Integration of Jet and Pool Fire Risk Models
with Process Simulator for Inherent Safety Design

by

Aliza Binti Hasan

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

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
Malaysia

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CERTIFICATION OF APPROVAL

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Approved by,

(Puan Risza binti Rusli)

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TRONOH, PERAK
July 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.

ALIZA BINTI HASAN

ABSTRACT

In the last 50 years, the chemical process industries have moved to large, world scale plants. Because of their size, these plants have an increased potential for major accidents such as fire outbreaks, explosions, etc. Recognizing this potential, the industry incorporated many engineered safety features into these plants to manage and control the hazards. This has led to the development and use of better hazard identification and analysis techniques like Quantitative Risk Analysis (QRA) and Hazard and Operability Studies (HAZOP). However, current applied traditional method involves hazard identification to be conducted after any process design has been completed. Contrary, the best way of dealing with a hazard is to remove it completely. The provision of means to control the hazard is very much the second solution. The shift from traditional sequential design to concurrent design has contributed to the adoption of inherent safety measures. As Lees (1996) has said the aim should be to design the process and plant so that they are inherently safer. This report was produced intentionally to introduce the implementation of inherent safety principle into the development of a comprehensive risk model. The model developed will specifically focused on 2 major fire outbreaks in chemical plants namely; jet fire and pool fire. The model provides results in terms of thermal radiation flux plotted against distance to thermal dose. Based on the graphical representation, effects on injury can be predicted.

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ABBREVIATIONS

QRA	*Quantitative Risk Analysis*
HAZOP	*Hazard and Operability Studies*
FYRP	*Final Year Research Project*
ISPD	*Inherently Safer Process Design*
OLE	*Object Linking and Embedding*
HYSYS	*Hyprotech System*
VCE	*Vapor Cloud Explosion*
EQA	*Environmental Quality Act 1974*
NFPA	*National Fire Prevention Agency*
LNG	*Liquefied Natural Gas*
BLEVE	*Boiling Liquid Expanding Vapor Explosion*
TRACE	*Toxic Release Analysis of Chemical Emissions*
FIERAsystem	*Fire Evaluation and Risk Assessment System*
NRC	*National Research Council, Canada*
DND	*Department of National Defence, Canada*
TCPA	*Toxic Catastrophe Prevention Act*
PFD	*Process Flow Diagram*
MLNG	*Malaysia LNG Sendirian Berhad*

NOMENCLATURES

I = *heat intensity* (kW/m^2)

τ = *atmospheric transmissivity of the thermal energy (0-1)*

f = *fraction of thermal energy radiated (assumed 20% for jet and 30% for pool)*

D = *hole diameter (m)*

T_a = *ambient temperature (°K)*

g = *gravitational acceleration* (m/s^2)

ρ_a = *ambient air density* (kg/m^3)

JFF (jet fire factor) = $((1 * .2 * H_c) / (4 \pi Dose^{3/4}))^{0.5}$

PFF (pool fire factor) = $((1 * .3 * m'' * H_c) / (4 \pi Dose^{3/4}))^{0.5}$

H_c = *heat of combustion (kJ/kg)*

C_p = *specific heat of liquid (kJ/kg°K)*

T_b = *normal boiling point (°K)*

H_{vap} = *enthalpy of evaporation (kJ/kg)*

ρ_l = *liquid density* (kg/m^3)

t_p = *combustion duration (sec)*

Y = *distance to thermal dose (m) - jet*

X = *distance to thermal dose(m) - pool*

m' = *jet release rate (kg/s)*

m'' = *pool mass burning rate (kg/s)*

t_j = *jet combustion duration (s)*

t_b = *pool combustion duration (s)*

q = *thermal radiation flux* (kW/m^2)

F_p = *view factor* (m^{-2})

E_s = *flame surface emissive power (kW)*

F_s = *surface fraction (0-1)*

A = *jet flame area or pool area* (m^2)

u_j = *jet velocity (m/s)*

MW = *molecular weight (kg)*

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Major fire accidents on process and storage sites occur rarely but can have severe consequences. Assessing the potential for such accidents requires a robust method so the risks can be evaluated in an appropriate manner.

Generally, the project work is an extension based on the framework proposed by T. L. Chan (2003) regarding the application of inherent safety in process plant design. The traditional method involves the use of procedural or administrative controls and the addition of safety devices at the end of design to deal with hazards that have been identified. This approach is sometimes referred to as extrinsic safety.

The consideration of inherent safety principles in process design generates the term 'inherently safer process design' (ISPD). Currently, there are still no suitable tools available for safety risk estimation at initial process design stage Development of such tool would promote inherent safety into practice respectively. Concisely, ISPD offers an alternative to traditional method, in that it eliminates or minimizes hazards instead of controlling them.

W. C. Low (2002) had developed Object Linking and Embedding (OLE) codes using Microsoft Visual Basic to integrate Hyprotech System (HYSYS) simulation with Microsoft Excel for estimation of Vapor Cloud Explosion (VCE) based on TNO Multi Energy Method. It is also important to develop similar model in accordance to analyse other common risks associated with process design such as fire outbreaks. Two distinguished types of fire risks; jet and pool fire shall be modeled based on established equations and data.

1.2 PROBLEM STATEMENT

In any process design stages, there exist numerous considerations including the need of safety risk assessment. This assessment is carried out for internal design uses as well as to oblige by government regulations. In Malaysia, chemical and petrochemical industries are required to perform risk assessment as part of any project approval process (Environmental Quality Act (EQA) 1974).

Fires or explosions can be the quickest way of bringing a business to a halt, perhaps for a long time. Several recent major fire and explosion incidents, in both industry and public places, have increased the need for a greater awareness of fire and explosion phenomena so that potential hazards can be more readily assessed. With fire losses in estimated material damage alone running at an annual rate of over RM1 billion, there is an urgent need for those responsible for fire safety to be aware of the potential fire and explosion hazards of flammable material. A major safeguard against fire is to know the facts about fire and how it can be prevented; only on this basis of knowledge can fire risk assessment with safe design and working practices be established.

Measurement tools which can be quickly and easily used early in the life cycle of the process design are particularly important, because that is the time at which the designer has the greatest opportunity to change the basic process technology. However, the traditional method being conducted so far only allows this analysis to be done towards the completion of overall plant design.

Such safety analyses at later stages complicate the design and prompt additional costs. If it happens that any risk assessment studies can be conducted at earlier stage, adequate time can be allocated to provide necessary training for plant operators and technicians. In addition, huge losses would be prevented and safety is ensured.

Currently, it is very difficult for any process designer to determine the consequence that may result in deviation of their process conditions in the earlier design stage. The inherently safer design approach is intended to eliminate or reduce the hazard by changing the process itself, rather than by adding on additional safety devices and layers of protection at later design stages.

Despite the growing interest and obvious importance of inherently safer design, its adoption into practice has been slow. The non-availability of systematic tools is perhaps the most important reason for the lack of widespread use.

Apart from introducing inherent safety features into the model, this project work also intends to integrate process simulator accordingly. Present process simulators such as HYSYS does not equipped with tool to determine risk and related effects. It only helps process designers to choose and develop economically desired routes based on the optimized condition.

The development of the fire risk model integrated with process simulator will eventually provide a powerful tool to aid process designers in incorporating inherent safety concept into design respectively.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objective of this project work is to develop and improve the existing flammable models specifically on the risk possessed by two types of industrial fire outbreaks; jet and pool fire. Literature review should be done to identify the appropriate and necessary method to be used.

Based on established equations and data, the respective fire risk spreadsheets models are built using Microsoft Excel. The models may produce results in graphical terms of thermal radiation and effects possessed by each type of fire classification.

The development of interface OLE codes using Microsoft Visual Basic shall integrate the respective Microsoft Excel models with HYSYS process simulator accordingly. Upon this integration, few case studies involving any leakage scenarios will be conducted.

Risk control strategies in the first two categories, inherent and passive, are more reliable and robust because they depend on the physical and chemical properties of the system rather than the successful operation of instruments, devices, and procedures. The best opportunities for development of inherently safer processes come early in the process life cycle.

All processes and products have a life cycle. It begins with discovery at the research stage. Then a process grows through stages of process development as well as process design. Maturity of a life cycle is impacted by operations, maintenance and modification. The life cycle is not complete until the process is shut down and the plant decommissioned.

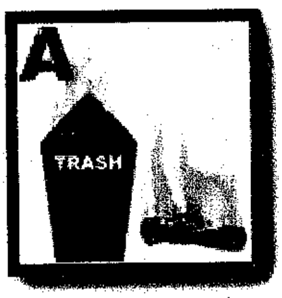
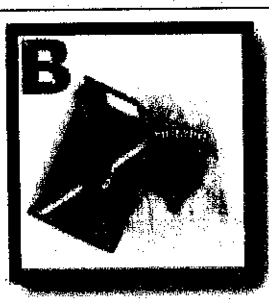
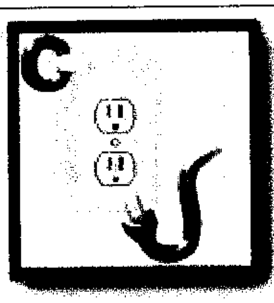
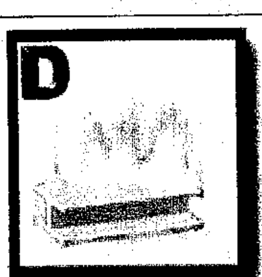
The main advantage of implementing inherent safety consideration in the early part of design stage is its cost effectiveness and safety prioritization. For example, if a designer can discover a way to eliminate a potential formation of industrial fires, the process design and operating engineers will not have to concern themselves with protecting operators and other personnel from contact with flammable substances which might leak from any one of the streams, storage tanks, separators, and other possible leak points in a large plant.

