Enhanced Inherent Safety Intervention Framework

by

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Dzulkarnain B. Zaini)

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BANDAR SERI ISKANDAR, PERAK

SEPTEMBER 2015

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.

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VARSHA JHA

ABSTRACT

Inherent safer design focuses on avoiding hazards rather than controlling them, especially by reducing the amount of hazardous materials or the number of hazardous operations in the plant. Usually, the assessment of safety in a plant is done towards the end of the process design stage, however inherent safety is applied in the initial stages of process design. The concept of inherent safety has been around for quite some time although it is yet to be widely accepted in the industries. The predecessor of this research has been successful in inventing a few indices that have been able to gauge the level of inherent safety in various process routes and process streams. This research aims to further improve the existing work by adding in the evaluation of the consequences and the frequencies of the risks in the streams that are found to be the least inherently safe. A methodology has been developed that enables the calculation of these factors. The combined values of the consequence and frequency indices will help determine if the selected streams are to be redesigned to better fit the inherent safety standards.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Event Tree Analysis	ETA
Methyl Methacrylate Acid	MMA
Inherent Risk Assessment	IRA
Inherently Safer Design	ISD
Inherent Safety Intervention Framework	ISIF
Process Route Index	PRI
Process Stream Index	PSI
Tert-butyl Alcohol	TBA

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The objective of the process design phase is to create a process that is economically viable, safe, environmentally friendly, and is easy to use. This can only be done by fully enhancing the process and finding alternatives that will be the most suitable.

Safety is a major aspect that is considered during the design of a process plant. There are many techniques and methodologies of assessing the level of safety in a plant however; they are usually applied in parallel or towards the final stages of the design. Safety should not be added to the plant at the end of the process as an afterthought, it should be a fundamental part of the designing process. This is where the concept of inherent safety comes to play.

"Inherently Safer Design (ISD) focuses on eliminating or significantly reducing hazards" (Hendershot, 2006). This method of risk analysis avoids hazards by reducing the amount of hazardous substance or operations in a plant rather than trying to mitigate them by adding external safety devices.

ISD focuses on the effects of single events such as fires, explosions and toxic releases on the environment, people, property and businesses. This method works by making the process itself less hazardous but only to a point so that the process or the design of the plant doesn't change. ISD has been spilt by The Center for Chemical Process Safety (2009) into four strategies that help design safer processes:

- ***Minimize -*** use small quantities of hazardous materials or reduce the size of equipment operating under hazardous conditions
- ***Substitute –*** use less hazardous materials.

- ***Moderate* –** reduce hazards by dilution, refrigeration or process alternatives that operate at less hazardous conditions.
- ***Simplify* –** eliminate unnecessary complexity and design user friendly plants.

The idea of inherently safer design has been around since the 70's but it has not been successfully combined into process design stage due to the lack of "systematic methodology and technology" (Leong, 2008).

To help with the adaptation of inherently safer design into the initial process design phase, an Inherent Safety Intervention Framework (ISIF) was developed by Dr. Chan Tuck Leong. This framework takes the structured approach of QRA and implements them at the early phases of the design to enable the assessment, control and reduction of risk as per the philosophies of inherent safety.

This framework estimates the probability and the consequences of undesired events during the initial stages of design and is developed to access the various hazards caused by explosions. The study starts off from evaluating the different process routes using the Process Route Index (PRI) to rank them from the safest route to the lowest. It is then followed by an Inherent Risk Assessment (IRA) that estimates the risk of the selected route due to its design and the materials used. After the route is selected, it can either be sent for detailed design or can be further scrutinized to ensure the process streams are designed in the safest possible way using the Process Stream Index (PSI).

The figure below shows the inherent safety intervention algorithm. Another few steps will be added after the fifth step, the PSI to evaluate the consequences and the frequencies of the risks in streams ranked highest by the PSI.

