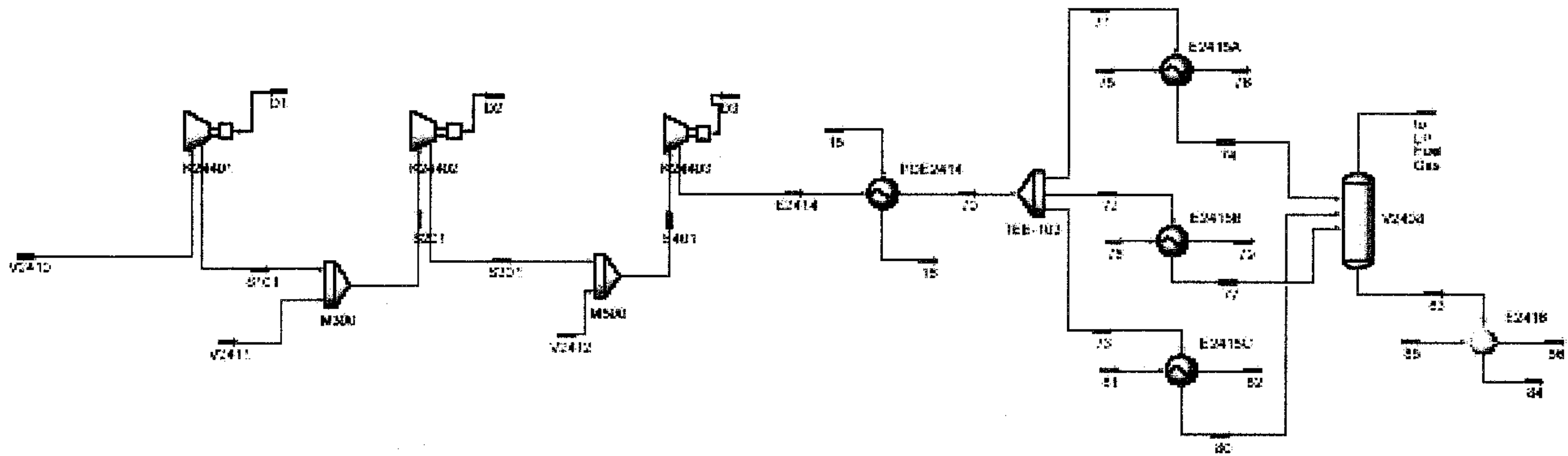

Figure B.1: Process Flow Diagram (PFD) of the cryogenic process of LPG processing (Malaysia LNG Dua Sdn. Bhd., 2004)

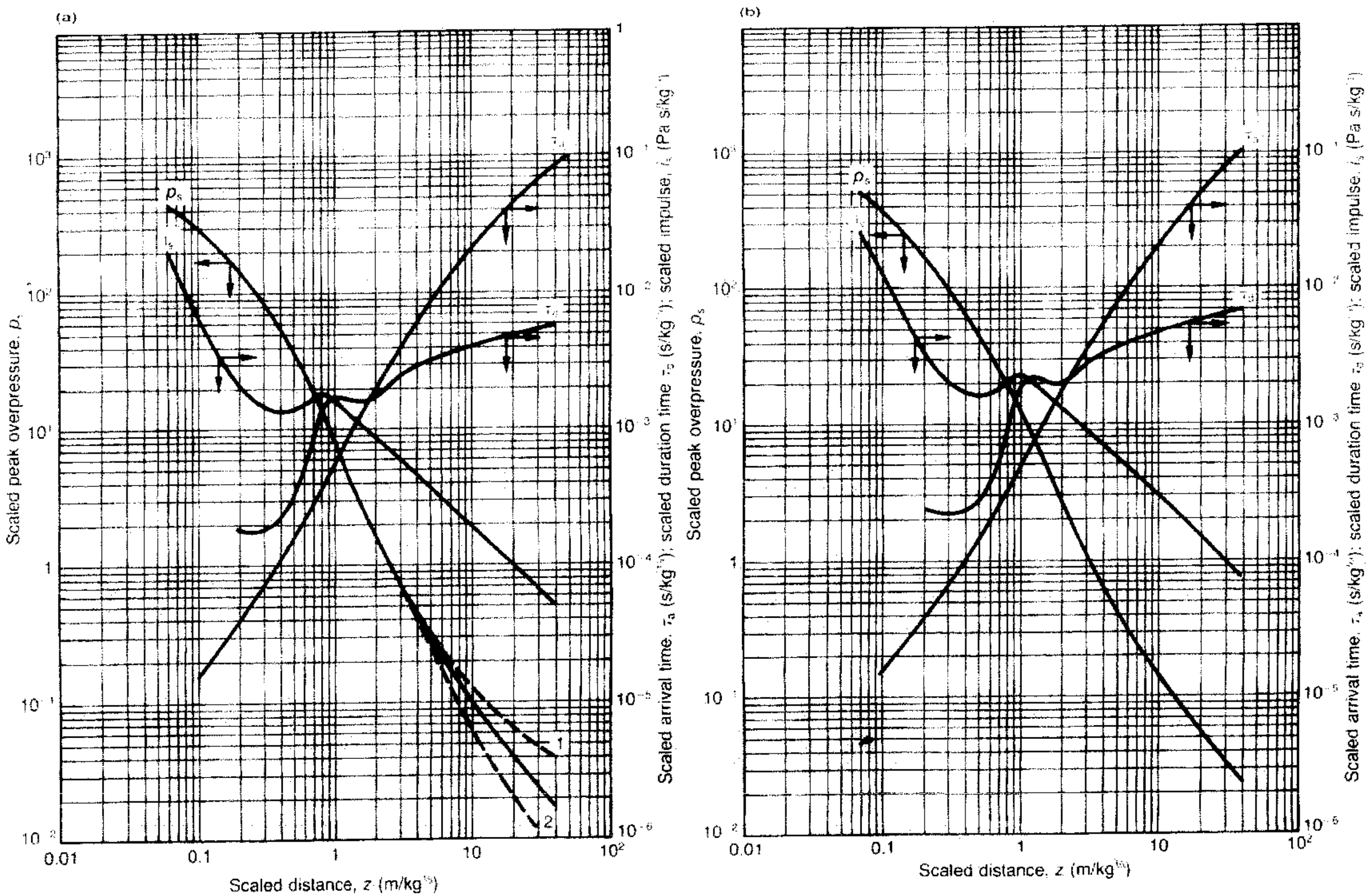

Figure B.2: Some blast parameters for a TNT explosion (Kingery and Bulmash, 1985)

APPENDIX C

No.	Detail	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**<u>Preliminary research</u>** o Background of study o Problem statement o Objective of study o Scope of study o Literature review o Draft of methodology								Semester Break							
2	Submission of preliminary report			●												
3	**<u>Project work</u>** o Detail research on BLEVE effects o Construct mathematical calculation in Microsoft Excel o Develop HYSYS steady state model															
4	Submission of progress report							●								
5	**<u>Project work</u>** o Additional research on correlation for BLEVE effects o Reconstruct mathematical calculation in Microsoft Excel o Develop VB-ME interface															
6	Pre-EDX presentation											●				

7	**<u>Project work</u>** o Research on additional case study o Construct mathematical calculation in Microsoft Excel o Develop HYSYS steady state model o Develop VB-ME interface o Integrate case study								**Semester Break**							
8	Submission of dissertation draft														●	
9	Submission of dissertation final draft															●

Figure C.1: Gantt chart