Inherently safer design represents a fundamentally different approach to chemical process safety. Rather than accepting the hazards in a process, and then adding on safety systems and other barriers to manage those hazards, the process designer is challenged to reconsider the process and eliminate the hazards. The understanding of inherent safety principles will allow process designer to make intelligent decisions on the selection of inherently safer process technology.

2.2 FIRE CLASSIFICATION

Generally, fire can be grouped into 4 classes based on National Fire Protection Agency (NFPA) codes developed in 1984. Table 2 below described briefly about these 4 classes of fire.

Table 2: Fire Category and Sources

	Category	Fire Sources
	Class A	Ordinary combustibles or fibrous materials, such as wood, paper, cloth, rubber and some plastics.
	Class B	Flammable or combustible liquids such as gasoline, kerosene, paint, thinners and propane.
	Class C	Energized electrical equipments, such as appliances, switches, panel boxes and power tools.
	Class D	Certain combustible metals, such as magnesium, titanium, potassium and sodium.

2.3 JET FIRE

There is a wide variety of situations in which a jet fire can occur in the process industries. If compressed or liquefied gases are released from storage tanks or pipelines, the materials discharging through the hole will form a gas jet that entrains and mixes with the ambient air. If the material encounters an ignition source while it is in the flammable range, a jet fire may occur. For LNG stored at low pressure as a liquid, as it is in an LNG carrier, this type of fire is unlikely. Jet fires could occur during unloading or transfer operations when pressures are increased by pumping. Such fires could cause severe damage but will generally affect only the local area.

A large jet fire may have a substantial reach up to 50 meters or more. Therefore, scenarios involving jet fires are difficult to handle. Perhaps the most dramatic were the large jet fires from the gas riser on the Piper Alpha oil platform tragedy.

Figure 1 below illustrates the formation of a jet fire.

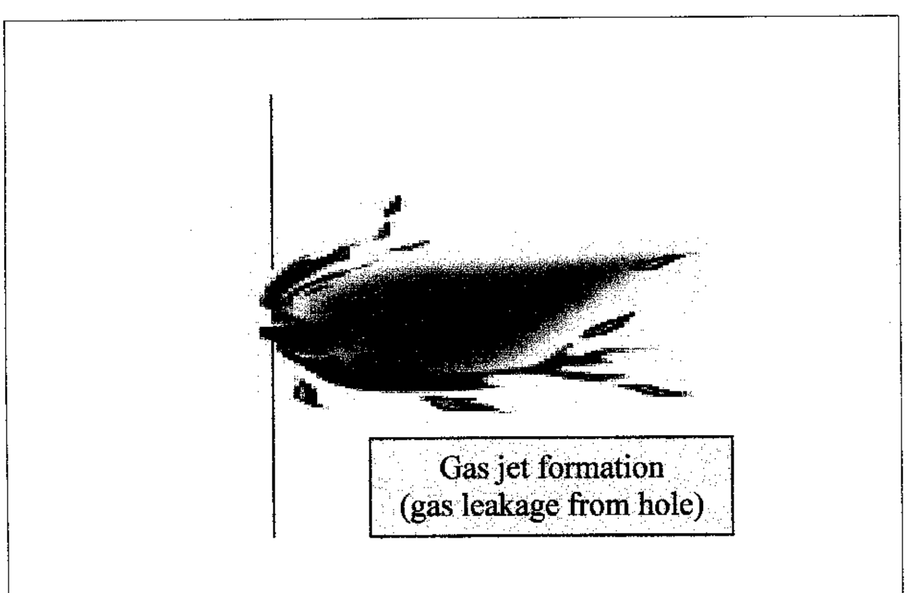


Figure 1: Jet Fire Formation

2.4 POOL FIRE

A pool fire is a complicated phenomenon and the theoretical treatment is correspondingly complex. When a flammable liquid is released from a storage tank or pipeline, a liquid pool may form. As the pool forms, some of the liquid will evaporate and, if flammable vapour finds an ignition source, the flame can travel back to the spill, resulting in a pool fire, which involves burning of vapour above the liquid pool as it evaporates from the pool and mixes with air.

The characteristics of a pool fire depend on the pool diameter. The liquid burning rate increases with diameter until for large diameters it reaches a fixed value. The heat radiated from the flame behaves similarly. A pool fire burns with a flame which is often taken to be a cylinder with a height twice the pool diameter.

Figure 2 below illustrates the formation of a pool fire.

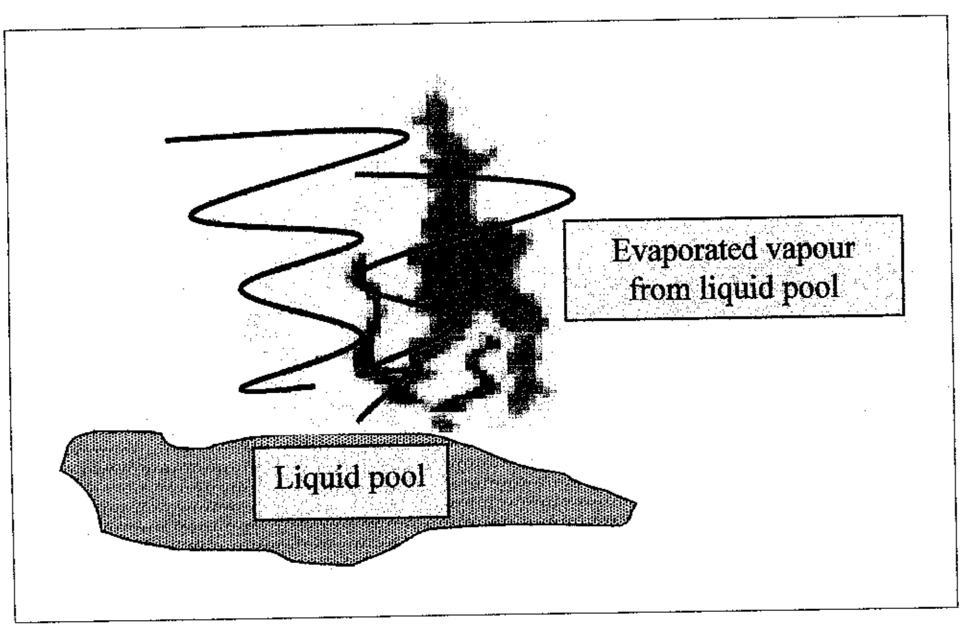


Figure 2: Pool Fire Formation

2.5 THERMAL RADIATION

The ignition of a flammable liquid or gas will result in a fire which may take a variety of forms, depending upon the nature of the release, the manner in which any dispersion takes place, the time and location of ignition etc. Whilst the various fire types have a wide range of characteristics, their primary significance within a risk assessment generally depends upon the effects of thermal radiation. Since complete engulfment within a fire is likely to result in almost instant fatality, most interest has been focused upon the effects to people outside the flame, who therefore receive a *thermal dose* which depends upon the heat flux and the duration of exposure.

Exposure to thermal radiation leads to skin damage. Examples of values of heat intensity for which pain and burning occur are widely available and ranges are given in Table 3.

Table 3: Effects of Thermal Radiation

Heat Intensity, I (kW/m^2)	Typical conditions
0.8 – 1.2	Solar radiation
1.6	No discomfort for long exposures
2.1	Minimum for pain after 60s
4.0	First degree burn
4.7	Causes pain in 15 – 20s, injury after 30s
9.5	Causes pain in 8s, Second degree burn after 20s
12.5	Minimum intensity for piloted ignition of wood
37.5	Damage to process equipment

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2.6 FIRE CHARACTERISTICS

The characteristics of different types of fire will affect both the intensity of radiation, and the duration of exposure. The intensity of radiation received is defined by the fire conditions and the extent of atmospheric attenuation. The exposure duration depends on the location of the victim relative to sources of shelter, reaction time and escape velocity.

The main types of fire considered in this study are industrial hydrocarbon fires, namely: jet fire and pool fire. These fires emit infrared radiation with varying wavelengths. The wavelength of radiation emitted during the transient stage is shorter than that produced during the diffusive stage.

Jet fires and pool fires have the longest duration of any other industrial fires such as flash fires or fireballs, but pool fires tend to have the lowest intensity of radiation. However, it is highly likely that people could escape from the vicinity of a pool fire to a safe distance from the fire. Jet fires tend to have slightly higher radiation intensity than pool fires. The duration may be extended and therefore consideration of escape is important.

Table 4 summarizes the characteristics of typical process fire incidents.

Table 4: Characteristics of Process Fire Incidents

Fire Type	Duration	Size	Intensity	Effects on people
Fireball	Short	Large	Very high	Large hazard ranges, little opportunity for escape
Flash fire	Short	Large	Medium	Fatalities usually within fire boundary only
Pool fire	Long	Medium	Low/Medium	Possibility of escape from fire site results in small hazard ranges
Jet fire	Medium/Long	Small/Medium	High	

2.7 ESTABLISHED FIRE RISK MODELS / TOOLS

FREIA, which was named after a German word, 'Freia' that means fire, is a common simple tool for evaluating industrial fire safety. FREIA was developed within a project at the Department of Fire Safety Engineering at Lund University in close co-operation with Sydkraft AB in 1997. The objective of FREIA is to guide fire protection engineers in designing and analysing risk in process industries as well as at power plants. The release rate can be specified as input data by the user. The release rate may result in a Boiling Liquid Expanding Vapour Explosion (BLEVE), pool fire, jet fire, flash fire, spray fire, Vapour Cloud Explosion (VCE), an explosion inside a building, or spreading of toxic gases, or any combination of these. Although FREIA provides good evaluation of various fire risk models, no account is taken of process response to the release rate.

Other established tool is Toxic Release Analysis of Chemical Emissions (TRACE) software developed by SAFER Systems in 1986. TRACE is used for facility siting studies, emergency preparedness planning and quantitative risk analysis studies. TRACE evaluates thermal radiation variables from several fire-related scenarios. These include fireballs, BLEVEs, liquid pool fires, jet fires, flash fires and generic sources (user-specified).