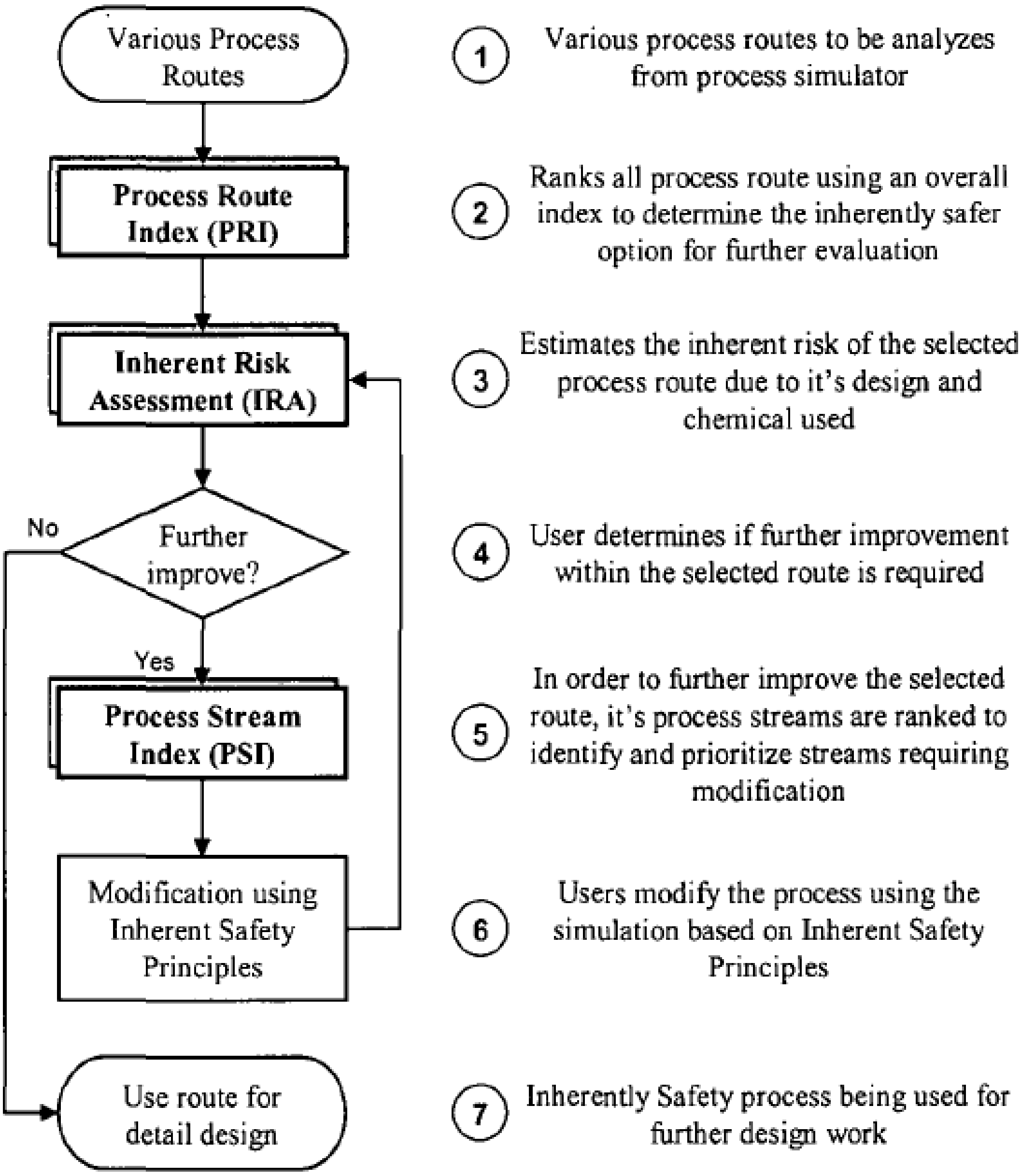


Figure 1.1 Inherent Safety Intervention Algorithms

1.2 Problem Statement

In this framework, the PSI only sees the overall risk of each stream and ranks them based on streams that need to be modified. This index can be further improved by evaluating the consequences and the frequencies of risks in the streams that are ranked highest by the PSI.

This in-depth study of the risks will help make a better judgment in choosing the safest process stream in a route, which in turn make the whole process safer.

1.3 Objectives

The main objectives of this project are to enhance the existing framework by:

(i) Evaluating the consequences of hazards in the streams ranked highest using the Process Safety Index.

(ii) Estimating the frequency of the hazards identified.

1.4 Scope of Study

As this project aims to enhance the previously created framework, it will continue with the work done and focus on the risk assessment of explosions. The process that will be considered will be the production of Methyl Methacrylate acid (MMA).

(i) The project will focus on Vapour Cloud Explosions.

(ii) The research will study the ruptures from process streams under steady state conditions and evaluate the consequences and frequencies of the risk.

(iii) The software used will be Microsoft Excel for data entry and risk assessment and HYSYS for process simulations.

1.5 Feasibility of Project

This project aims to extend an existing inherent safety framework by adding in the evaluation of consequence and frequency of process streams that have deemed the most inherently unsafe. The project will require extensive research on vapour cloud explosions and their analysis. It will also require the student to familiarize with software such as Aspen HYSYS and Microsoft EXCEL to carry out the evaluation.

This project is within capability of a final year student to be executed with help and guidance from the supervisor and the coordinator. The time frame is also feasible and the project can be completed within the time allocated

CHAPTER 2
LITERATURE REVIEW

2.1 Theory of Explosion

An explosion is defined as sudden and violent release of mechanical, chemical or nuclear energy from a confined space which creates a heat wave that travels at subsonic speeds. It can be classified as detonation or deflagration depending on the speed of the accelerating flame fronts. If the flame front moves above the speed of sound (≤ 2000 m/s), then the explosion is called a detonation. Otherwise, it is a deflagration (≤ 100 m/s).

Explosions in the process plants usually happen due to the loss of containment of pressurized fluids, the rapid combustion of a flammable material or uncontrolled reaction between chemicals. Explosions are one of the highest causes of damages in gas and petrochemical plants.

2.1.1 Vapour Cloud Explosions (VCE)

Vapour cloud explosions (VCEs) are serious hazards in the refining and oil and gas industries. These occur when a large quantity of flammable gas or vapour is accidentally released into the atmosphere forming a vapour cloud and if there is a delay in ignition of about 5-10 minutes, it may cause a vapour cloud explosion. These leaks may occur through pipe failures and equipment failures but also often occur through human error

Table 2.1: Types of Explosions

Types of Explosions	***Features***
Chemical Explosion	Uncontrolled chemical reaction leading to the failure of vessel causing overpressure.
Physical Explosion	Due to overpressure in vessels causing release. No chemical or nuclear reactions take place.
Boiling Liquid Expanding Vapour Explosions (BLEVE)	Occurs if a vessel ruptures which contains a liquid at a temperature above its atmospheric-pressure boiling point.
Vapour Cloud Explosion (VCE)	Occurs when a flame front propagates through a mixture of air and flammable gas or vapour.

The major damages caused by these explosions are due to the overpressure created from the fast expansions and the combustion of the released material. This phenomenon causes damages to people, equipment and facilities.

This occurrence can also be referred to as an unconfined vapour cloud explosion. While unconfined VCEs are possible, most of the times, there are some restrictions in pressure involved by surrounding structures adding onto the intensity of the explosion.

2.2 Methyl Methacrylate Acid

Methyl methacrylate (MMA) is an organic compound with the formula CH_2=C(CH_3)$COOH_3$. It is a colourless liquid and has an acrid and fruity smell.It is one of the most produced methacrylate monomer.

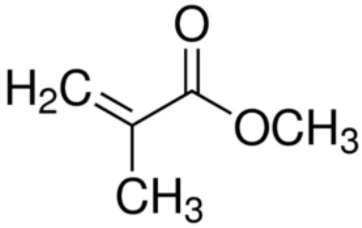


Figure 2.1 Molecular Structure of MMA

It is used in the manufacture of methacrylate resins and plastics (e.g., Plexiglas). The principal uses of methyl methacrylate are: cast sheet and other grades (advertising signs and displays, lighting fixtures, glazing and skylights, building panels and sidings, and plumbing and bathroom fixtures), molding/extrusion powder, and coatings (latex paints, lacquer, and enamel resins). Methyl methacrylate is used to make concrete water-repellent, and also has uses in the fields of medicine and dentistry to make prosthetic devices and as a ceramic filler or cement.

Figure 2.2 Products of MMA

This chemical is most commonly produced using the Acetone Cyanohydrin route, with acetone and hydrogen cyanide as raw materials, and ammonium bisulphate as by-products.

Many new methods for MMA production also have been created. These processes are based upon C2 (ethylene) or C4 (butene). These processes were come up with to replace the commonly used ACH route due to the unwanted by-products created and also to avoid the handling of highly corrosive material.

CHAPTER 3
METHODOLOGY

3.1 Project Methodology

This is an experimental project using computer simulations. Hence, the analysis will be focused on the results obtained from the simulations done using HYSYS and Microsoft Excel. The results gained will be analyzed and justified accordingly.

3.2 Research from literature

The first phase of this project was started by studying the Inherent Safety Intervention Framework (ISIF) created by Dr. Chan Tuck Leong. Then all the relevant literature related to inherent safety, Process Stream Index (PSI), Methyl Methacrylate Acid (MMA) production and Vapour Cloud Explosions (VCEs) were collected and studied.

3.3 Simulation work and Project activity

In this project, the process routes of producing MMA will be simulated using the HYSYS software. The simulations will provide crucial process data. These values will be put into an Excel spreadsheet template with formulas that will calculate the PRI of the process route. A larger PRI value will indicate a less inherently safer process route. After the process routes are evaluated using the PRI. The process streams in that route will be looked over

The PSI evaluates every process stream based on the heating value, pressure value, density value and the flammability level of those streams. The streams with higher values of PSI will be less inherently safe. After the PSI evaluation, the extension of the project will look at the consequences and frequencies of the hazard of the streams that are the most unsafe and evaluate them to verify if the calculated risk is within the accepted range.

3.4 Simulation Framework

This project aims to enhance the framework shown in Figure 1. This framework focuses on explosion hazards. To make the most efficient use of this framework, it is important to provide important information regarding the process at the earliest stage of the design process. Some of the process parameters that will be used are:

- Temperature
- Pressure
- Composition of the fluid being processed
- Density
- Heat of combustion.

Enhanced Inherent Safety Intervention Framework Algorithm

This algorithm shows the extension added to the previously developed framework in Figure 1. In the enhanced framework, the consequences and the frequencies of the hazards in streams ranked highest by the PSI will be evaluated. The algorithm shows the continuation of the framework after the routes have been selected using the Process Route Index (PRI)

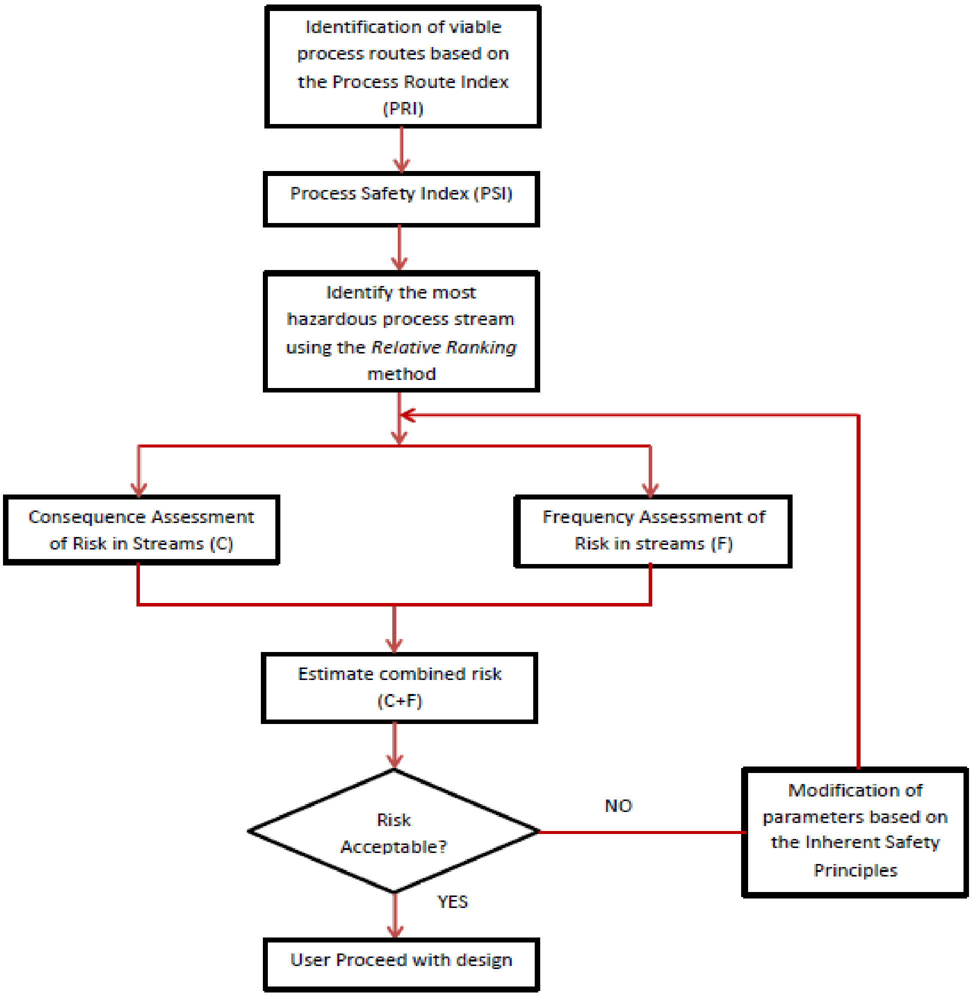


Figure 3.1 Enhanced ISIF Algorithm

As per the developed algorithm, after the process routes are selected using the PRI, the process streams of the selected routes will be evaluated using the PSI. These streams will be ranked using the ***Relative Ranking*** method which means that after the PSI values for each of the streams will be calculated, they will be ranked from the lowest values to the highest. The streams with the highest values are the ones that pose the most risk that can be caused by ruptures.

After the streams with the highest PSI values have been identified, the consequences of the hazard and their frequencies will be evaluated. The combined evaluated risk of consequences and frequencies will be calculated. This combined risk will be an indicator of whether the risk is within the acceptable limit.

If the risk is in acceptable levels, the proposed stream will be sent for detailed design. If the risk levels are too high, then the parameters for the consequence or frequency (or both) will be reiterated based on the Inherent Safety Principles to get an acceptable risk value.

Process Stream Index

After the evaluation of the process routes which is done in the previous work, the evaluation of the process stream is performed using the Process Stream Index. To make an unbiased comparison between the streams for a particular property, a particular property of the stream is compared against the average value of the property in the simulation.

- Heating Value

$$I_e = \frac{\text{heating value of individual stream}}{\text{average heating value of all streams}} \quad (1)$$

- Pressure Value

$$I_P = \frac{\text{pressure value of individual stream}}{\text{average presssures of all streams}} \quad (2)$$

- Density Value

$$I_\rho = \frac{\text{density value of individual stream}}{\text{average density of all streams}} \quad (3)$$

- Flammability Limit

$$I_{FL} = \frac{\Delta \text{FL of individual stream}}{\text{average } \Delta \text{FL of all streams}} \quad (4)$$

These dimensions can be used to differentiate the streams when considering the parameters individually and they can also be combined to give and index that reflects the severity of a process stream in case of leakages that may lead to fires and explosions.

$$\text{PSI} = 10 \times (I_P \times I_\rho \times I_e \times I_{FL}) \quad (5)$$

Since the individual numbers are dimensionless and are of small values, a multiplier of 10 is used to enlarge the number to ease evaluation. Using this index, the users can easily identify the streams that pose the highest risk.