One of the latest fire development models is the FIERAsystem, which stands for Fire Evaluation and Risk Assessment System. FIERAsystem was developed in 2002 by National Research Council (NRC), Canada in partnership with the Department of National Defence (DND), Canada. FIERAsystem is based on a framework that allows designers to establish objectives, select possible fire scenarios, and evaluate the impact of each scenario on life safety and property protection. Each model has its own user interface and is designed as a stand-alone module. Each sub-module contains equations that describe the fire, and the effects of the fire on the building and its occupants and contents.

CHAPTER 3
METHODOLOGY/PROJECT WORK

3.1 PROCEDURE IDENTIFICATION

This Final Year Research Project (FYRP) is an individual assignment to be completed in 17 weeks duration. The project title is, 'Integration of Jet and Pool Fire Risk Models with Process Simulator for Inherent Safety Design.' The project work milestone is summarized in Table 5 while the project work methodology is outlined in Figure 3 accordingly.

Table 5: Project Work Milestone

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	**Introduction**																	
	- Topic Assignment																	
	- Briefings																	
2	**Preliminary Research Work**																	
	- Literature Review																	
	- Preliminary Report Submission																	
3	**Project Work**																	
	- Microsoft Excel Spreadsheets Development																	
	- HYSYS Process Simulation Development																	
	- HYSYS-Excel Integration Development																	
	- Progress Report Submission																	
	- Model Testing, Case Studies, SAFETI Validation, Benchmarking, Pre-EDX																	
	- Dissertation Draft Submission																	
	- Dissertation Final Draft Submission																	
	- Oral Presentation																	

Note: Project Dissertation Submission is due on the first week of Semester July 2005.

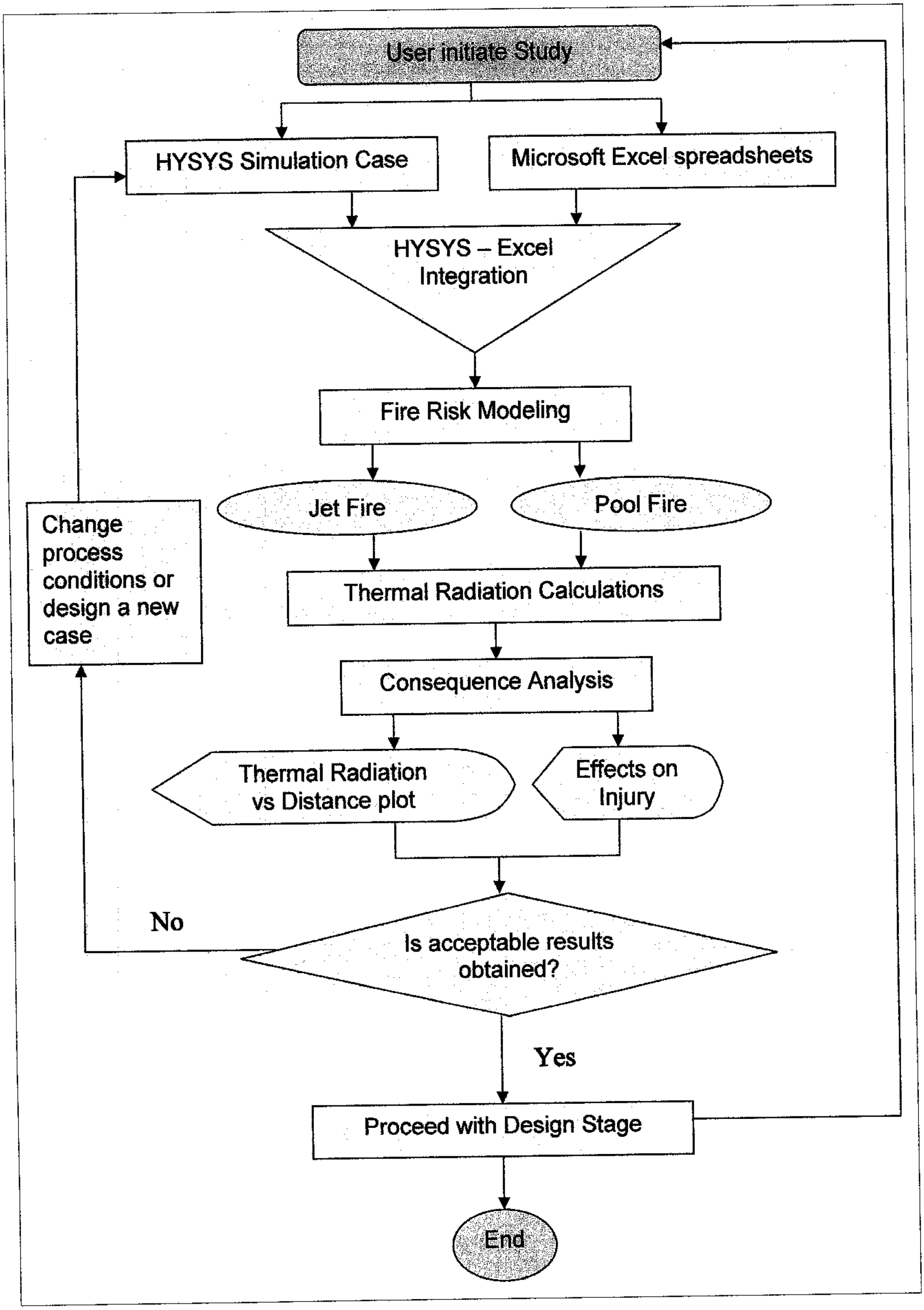


Figure 3: Project Work Methodology

Figure 3 actually summarizes the sequential steps of the completed model in generating the desired output of consequence analysis. In this particular project work, the subject is to study the thermal radiation effects produced by 2 common fire outbreaks in industries; jet fire and pool fire.

The process starts by introducing a proposed study to be analysed. The main tool resides in Microsoft Excel spreadsheets, in which will calculate the necessary parameters based on data retrieved from HYSYS simulation case. Thus, the HYSYS – Excel integration function to ease the manual input process respectively.

The user or designer is given two options for fire risk modeling; jet fire and pool fire. After any selection, the model performs calculations based on existing equations and results are generated.

Analysis of the results is the key for the designer decision making as to proceed with the design stage or do some modification. Alternatively, the user or designer may initiate another study.

3.2 REQUIRED TOOLS

The required tools to develop this project work include HYSYS, Microsoft Excel as well as Microsoft Visual Basic.

The main tool identified is the Microsoft Excel spreadsheets. These spreadsheets are built by inserting established equations specifically for calculating the thermal dose endpoint distance for each type of fire. Upon calculations obtained, results will be in graphical display of thermal radiation against distance plot.

Simulation of case studies will be generated by means of HYSYS. These simulations will provide necessary parameters required for the calculations in the Microsoft Excel spreadsheets. Therefore, it should be noted that Microsoft Excel spreadsheets must have the capability of extracting the required information automatically from any HYSYS simulation to be analyzed.

In order to do so, Microsoft Visual Basic will assist in the Automation part. Automation, defined in its simplest form, is the ability to drive one application from another. It is desirable for the Object Linking and Embedding (OLE) codes from Microsoft Visual Basic to link the simulation in HYSYS and be analyzed by Microsoft Excel spreadsheets.

Using this functionality, front-end is created in the Microsoft Visual Basic simultaneously. Hence, the complexities of HYSYS simulation and Microsoft Excel calculations can be suppress.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 CASE STUDY