PROCESS STREAM INDEX (PSI)										
STREAM	*DESCRIPTION	PRESSURE		DENSITY		HEAT OF COMBUSTION		FLAMMABILITY LIMIT		PSI
		bar	I_p	kg/m^3	I_ρ	kJ/kg	I_e	%	I_{FL}	
1	CRV 101- Feed	4.864	1.17967	10.25	0.01424	-3999	1.05393884	5.6	0.4646137	0.00822515
2	O2 to CRV 101	4.864	1.17967	6.075	0.00844	9.164	-0.00241518	2.03	0.1684225	-4.04956E-06
3	CRV 101- Bottom	4.864	1.17967	3051	4.23832	-737.6	0.19439492	13.31	1.1042873	1.073301389

Figure 3.2: Process Stream Index Evaluation Spreadsheet Sample

Consequence Analysis

A few major accidents such as the Buncefield explosion and the incident at the Petroleum Oil Lubricants in Jaipur, India are causes that have led to the development of various methods to predict the possible consequences associated to VCEs and to ensure the safe design of existing and new installations.

Some of the factors that influence the development and the intensity of the explosion are (Viitala & Hyyppa, 2013):

- The type and the quantity of the flammable substance
- The time span from the onset of the leakage till the ignition
- The configuration of the space where the leakage took place
- The position and number of ignition sources in relation to the place of leak

However, through the various studies done, it has been established that rather than the size of the vapour cloud, the degree of confinement of the cloud is a bigger factor when it comes to the blast strength. Therefore, it is important to evaluate the overpressure and the obstructed regions of the vapour cloud. These estimations are usually done via empirical methods, phenomenological models or computational fluid dynamic models. For this project, the empirical methods were chosen to maintain the simplicity of the evaluation. The two most commonly used empirical methods are the TNT equivalent method and the TNO Multi Energy Method.

(i) TNT Equivalent Method.

TNT equivalent method equates the power of the vapour cloud explosion to an equivalent mass of TNT that would produce the same explosive power (Soman & Surdararaj, 2012). Which means that when using the TNT method, it is assumed that the fuel-air mixture is an explosive in itself. However, recent studies have shown that a fuel air mixture is only explosive under appropriate conditions; which is when there is partial confinement or the presence of obstructions. Therefore, the TNT method is not the most accurate measure of the effects of a vapour cloud explosion.

(ii) TNO Multi-Energy Method.

To rectify the shortcomings of the TNT equivalent method, The Netherlands Organizations for Applied Scientific Research (TNO) has come up with the Multi-Energy method. This method assumes that the vapour cloud explosion consists of a number of smaller explosions taking place inside specific areas of the cloud, which are resultant of the various sources of blasts that exist in the cloud. The most vital assumption is the strength of the explosion blast where the obstructed regions of the cloud will result in a high strength explosion blast and the remaining portions of the cloud will slowly burn without any major contributions to the blast strength. Therefore, this method was chosen to be employed to perform the consequence analysis of the blasts as follows:

A. Cloud Dimension.

The volume, V (m^3) of the vapour cloud is calculated. It can either be found using the reaction's stoichiometry, based on the volume of the container of the vapour, dispersion model or, the cloud is considered as a hemisphere and the volume is found using the following equation:

$$V = \frac{Q_{ex}}{(\rho \times c_s)} \quad (6)$$

Where:

Q_{ex} = Flammable Mass Quantity
ρ = Density
c_s = Stoichiometric Concentration

However, the current research will be adopting a simple approach to estimate the consequences in the preliminary stages, so the dispersion modeling and volume calculation is intentionally left out.

B. Explosion Mass

Estimation of the explosion mass is done by using the following equation:

$$\frac{m_f}{m} = \text{erf}\left[\sqrt{\ln\left(\frac{C_o}{C_{LFL}}\right)}\right] - \frac{2C_{LFL}}{C_o\sqrt{\pi}}\sqrt{\ln\left(\frac{C_o}{C_{LFL}}\right)} \qquad (7)$$

Where:

C_{LFL} = Lower Flammability Limits of mixture

C_{UFL} = Upper Flammability Limits of mixture

C_o = Initial concentration of mixture

m_f = Flammable mass fraction

m = Mass released

If the initial concentration of the mixture is greater than the upper flammability limit, the mixture will be out of the flammability limit and therefore wouldn't explode. However, it is also assumed that the concentration of mixture will fall within the flammability limits and thus create a possible explosive condition. Therefore, the C_o has to be larger than the C_{LFL}.

C. Energy of Explosion

The energy, E (MJ) released by the explosion is calculated using the equation:

$$E = \Delta H_c \times m_f \qquad (8)$$

Where:

ΔH_c = the combustion energy (J/kg)

m_f = explosive mass

D. Scaled Distance

The blasts from vapour cloud explosions are modeled by the specification of an idealized explosive charge whose blast characteristics are available in the form of charts shown in Appendix A. These charts have lines representing ten different blast strengths with line 1 being the weakest and 10 being the strongest. It has been established that line 7 seems to be more accurately representing actual hydrocarbon explosions, however a strength of 10 can be used when a detonation is to be assumed to derive the most conservative overpressure.

The Sachs scared distance is calculated using:

$$\overline{R} = \frac{R}{(E/P_o)^{1/3}} \tag{9}$$

Where:

$\overline{R}$ is the Sachs-scaled distance from charge (dimensionless)

R is the distance from charge (m)

E is the charge combustion energy (J)

P_o is the ambient pressure, (Pa)

E. Side On Overpressure

The Sachs side on overpressure is related to the actual side-on overpressure by:

$$P_s = \Delta\overline{P}_s \times P_o \tag{10}$$

Where:

P_s is side-on blast overpressure (Pa)

$\Delta\overline{P}_s$ is the Sachs-scaled side-on overpressure (dimensionless)

P_o is the ambient pressure (Pa)

F. Evaluation of Damage and Injuries caused

The damages and injuries caused by the overpressure can be calculated using probit functions. In the following equation, the probability of a certain event occurring has been related to the probit values that can be found using the overpressure.

$$P = 50\left[1 + \frac{P_r - 5}{|P_r - 5|}\,\mathrm{erf}\left(\frac{|P_r - 5|}{\sqrt{2}}\right)\right] \qquad (11)$$

Where:

P_r = probit variable, which depends on type of hazard, damage and injuries
P = probability or percentage
erf = error function (computed within spreadsheet)