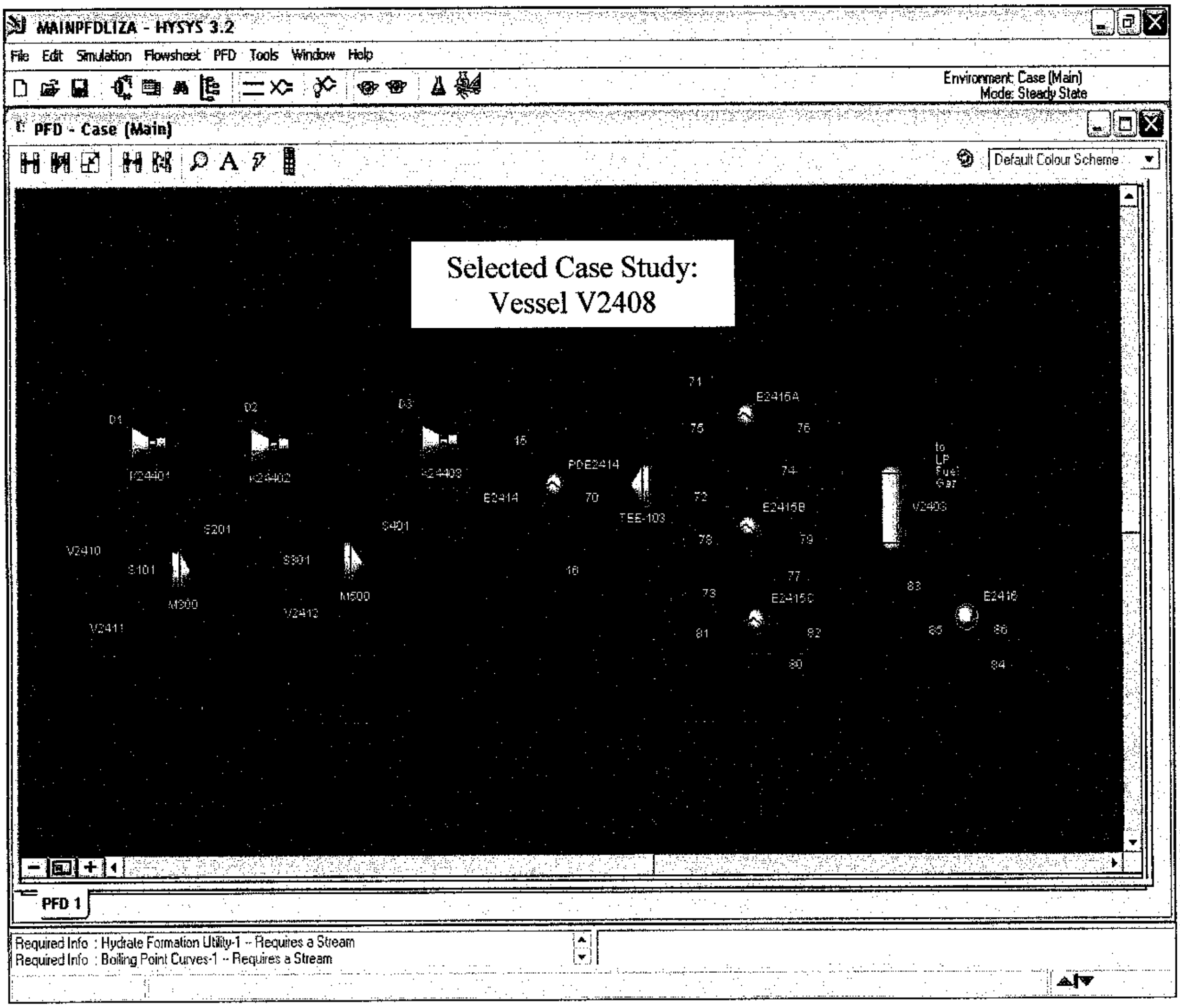


Figure 4: Main PFD in HYSYS Simulation Case

Figure 4 provides the overall dimensions of the main Process Flow Diagram (PFD) in HYSYS Simulation Case developed upon actual data of process Unit 2400 in Malaysia Liquefied Natural Gas (MLNG) Sendirian Berhad. Vessel V2408 has been chosen as the basis for the case study. To simulate jet fire scenario, a gas dispersion due to a hole leakage at the upper outlet stream of Vessel V2408 will be considered whereas a pool fire scenario is simulated as liquid spills due to leakage at the lower Vessel V2408 outlet stream respectively.

In this case study, Vessel V2408 is actually a separator whereby the possibility of a gas leakage will be on the upper outlet stream while the possibility of a liquid spillage will be on the lower outlet stream.

Figure 5 below provides the dimensions of the selected case study taken from the main PFD.

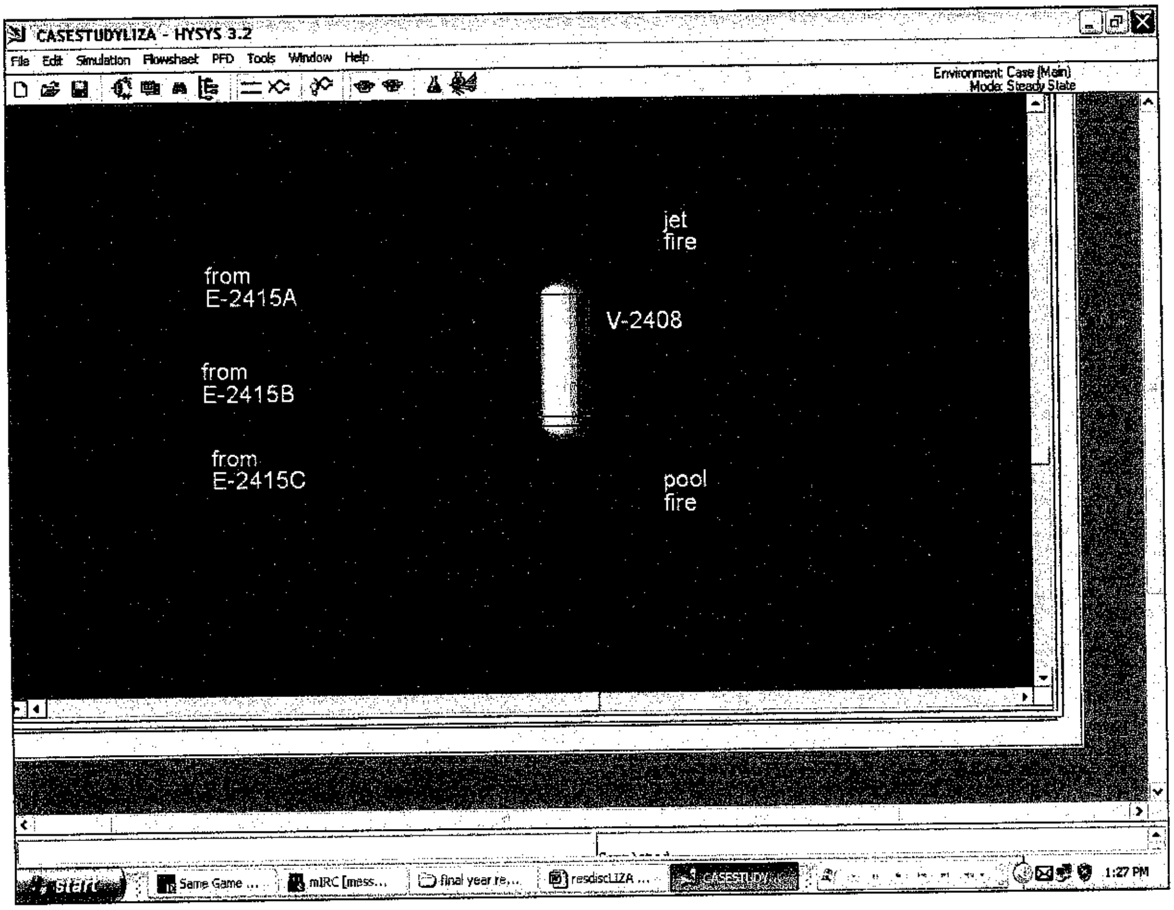


Figure 5: Selected Case Study of Vessel V2408

Assumptions made for the case study as well as required model parameters are listed in Table 6 below.

Table 6: Case Study Assumptions and Parameters

Case Study	Fixed Constants	Table Properties	HYSYS Properties	User-Specified Input
Jet Fire	• Atmospheric transmissivity, $\tau = 1$ • Fraction of thermal energy radiated, $f = 0.2$ • Hole diameter, $D = 0.15m$	• Jet Fire Factor, JFF • Heat of Combustion, H_c	• Jet release rate	• Jet amount
Pool Fire	• Ambient temperature, $T_a = 303.15°F$ • Gravitational acceleration, $g = 9.81 m/s^2$ • Pool amount = 100 kg • Ambient air density, $\rho_a = 1.2\ kg/m^3$ • Atmospheric transmissivity, $\tau = 1$ • Fraction of thermal energy radiated, $f = 0.3$	• Pool Fire Factor, PFF • Heat of Combustion, H_c • Pool mass burning rate • (% radiative /combustion output) / 100	• Specific heat of liquid, C_p • Normal boling point, T_b • Enthalpy of evaporation, H_{vap} • Continuous liquid spill rate • Liquid density, ρ_l	• Pool combustion duration, t_p

It should also be noted that all gas jet releases and vapour evaporated from liquid pool for this case study is considered to lie within its flammable range respectively. This is important because consequences of jet and pool fire only occur when the situation is within the flammability limits.

4.2 MICROSOFT EXCEL SPREADSHEETS

Microsoft Excel serves as the heart of this project work. The spreadsheets developed in Microsoft Excel are used to calculate thermal radiation flux for both jet and pool fire scenarios. Established equations and formulas used will be discussed further in *Section 4.2.1* and *Section 4.2.2.*

The important features of Microsoft Excel application is its capability to communicate with the other tools, namely HYSYS and Microsoft Visual Basic through Automation coding via Object Linking and Embedding (OLE).

For uniformity, similar representation of HYSYS case study has been developed in the main Microsoft Excel environment. This is shown in Figure 6 below.