The probit variable Pr was calculated using the following formula

$$P_r = a + b.\ln(P_s) \qquad (12)$$

Where:

P_r = probit variable
a, b = constants
P_s = overpressure f

The constants are predetermined and are given by Salzano and Cozzani (2005) and The Netherlands Organization (TNO):

Table 3.1: Probit Equation Constants

Case	Constant	
	a	b
Structural damage due to overpressure	-23.8	2.92
Glass breakage due to overpressure	-18.1	2.79
Death from lung hemorrhage due to overpressure	-77.1	6.91
Eardrum rupture due to overpressure	-15.6	1.93
Damage to atmospheric vessels due to overpressure	-18.96	2.44
Damage to pressurized vessels due to overpressure	-42.44	4.33
Damage to elongated vessels due to overpressure	-28.07	3.16
Damage to small equipment due to overpressure	-17.79	2.18

Frequency Analysis

The frequency analysis measures the likelihood of a certain event occurring and also the likelihood of the consequences of that event. In this project, the frequency of the resulting consequences of a VCE will be measured. There are many methods of evaluating frequencies. The most common ones are the Fault Tree Analysis (FTA) and the Event Tree Analysis (ETA).

(i) Fault Tree Analysis

The fault tree analysis is a top down, deductive failure analysis in which an undesired event is broken down into its contributing factors. Then, combination of all the events and conditions are investigated to find what leads to the hazard. This analysis uses graphical symbols for the ease of understanding to represent the events that lead to a system failure.

In the FTA, the system failure is considered as the top from which the analysis starts. The FTA basically has three logical possibilities:

i. The AND gate: all the inputs need to occur for the output to occur.
ii. The OR gate: any one of the inputs has to occur for the output
iii. The VOTED gate: two or more of the inputs need to occur for the output.

Although, the evaluation method is simple, it needs a certain amount of expertise to be conducted and the tree may grow rapidly depending on the event which may add on complexities to the analysis.

(ii) Event Tree Analysis

Unlike the Fault Tree Analysis, the Event Tree Analysis is a forward thinking process and it starts off with the resulting events and works up to the accident. These initiating events can range from equipment failure, process disturbances to human error. In this method, the tree is started off at the left with the initiating event and then the failure probabilities are branched out to the right. The probability of success or failure of a control event are defined.

Just like the Fault Tree Analysis, the ETA has a tendency to grow large and complex and there might be times when a few branches may go missing. However, it is easier to detect a mistake in this analysis as the combination of all the possibilities of a control event should sum up to one. The ETA technique also has been proven to be able to better represent the agents of a failure in comparison to the FTA technique especially for events that are sequential in nature such as explosions. So, for the frequency analysis of the consequences, the ETA method is chosen in this project.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Process Safety Index

The process safety index for all the 23 streams of the TBA method of producing MMA was calculated using MS Excel. After the evaluation, based on relative ranking, the Methanol stream proved to be the most inherently unsafe with a PSI value of 8.47 in a range of mostly smaller values.

PROCESS STREAM INDEX (PSI)										
STREAM	*DESCRIPTION	PRESSURE		DENSITY		HEAT OF COMBUSTION		FLAMMABILITY LIMIT		PSI
		bar	I_p	kg/m^3	I_ρ	kJ/kg	I_e	%	I_{FL}	
18	Methanol	7.093	1.72027	737.5	1.0245	-7307	1.92576421	30.1	2.4972988	8.475874966

Figure 4.1: PSI analysis of Methanol Stream

So, this stream was chosen to perform the consequence and frequency analysis on.

4.2 Consequence Analysis

The consequence analysis calculations were also carried out using an excel spreadsheet.

4.2.1 Explosion Mass

For calculating the explosion mass, the flammable fraction needs to be calculated. The values of C_o = 23 mol/dm^3 and C_{LFL} = 5.9 were used to find the flammable fraction.

						C_o mol/dm3	C_{LFL} %
A. EXPLOSION MASS						23	5.9

$$\frac{m_f}{m} = \mathrm{erf}\left[\sqrt{\ln\left(\frac{C_o}{C_{LFL}}\right)}\right] - \frac{2C_{LFL}}{C_o\sqrt{\pi}}\sqrt{\ln\left(\frac{C_o}{C_{LFL}}\right)}$$

Flammable fraction =		0.563344

Figure 4.2: Flammable Fraction Calculation

4.2.2 Energy Of Explosion

After the explosion mass was found, the energy of explosion was calculated:

B. ENERGY OF EXPLOSION							
$E = \Delta H_c \times m_f$						ΔHc	mf
						22700000	0.867841
E =	19700000 J						

Figure 4.3: Energy of Explosion Calculation

4.2.3 Scaled Distance

The sach's scaled distance is needed to calculate the scaled overpressure which will be used to find the probit equations that evaluate the consequence.

C. SCALED DISTANCE							
					R	E j/h	P_0
					50	19700000	101325
	0.77151						

$$\overline{R} = \frac{R}{(E/P_o)^{1/3}}$$

Figure 4.4: Scaled Distance Calculation

The distance from charge (R) was assumed to be 50 m.

4.2.4 Side On Overpressure

Using the scaled distance calculated, the scaled overpressure was determined using the graph to be around 0.9.

	ΔP	From the graph
D. SIDE ON OVERPRESSURE	0.9	
$P_s = \Delta \overline{P}_s \times P_o$		
91192.5 Pa		

Figure 4.5: Side on overpressure calculation

4.2.5 Probability/Percentage Of Event

The percentage of an event occurring was calculated as described in chapter 3. The formulae were entered into the excel sheets to calculate the percentage of a certain event occurring based on the side on overpressure that has been calculated.

Case	Constant a	Constant b	Probit Variable (P_r)
Structural Damage due to overpressure	-23.8	2.92	9.548525573
Glass breakage due to overpressure	-18.1	2.79	13.76383094
Death from lung hemorrhage due to overpressure	-77.1	6.91	1.817230037
Eardrum rupture due to overpressure	-15.6	1.93	6.442004916
Damage to atmospheric vessels due to overpressure	-18.96	2.44	8.906576163
Damage to pressurised vessels due to overpressure	-42.44	4.33	7.011751962
Damage to elongated vessels due to overpressure	-28.07	3.16	8.019500277
Damage to small equipment due to overpressure	-17.79	2.18	7.1071869

Figure 4.6(a): Probit Variable Calculation

P_r - 5	Pr - 5/|Pr-5|	|Pr - 5|/sqrt2	ERF|Pr - 5|/sqrt2	Probability/Percentage
4.548525573	1	3.216293277	0.999994598	99.99972988
8.763830941	1	6.196964288	1	100
-3.182769963	-1	2.250558224	0.998541265	0.072936729
1.442004916	1	1.019651455	0.850699013	92.53495066
3.906576163	1	2.762366496	0.999906387	99.99531934
2.011751962	1	1.422523455	0.95575391	97.7876955
3.019500277	1	2.135109122	0.997468079	99.87340397
2.1071869	1	1.490006146	0.964898618	98.2449309

Figure 4.6(b) : Percentage of Event Calculation

As per the spreadsheet, it can be seen that the event of glass breaking due to overpressure is most likely to happen. Therefore, this event will be further evaluated using the Event Tree Analysis to determine the frequency of the event.