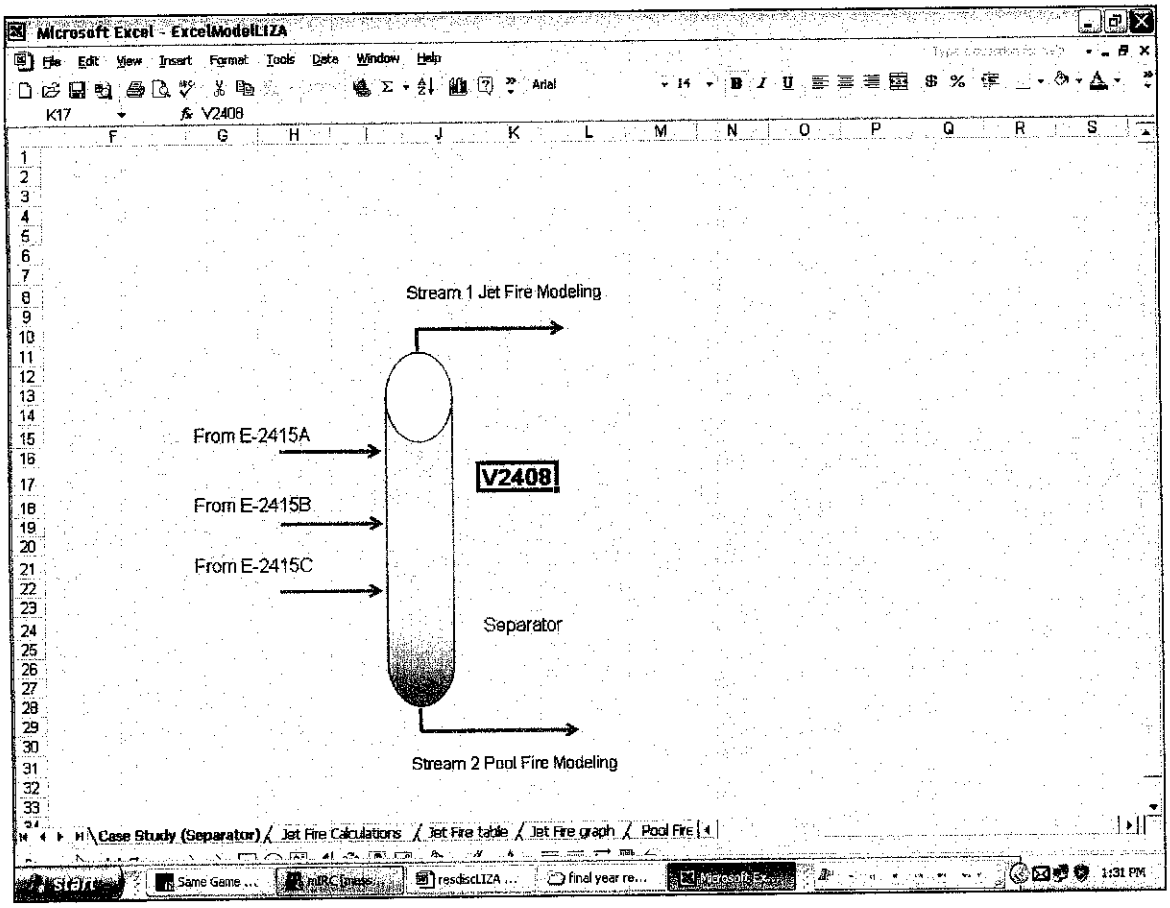


Figure 6: Case Study Representation in Microsoft Excel

4.2.1 *Jet Fire Calculations*

Jet fire results from the immediate ignition of a released jet of pressurized flammable gas or vapour from a vapour space opening of the containment. The resulting major effect is that of thermal radiation.

The thermal dose endpoint distance for a jet fire is calculated by using this formula:

$$Y = m'^{0.5} \times JFF \times (t_j^{0.375})$$

where:

Y = distance to thermal dose (m)

m' = jet release rate (kg/s)

JFF = jet fire factor

t_j = jet combustion duration (s)

In this project work, the thermal radiation flux, q for jet fire is calculated using two methods. Method 1 refers to the calculations generated by the New Jersey Department of Environmental Protection Bureau of Release Prevention used for the Toxic Catastrophe Prevention Act (TCPA) Program. This simplified method is in the form of reference tables and equations that are used to determine the endpoint distances for releases of a regulated flammable substance. Method 2 implements the Thornton model. This method will utilize the calculated value of the flame surface emissive power, E_s to obtain the thermal radiation flux, q.

The thermal radiation flux for Method 1 (TCPA) is obtained from a radiating point source equation as follows:

$$q = \tau \times f \times m' \times H_c \times F_p$$

where:

q = thermal radiation flux (kW/m^2)

τ = atmospheric transmissivity

f = fraction of thermal energy radiated

m' = jet release rate (kg/s)

H_c = heat of combustion (kJ/kg)

F_p = view factor (m^{-2})

F_p is calculated by:

$$F_p = 1/(4 \times \pi \times Y^2)$$

where:

Y = distance to thermal dose (m)

The thermal radiation flux for Method 2 (Thornton) is obtained from the following relation, which are extended from the flame surface emissive power calculated value:

$$q = \tau \times F_p \times E_s$$

where:

q = thermal radiation flux (kW/m^2)

τ = atmospheric transmissivity

F_p = view factor (m^{-2})

E_s = flame surface emissive power (kW)

E_s is calculated by:

$$E_s = (F_s \times m' \times H_c \times 10^{-3}) / A$$

where:

F_s = surface fraction

m' = jet release rate (kg/s)

H_c = heat of combustion (kJ/kg)

A = jet flame area (m^2)

F_s is calculated by:

$$F_s = [0.21e^{-0.00323uj} + 0.11] \times f \times MW$$

where:

u_j = jet velocity (m/s)

f = fraction of thermal energy radiated

MW = molecular weight

A is calculated by:

$$A = \pi D^2 / 4$$

where:

D = hole diameter (m)

4.2.2 Pool Fire Calculations

Pool fire is the result of the ignition of an evaporating flammable liquid pool that spills from the liquid space opening of the containment. The resulting major effect is that of thermal radiation.

The thermal dose endpoint distance for a pool fire is calculated by using this formula:

$$X = A^{0.5} \times PFF \times (t_b^{0.375})$$

where:

X = distance to thermal dose (m)

A = pool area (m^2)

PFF = pool fire factor

t_b = pool combustion duration (s)

In this project work, the thermal radiation flux, q for pool fire is also calculated using two methods. Method 1 still refers to the simplified method generated for the TCPA Program as well but Method 2 will consider the Point Source model. For both models, the pool fire scenarios will be evaluated using two different cases. Case 1 is subjected to continuous spills and Case 2 deals with instantaneous spills.

Case 1 and Case 2 will provide different values of pool diameter for the calculations of pool area due to different characteristics of pool spreading. For continuous spills, the liquid will spread and increase the burning area until the total burning rate is equal to the spill rate. For instantaneous spills, the unconfined pool fire grows in size until a barrier is reached or until all the fuel is consumed.

The thermal radiation flux for Method 1 (TCPA) is obtained from a radiating point source equation as follows:

$$q = \tau \times f \times m'' \times H_c \times A \times F_p$$

where:

q = thermal radiation flux (kW/m^2)

τ = atmospheric transmissivity

f = fraction of thermal energy radiated

m'' = pool mass burning rate (kg/s)

H_c = heat of combustion (kJ/kg)

A = pool area (m^2)

F_p = view factor (m^{-2})

F_p is calculated by:

$$F_p = 1/(4 \times \pi \times X^2)$$

where:

X = distance to thermal dose (m)

The thermal radiation flux for Method 2 (Point Source) is obtained from the following relation, which are extended from the total heat radiated calculated value:

$$q = (\tau \times Q_R) / 4\pi \times X^2$$

where:

q = thermal radiation flux (kW/m^2)

τ = atmospheric transmissivity

Q_R = total heat radiated (kW)

X = distance to thermal dose (m)

Q_R is calculated by:

$$Q_R = (dm/dt) \times A \times H_c \times [(\%\ \text{radiative / combustion output}) / 100]$$

where:

dm/dt = rate of burning (kg/m^2s)

A = pool area (m^2)

H_c = heat of combustion (kJ/kg)

Note: [(% radiative / combustion output) / 100] is obtained from reference table.

dm/dt is calculated by:

$$dm/dt = (0.001\ H_c) / [C_p\ (T_b - T_a) + H_{vap}]$$

where:

C_p = specific heat of liquid (kJ/kg.°K)

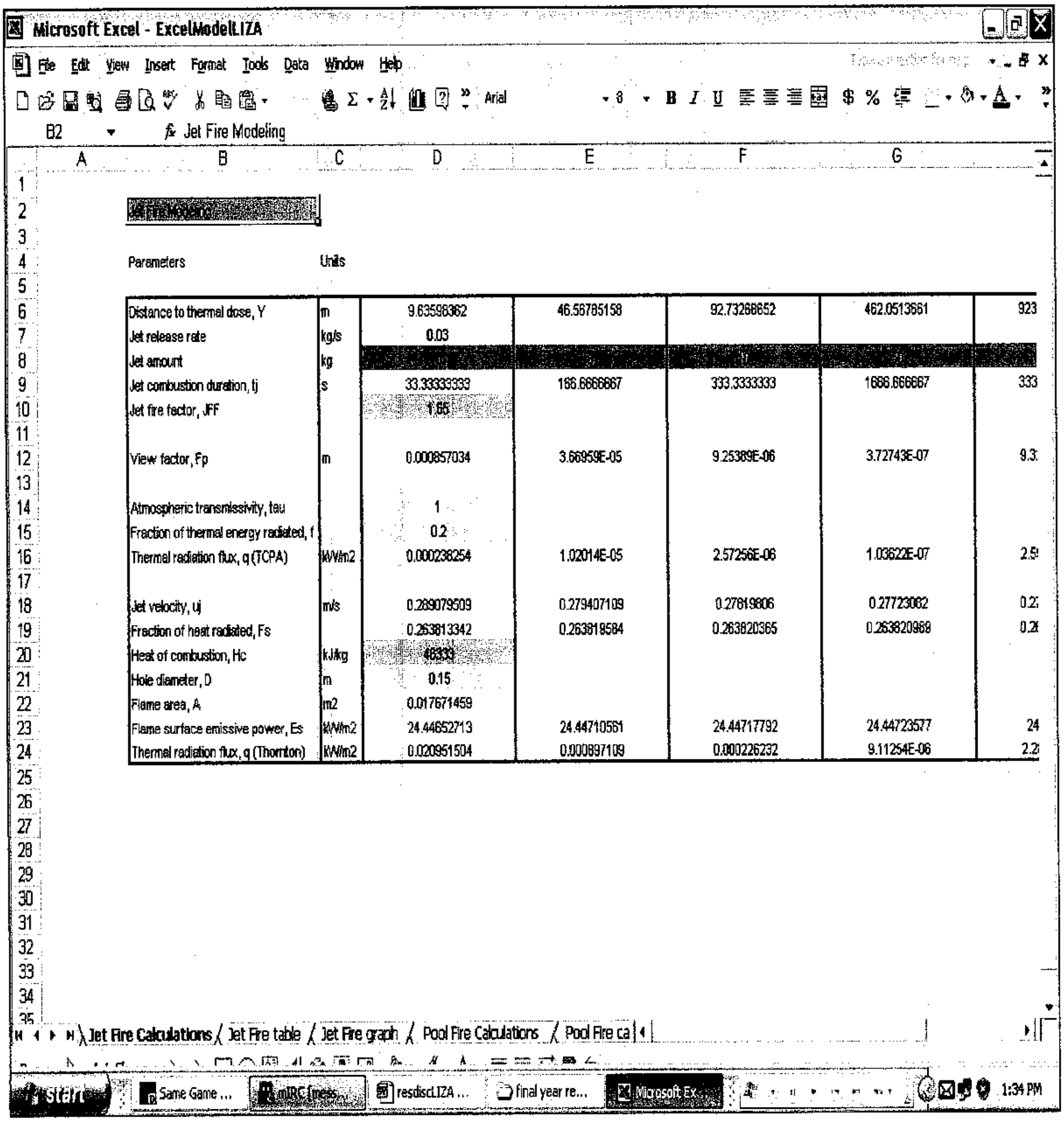
T_b = normal boiling point (°K)

T_a = ambient temperature (°K)

H_{vap} = enthalpy of evaporation (kJ/kg)

4.2.3 Microsoft Excel Interface

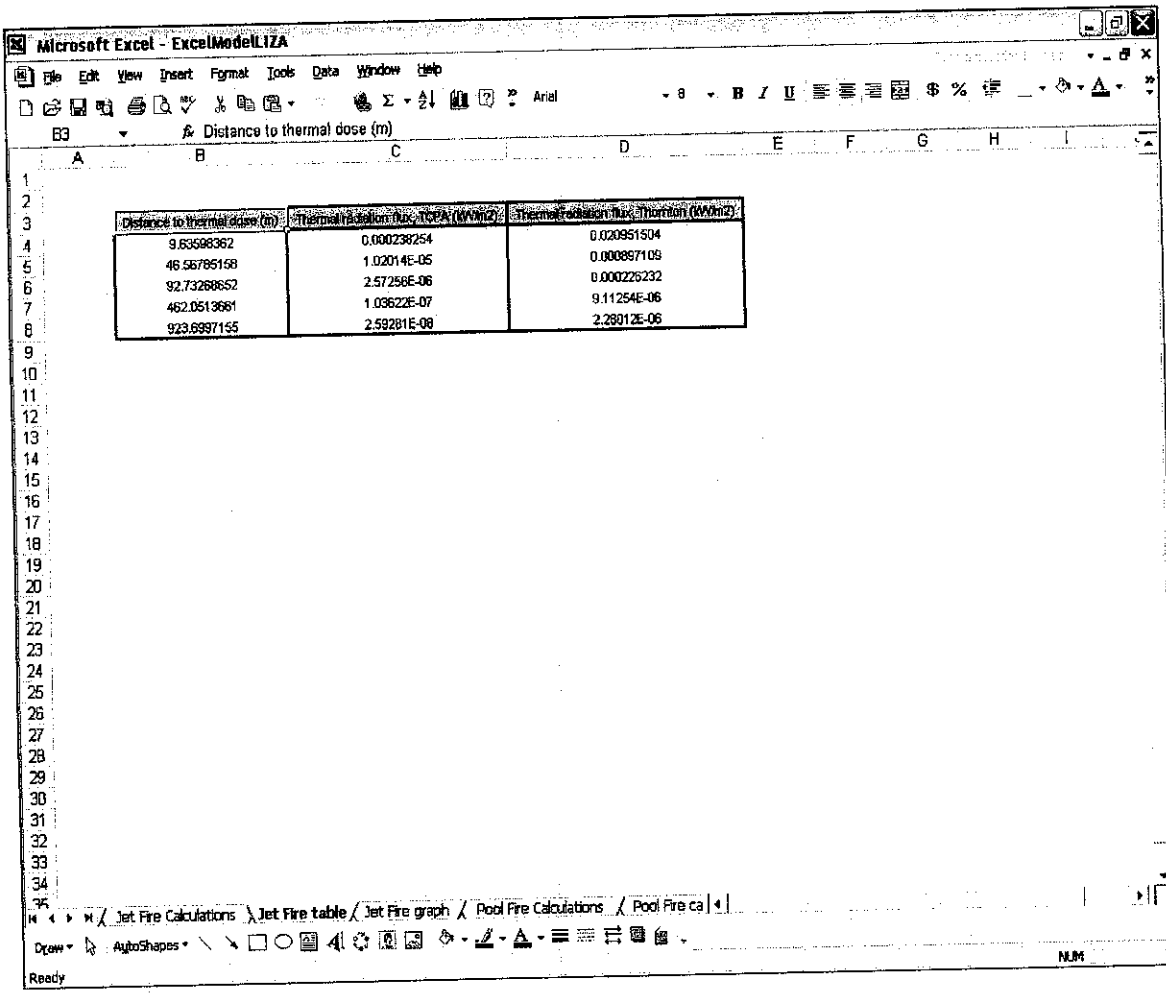
Figure 7 below displayed a sample window for Jet Fire Modeling calculations worksheet. This computational module has four distinguishable cell colour indicators. Brown cell refers to constants used in the calculations, green cell values are taken from "live" database of HYSYS simulation case, blue cell values come from respective reference tables while red cell corresponds to user-specified inputs.



Parameters	Units					
Distance to thermal dose, Y	m	9.63598362	46.56785158	92.73268652	462.0513661	923
Jet release rate	kg/s	0.03				
Jet amount	kg	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jet combustion duration, tj	s	33.33333333	166.6666667	333.3333333	1666.666667	333
Jet fire factor, JFF		1.66				
View factor, Fp	m	0.000857034	3.66959E-05	9.25389E-06	3.72743E-07	9.3
Atmospheric transmissivity, tau		1				
Fraction of thermal energy radiated, f		0.2				
Thermal radiation flux, q (TCPA)	kW/m2	0.000238254	1.02014E-05	2.57256E-06	1.03622E-07	2.5
Jet velocity, uj	m/s	0.289079509	0.279407109	0.27819806	0.27723082	0.2
Fraction of heat radiated, Fs		0.263813342	0.263818584	0.263820365	0.263820969	0.2
Heat of combustion, Hc	kJ/kg	46333				
Hole diameter, D	m	0.15				
Flame area, A	m2	0.017671459				
Flame surface emissive power, Es	kW/m2	24.44652713	24.44710561	24.44717792	24.44723577	24
Thermal radiation flux, q (Thornton)	kW/m2	0.020951504	0.000897109	0.000226232	9.11254E-06	2.2

Figure 7: Sample window of Jet Fire Modeling calculation

The results obtained from the calculations are then tabulated in another worksheet for easy reference. This is shown in Figure 8 below.



Distance to thermal dose (m)	Thermal radiation flux, TCPA (kW/m2)	Thermal radiation flux, Thornton (kW/m2)
9.63598362	0.000238254	0.020951504
46.56785158	1.02014E-05	0.000897109
92.73268652	2.57256E-06	0.000226232
462.0513661	1.03622E-07	9.11254E-06
923.6997155	2.59281E-08	2.28012E-06

Figure 8: Tabulated Calculation Results for Jet Fire Modeling

4.3 THE MODEL PREDICTIONS

In this project work, the results generated are in graphical display of thermal radiation flux in kW/m^2 plotted against distance to thermal dose in meters.

Figure 9 below has been obtained for jet fire simulation.

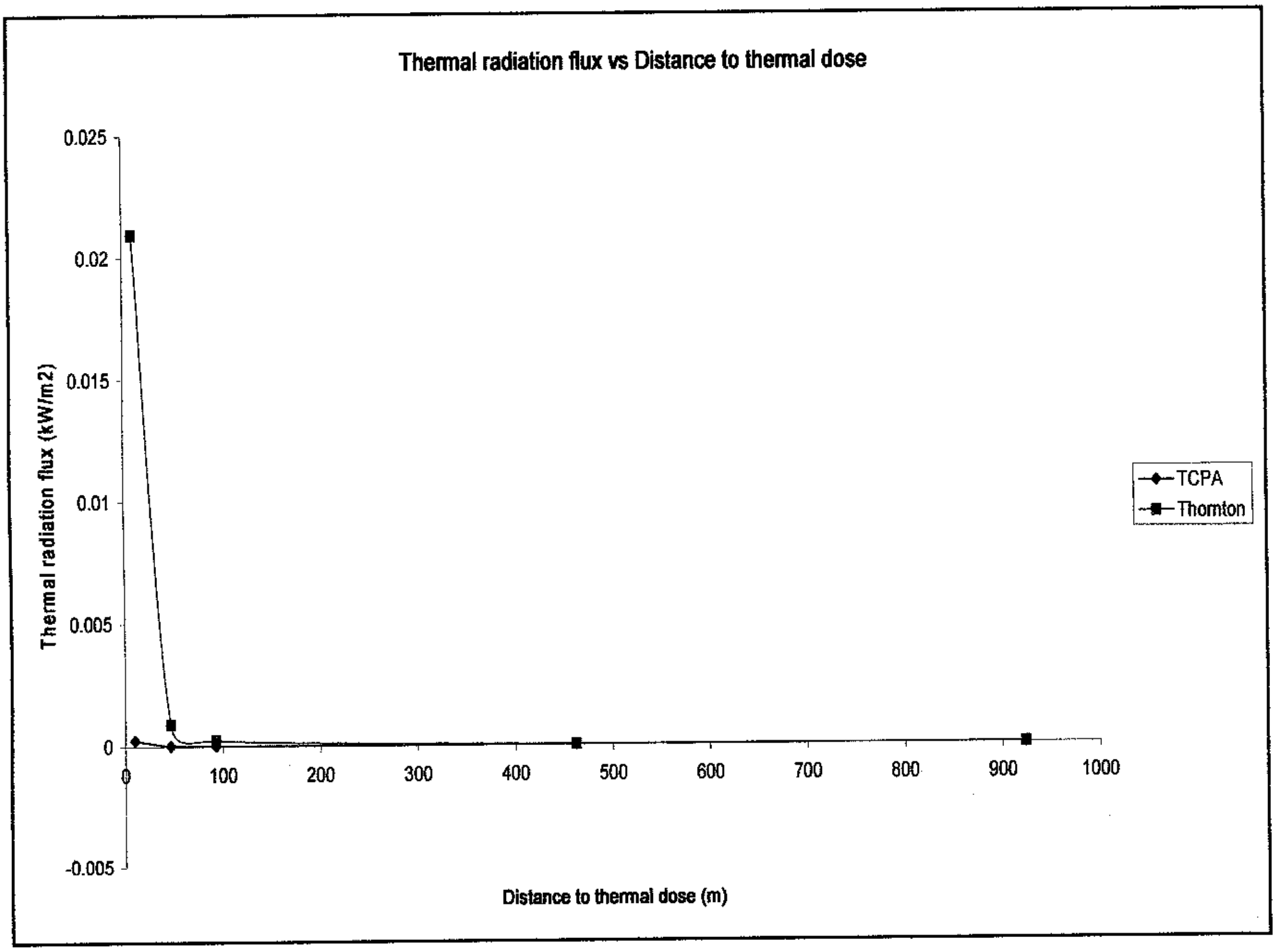


Figure 9: Graph for Jet Fire Model

It can be noted that as the distance to thermal dose increases, the thermal radiation flux will decreases. This follows the theoretical relationship of the distance versus thermal radiation. However, referring to the scale of thermal radiation flux, the case study being evaluated will yield no effects on injury as the values are so small. Effects of thermal radiation are referred based on Table 3 shown in Section 2.5 of Chapter 2.