4.3 Frequency Analysis

The frequency analysis was performed using the Event Tree Analysis technique. Here, the initiating event will be the explosion itself and the final event will be the breakage of glass due to the explosion. Since there was no safety instrumentations specified, a human failure scenario was considered as the second event in the analysis.

The length of the pipe was assumed to be 25 meters and the diameter 100mm. The scenario is the rupture of the Methanol pipeline.

The exposure frequency was calculated based on the following equation:

Exposure frequency = base failure frequency x length x time

$= 3E^{-7}$ x 25m x 1 year

$= 7.5 \times 10^{-6}$

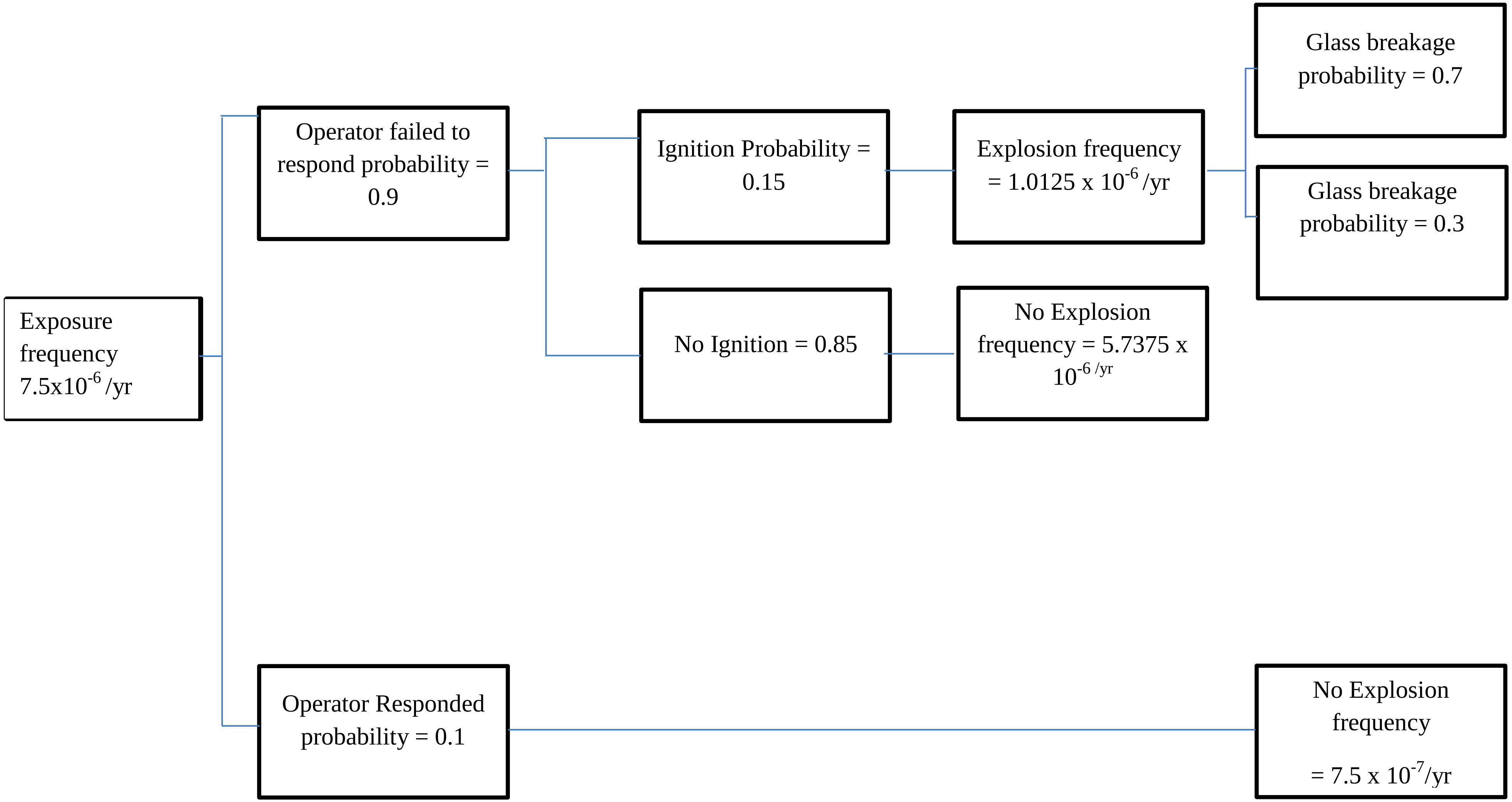


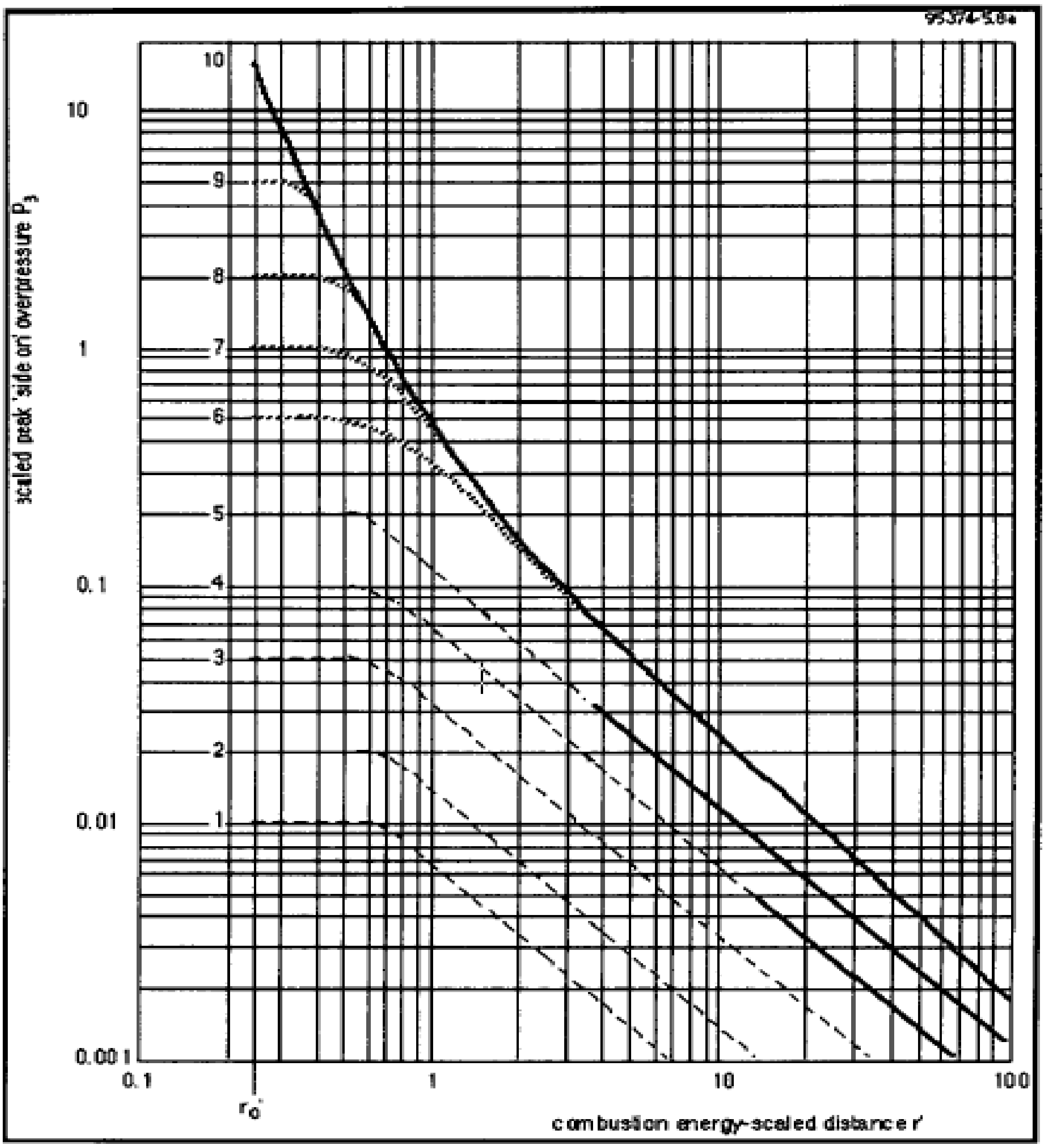
Figure 4.7: ETA analysis

So, the frequency of glass breaking due to an explosion is: 7.0875×10^{-7}/yr

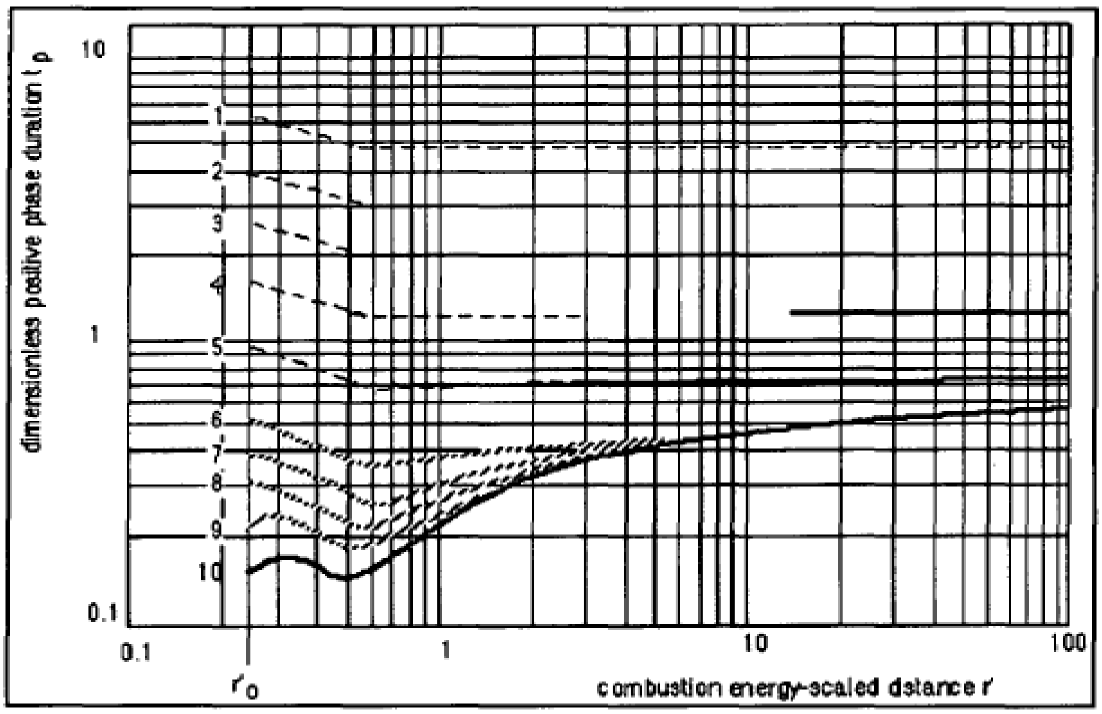
CHAPTER 5
CONCLUSION

To conclude, the main objective of the project is to enhance the Inherent Safety Intervention Framework (ISIF). This framework will be further developed to gauge the consequences and the frequencies of the risks in the streams that have been ranked highest as per the Process Safety Index (PSI). The risk analysis will be focused on Vapour Cloud Explosions that may occur in the process of Methyl Methacrylate acid (MMA) production. Software such as Microsoft excel and HYSYS will be utilized for performing this study. For the consequence analysis of the study, the TNO multi energy method will be employed. The frequency analysis is done using the Event Tree Analysis (ETA). After the consequence analysis, it was found that the Methanol stream was the most inherently unsafe. The stream was further analyzed to find that the probability of glass breaking during an explosion is the highest. The frequency of this event occurring due to an explosion was calculated to be 7.0875×10^{-7}/year.