Figure 10 below refers to Case 1 of pool fire simulation while Figure 11 displays the pool fire simulation for Case 2.

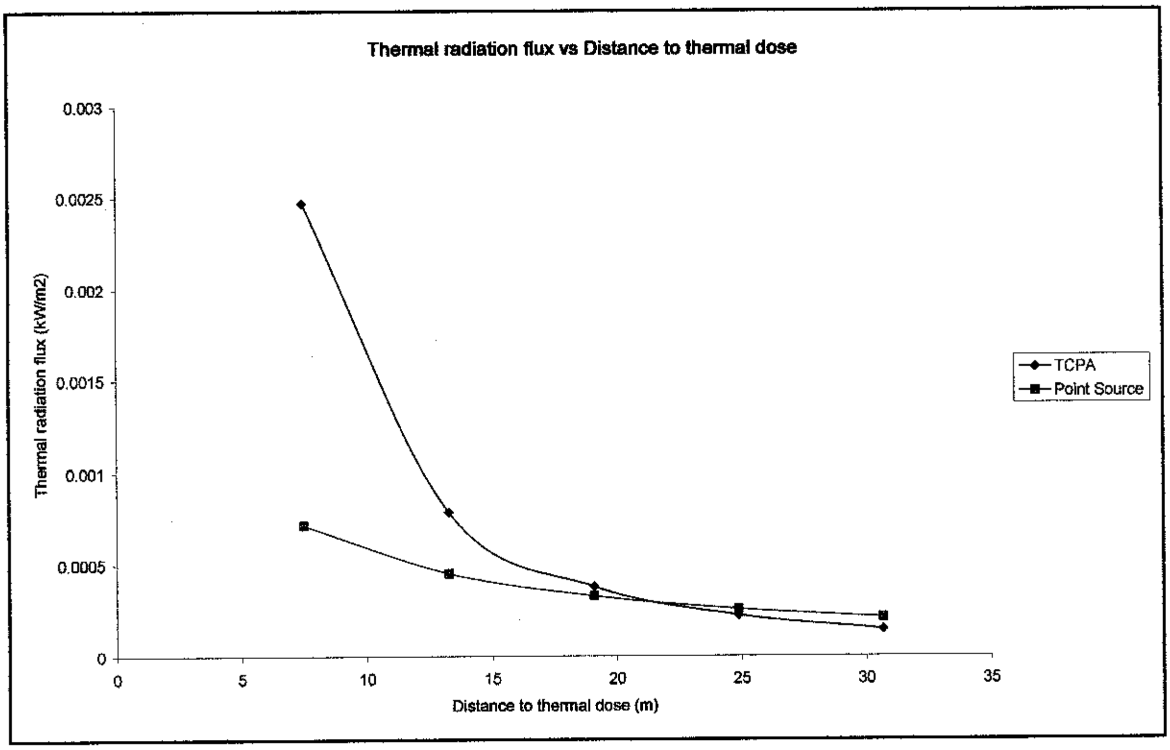


Figure 10: Graph for Pool Fire Case 1 (continuous spills) Model

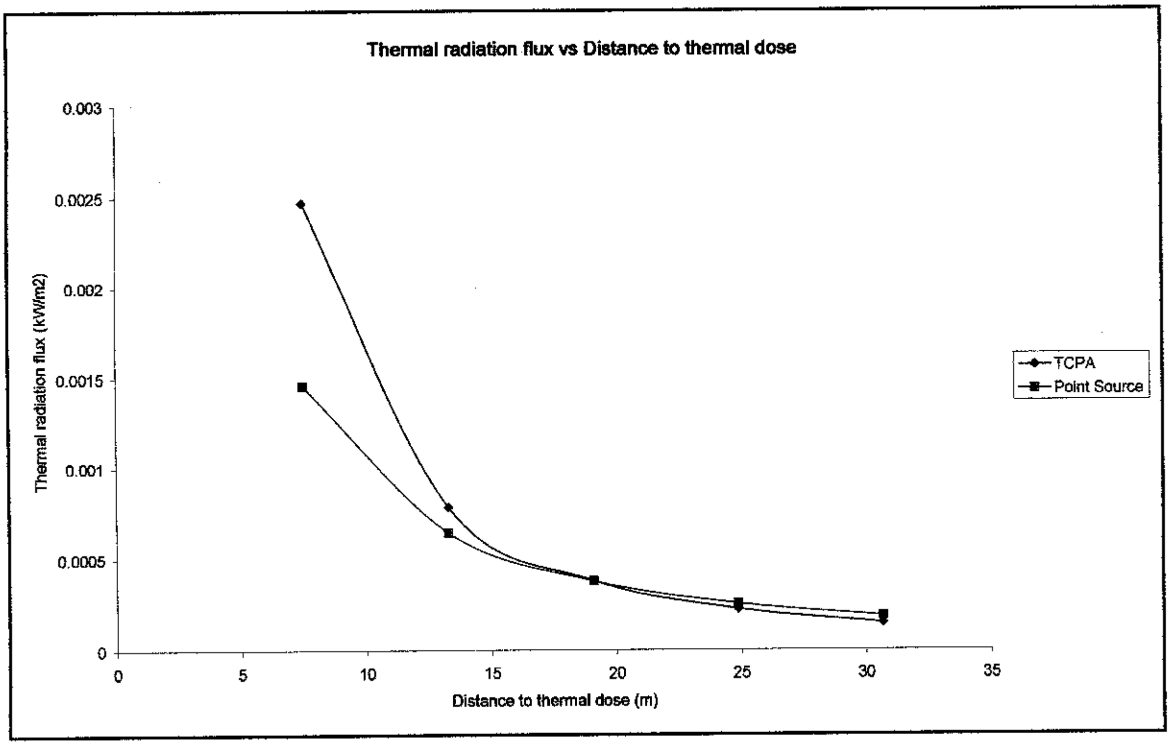


Figure 11: Graph for Pool Fire Case 2 (instantaneous spills) Model

Referring to both graphs, the TCPA Method as well as the Point Source Method being used yields similar trend of distance versus thermal radiation. This satisfies the relationship of as the distance to thermal dose increases, the thermal radiation flux decreases. The case study for pool fire also has no effects on injury as the scale for the thermal flux obtained is also relatively small.

Overall, for jet fire simulation, there exists significant difference between the calculations methods being used. The TCPA Model and the Thornton Model do not correspond similarly although both models are using the same parameters.

Contrary, for pool fire simulation, the TCPA Model and the Point Source Model being used tend to generate nearly the same values of thermal radiation flux.

Based on the results generated, the model is able to demonstrate the relationship of thermal radiation flux against the distance to thermal dose. The trend obeys the theoretical predictions of equations being used whereby, as the distance of thermal dose increases, the thermal radiation flux decreases.

However, since the basis of calculations for the case study are utilizing the real equipment of existing plant operating condition, values obtained for thermal radiation flux are extremely low. This indicates that the upsets of leakage or spillage at that vessel will not yield any effects on injury. This finding definitely proves that current plant operating condition for the equipment design is safe.

CHAPTER 5
CONCLUSION

- The modeling software developed is able to perform the calculations based on established equations.
- The results generated by the model are in terms of graphical display of thermal radiation flux versus distance to thermal dose.
- In ensuring the reliable of the tools, worst case scenario for case study shall be implemented instead of using existing safe plant design case study.
- For further development, it is recommended that this model to combine with other similar models of different associated risks of plant process design. This will create a useful and beneficial single assessment tool for various risk categories.

5.1 PROBLEMS ENCOUNTERED

The Fire Risk Model with Process Simulator developed actually consists of two modules; the computational module and the user interface module.

The role of the computational module is to perform the calculations involved in the modeling process. This has been developed within Microsoft Excel environment. The essential equations and formulas have been obtained from literature review respectively.

The purpose of the user interface module is to allow the user to define the parameters of the problem to be modeled, to activate the computational module and to present the results of the model to the user.

In order to provide a clear and effective user interface, the user interface module is programmed using Microsoft Visual Basic. However, due to the complexity of the coding, the integration of the tools has not yet accomplished.

The model developed so far acts as a stand-alone model. It is desirable to enhance the model by really focused on the integration section mainly on the coding used for retrieving data from the "live" database of HYSYS simulation to the computational module of Microsoft Excel. The Microsoft Visual Basic user interface will provide a user-friendly approach to the model.