APPENDIX A



APPENDIX A1: Sachs overpressure vs. scaled distance graph

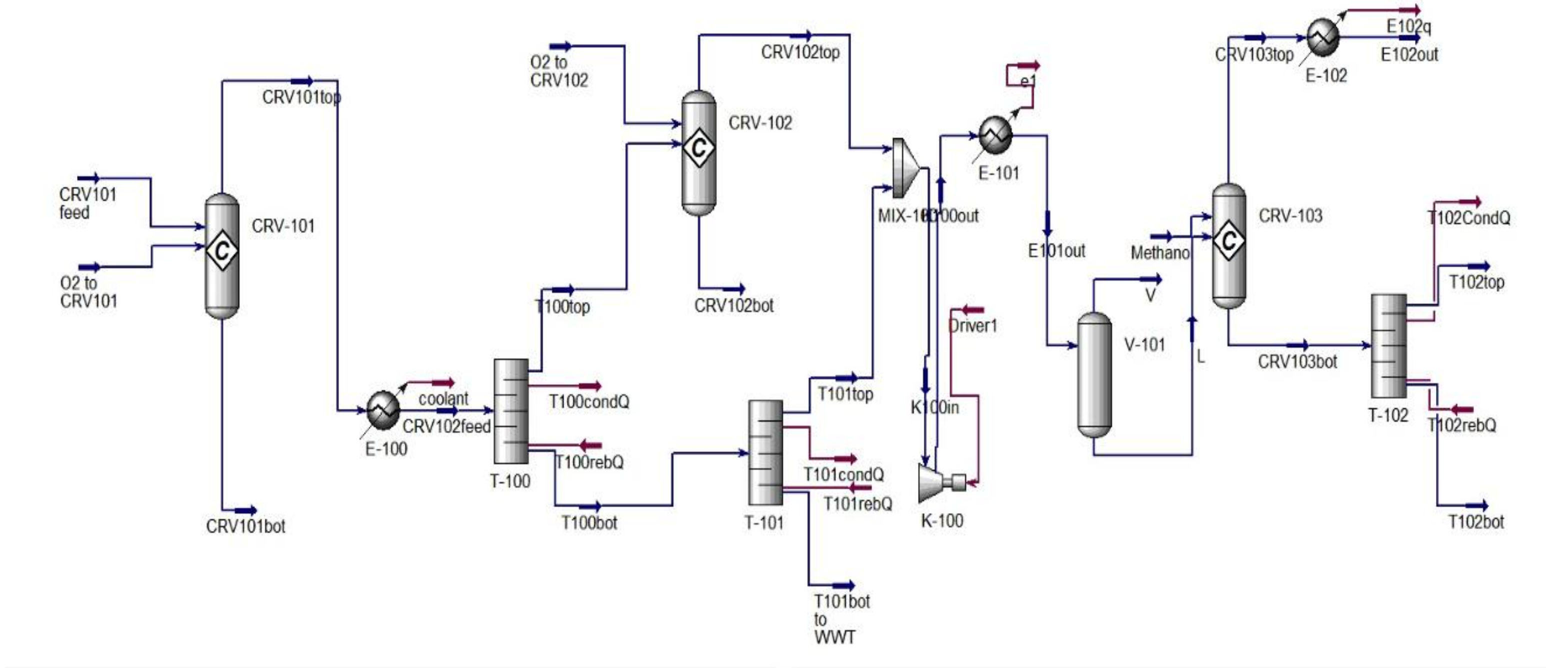


APPENDIX A2: Sachs dimensionless positive phase duration vs. scaled distance

APPENDIX B

PROCESS STREAM INDEX (PSI)										
STREAM	*DESCRIPTION	PRESSURE		DENSITY		HEAT OF COMBUSTION		FLAMMABILITY LIMIT		PSI
		bar	I_p	kg/m^3	I_ρ	kJ/kg	I_e	%	I_{FL}	
1	CRV 101- Feed	4.864	1.17967	10.25	0.01424	-3999	1.05393884	5.6	0.4646137	0.00822515
2	O2 to CRV 101	4.864	1.17967	6.075	0.00844	9.164	-0.00241518	2.03	0.1684225	-4.04956E-06
3	CRV 101- Bottom	4.864	1.17967	3051	4.23832	-737.6	0.19439492	13.31	1.1042873	1.073301389
4	CRV 101 - Top	4.864	1.17967	1.157	0.00161	-2790	0.73530617	13.31	1.1042873	0.001539558
5	CRV 102 - Feed	3.749	0.90925	3.439	0.00478	-5479	1.44399372	11.61	0.9632438	0.006041824
6	T 100 Bottom	3.500	0.84886	883.9	1.22788	-9755	2.57093608	22.16	1.8385429	4.926689159
7	T 100 Top	3.500	0.84886	707.1	0.98227	-2584	0.68101474	7.63	0.6330362	0.359461914
8	O2 to CRV 102	0.035	0.00851	1648	2.28933	-2643	0.69656423	-0.2	-0.0165933	-0.000225257
9	CRV 102 - Bottom	3.500	0.84886	3353	4.65784	-2008	0.5292096	0.2	0.0165933	0.034720203
10	CRV 102 - Top	3.500	0.84886	3.022	0.0042	-2620	0.69050256	8.38	0.6952613	0.001710782
11	T 101 - Top	3.500	0.84886	813.5	1.13008	-4082	1.07581354	22.15	1.8377133	1.896528121
12	T 101 Bottom to WW	3.500	0.84886	913.8	1.26941	-1.534	0.00040429	-0.000475	-3.941E-05	-1.71682E-08
13	K 100 - In	3.500	0.84886	3.615	0.00502	-2907	0.76614159	14.85	1.2320561	0.004023785
14	K 100 - Out	10.000	2.42531	9.618	0.01336	-2768	0.72950805	12.52	1.0387436	0.024555125
15	E 101 - Out	10.000	2.42531	225	0.31256	-4309	1.13563952	19.6	1.6261481	1.399916195
16	V	2.000	0.48506	2.816	0.00391	-577.8	0.15227954	19.78	1.6410821	0.000474191
17	L	2.000	0.48506	931.3	1.29372	-4514	1.1896674	19.78	1.6410821	1.225164473
18	Methanol	7.093	1.72027	737.5	1.0245	-7307	1.92576421	30.1	2.4972988	8.475874966
19	CRV 103 - Top	2.000	0.48506	3.423	0.00476	-4794	1.26346156	8.21	0.6811569	0.001985021
20	E 102 - Out	2.000	0.48506	783.6	1.08854	-5618	1.48062726	9.23	0.765783	0.598680087
21	CRV 103 - Bottom	2.000	0.48506	855.1	1.18787	-5385	1.41921997	8.21	0.6811569	0.557009652
22	T 102 - Top	5.000	1.21266	853.3	1.18537	-8840	2.32978728	22.06	1.8302463	6.129379015
23	T 102 - Bottom	5.000	1.21266	757.3	1.05201	-3560	0.93824013	6.7	0.5558772	0.665349318
	Average:	4.123		719.8615		-3794.33783		12.0530228		

Appendix B1 : PSI Calculation Spreadsheet



Appendix B2 : HYSYS Simulation of TBA route.

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