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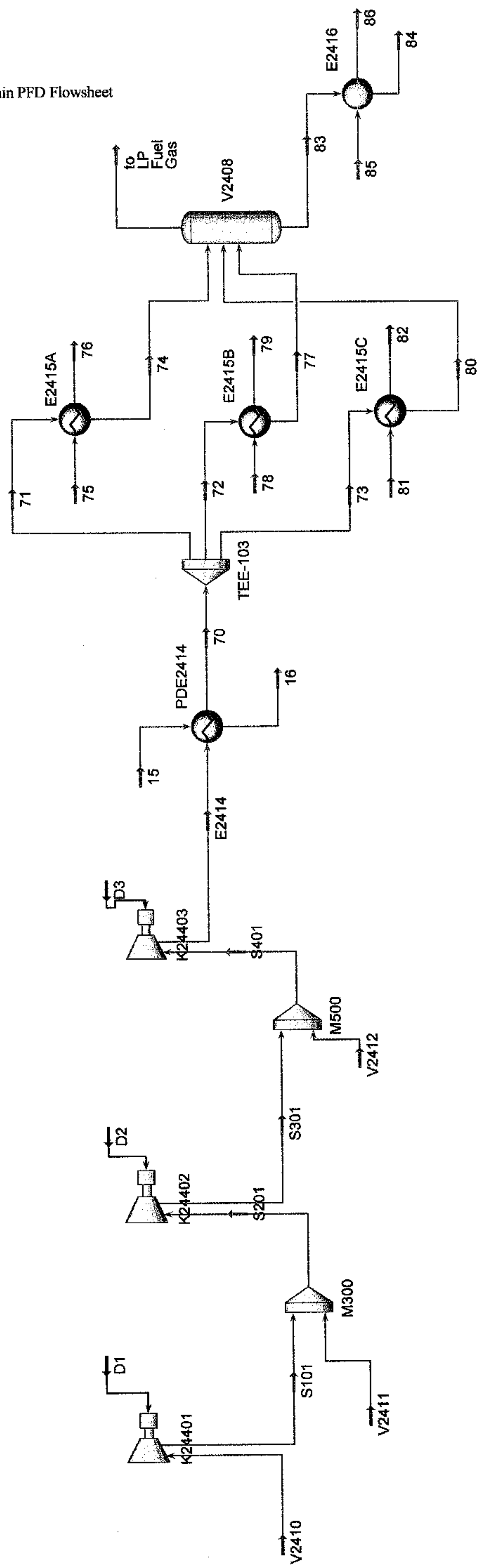
APPENDICES

Appendix I – Main PFD Flowsheet

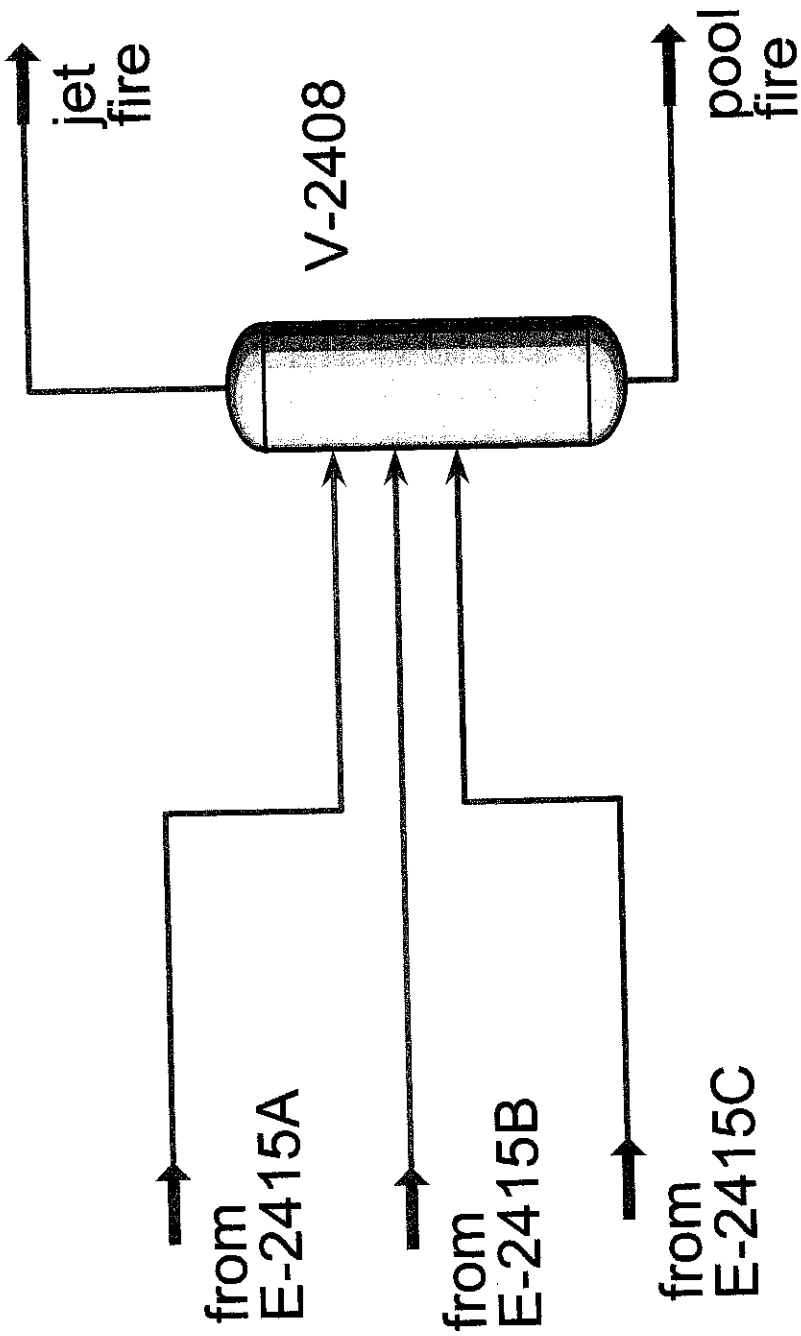
Appendix II – Case Study Flowsheet

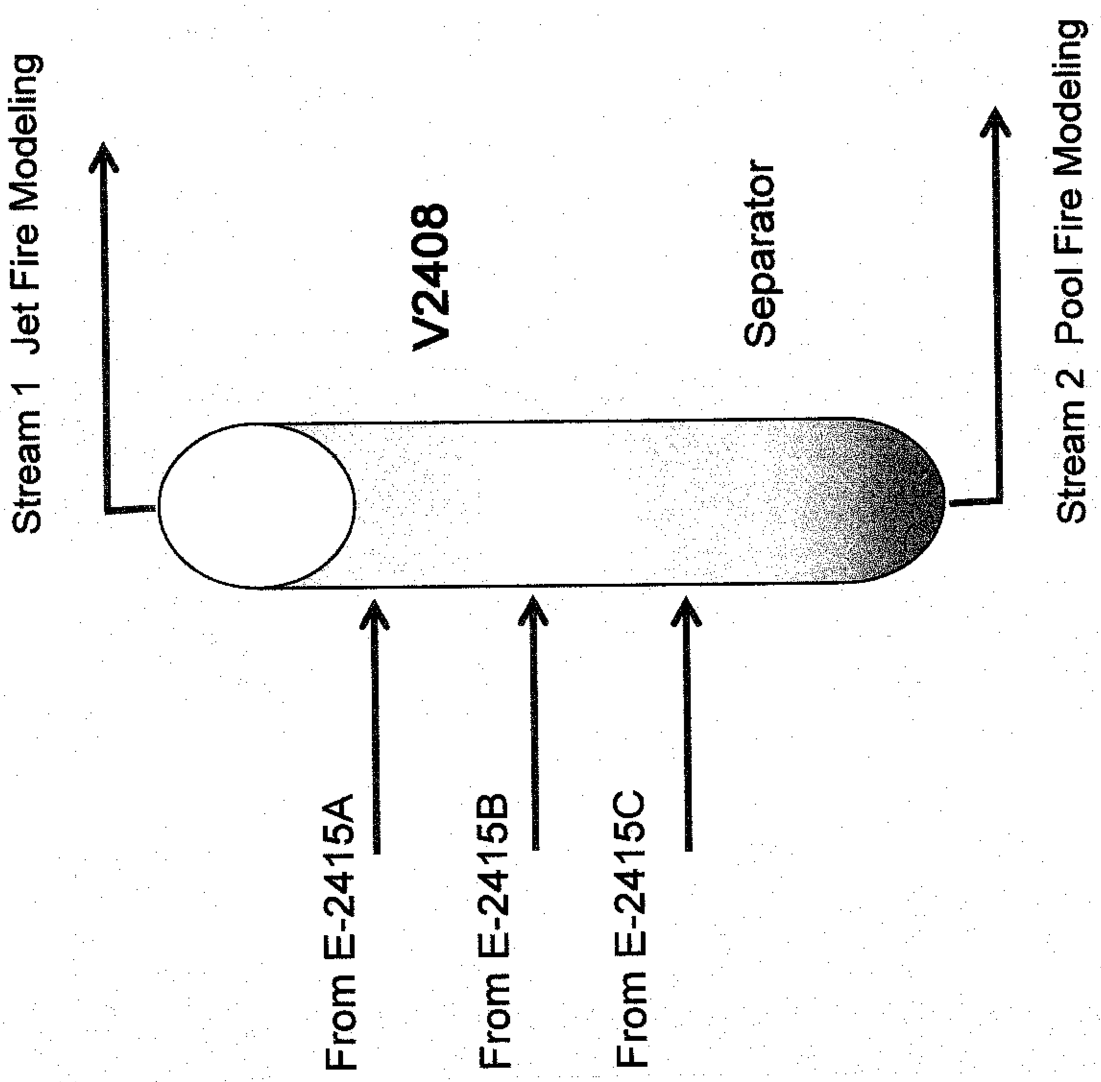
Appendix III – Case Study Representation in Microsoft Excel

APPENDIX I – Main PFD Flowsheet



APPENDIX II – Case Study Flowsheet




Stream 1 Jet Fire Modeling
V2408
Separator
Stream 2 Pool Fire Modeling
From E-2415A
From E-2415B
From E-2415C