

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**AN INVESTIGATION ON HAZARD AND OPERABILITY STUDY (HAZOP)
ACCORDING TO SEVESO III DIRECTIVE AND SPECIAL CASE STUDIES**



M.Sc. THESIS

Pelin GÜN

Department of Chemical Engineering

Chemical Engineering Programme

DECEMBER 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**SEVESO III DİREKTİFİ KAPSAMINDA YAPILAN TEHLİKE VE
İŞLETİLEBİLİRLİK ANALİZİ (HAZOP) ÇALIŞMALARININ İNCELENMESİ
VE ÖZEL ÖRNEKLEMELER**

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Date of Defense: 23 December 2016



FOREWORD

I would like to express my gratitude and thanks to my thesis advisor Asst. Prof. Dr. Hikmet İSKENDER for his guidance, support and kind advice throughout my research for this thesis.

I would like to thank to my family for their unconditional support and love.

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ABBREVIATIONS

NFPA	: National Fire Protection Association
BLEVE	: Boiling Liquid Expanding Vapor Explosion
UVCEs	: Unconfined Vapor Cloud Explosions
CHIP	: Chemicals Hazard Information and Packaging Regulation
CLP	: Classification, Labelling and Packaging Regulation
GHS	: Global Harmonised System
BEKRA	: Reducing The Risks of Major Industrial Accidents Legislation
CFD	: Computational Fluid Dynamics Models
PHA	: Preliminary Hazard Analysis
FMEA	: Failure Modes and Effects Analysis
HAZOP	: Hazard and Operability Study
FTA	: Fault Tree Analysis
ETA	: Event Tree Analysis
ERA	: Human Reliability Analysis
P&IDs	: Process/Piping and Instrumentation Drawings/Diagrams
ALOHA	: Areal Location of Hazardous Atmosphere Software
PHAST	: Process Hazard Analysis Software
FLACS	: Flame Acceleration Software
CHARM	: Complex Hazardous Air Release Software
ADORA	: Atmospheric Dispersion of Reacting Agents
GIS	: Geographic Information Systems
CAMEO	: Computer-Aided Management of Emergency Operations
EPA	: United States Environmental Protection Agency
NOAA	: National Oceanic and Atmospheric Administration



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AN INVESTIGATION ON HAZARD AND OPERABILITY STUDY (HAZOP) ACCORDING TO SEVESO III DIRECTIVE AND SPECIAL CASE STUDIES

SUMMARY

Big hazardous events can happen because of a technical failures, personal failures, natural disasters, terrorist attacks, sabotages, fires and consequences as fire, explosion and toxic release can be dangerous to the human health, environment and cause economic loss. Determination, prevention and control of these consequences are very important.

A major industrial event happened in Seveso (Italia) in 1976 because of an explosion occurred in a reactor of a chemical plant and caused human health problems and death of animals. After this accident, 82/501/EEC Directive (SEVESO I) released by the European Union for the control and prevention of major accidents. SEVESO II (96/82/EC) Directive released in 1996 and extended in 2003 (2003/105/EC Directive). On January 2016, Seveso III (2012/18/EU) Directive replaced the SEVESO II Directive.

The main changes from Seveso II to Seveso III are:

- The list of dangerous substances covered by the SEVESO Directive (Annex I), which bases on Chemicals Hazard Information and Packaging for Supply Regulations 2009 (CHIP), is organized for aligning to the EU Legislation (Classification, Labelling and Packaging (CLP) Regulation) on the classification of dangerous. CLP Regulation entered in the force in January 2009 and provides the hazards presented by the chemical materials are clearly informed to workers and consumers in EU through classification and labelling of chemicals with basing the method of the United Nations' Globally Harmonised System (GHS).
- More effective implementation and enforcement for inspections with introducing stricter standards and new obligation for the relevant departments of government's.
- Citizen's access to true information about big hazardous accidents and more efficient participation in decision-making will ensure.
- The way of information collected, managed and shared will improve.

On 30 December 2013, SEVESO II came into force in Turkey with publishing in the Official Gazette No.28867.

In Turkey, according to Reducing The Risks Of Major Industrial Accidents Legislation (Büyük Endüstriyel Kaza Risklerinin Azaltılmasına ilişkin mevzuat – BEKRA), companies must make a statement about the dangerous materials they used and/or stored and their quantities using BEKRA Reporting System to get classification as high dangerous, low dangerous or out of scope. Turkey has 421 high dangerous and 521 low dangerous classified, total 942 SEVESO companies (December 2015).

Safety assessments and precautions are undertaken by the industries and organizations for determination and prevention of the hazards occurred by the accidental cases resulting injuries, deaths, economic loss, environmental problems.

Risk assessment is an important study which includes the stages as hazard identification, definition, analysis and risk evaluation giving understanding of their causes, results and possibilities and simulation softwares are help us to see the effects of possible hazards.

Hazard identification can be done using Qualitative Techniques which are Preliminary Hazard Analysis (PHA), What-If Analysis, Check-List Analysis, Failure Modes and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP) or using Quantitative Techniques such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA). Simulation can be done using Areal Location Of Hazardous Atmosphere (ALOHA) Software, Process Hazard Analysis (PHAST) Software, BREEZE, EFFECTGIS, FLACS, CEBAM, SAFER TRACE, BLEVE Incident Simulator (BIS), AUTOREAGAS, CHARM, ADORA, HAMS-GPS softwares.

In this study, hazards, risks, hazard identification methods, hazard evaluation models and modelling softwares for industrial facilities are examined and used for the case studies with Hazard and Operability Study (HAZOP) methodology and Areal Location Of Hazardous Atmosphere (ALOHA) software under the SEVESO Directive scope for prevention and control of big hazardous events at chemical industries and application of SEVESO III Directive in Turkey.

SEVESO III DİREKTİFİ KAPSAMINDA YAPILAN TEHLİKE VE İŞLETİLEBİLİRLİK ANALİZİ (HAZOP) ÇALIŞMALARININ İNCELENMESİ VE ÖZEL ÖRNEKLEMELER

ÖZET

İlerleyen teknoloji, artan üretim ve endüstriyel atıkların artması ile birlikte günümüzde üretim yapmak, yeniden değerlendirmek, imha etmek ya da depolamak üzere endüstrilerde bulunan kimyasal maddelerin miktarı artmıştır. Özellikle üretim, laboratuvar ve depo alanlarında hammadde, yarı mamul ve ürün olarak bulunan bu kimyasalların, hem kendi doğal durumları, yoğunlukları, çeşitliliği, hem de dış etkenler, dikkatsizlik ve kazalar ile canlılar ve çevre üzerinde geri dönüşü mümkün olmayan etkiler bırakan bazı büyük kaza ve kirlilikler meydana getirebilme riskleri bulunmaktadır. Ekipman bozuklukları, insan kaynaklı hatalar, doğal afetler, terör olayları, yangınlar, sabotaj, teknik problemler gibi nedenler tehlikeli kazaların meydana gelmesine yol açabilmektedir.

Örneğin Çin'in Tiancin kentinde Yeni Binhay bölgesinde, Ağustos 2015'te gece saatlerinde, tehlikeli kimyasal maddelerin saklandığı bir depoda arka arkaya iki büyük bir patlamanın meydana geldiği olayda birçok kişi yaşamını yitirmiş, yaralanmış, büyük maddi zarar oluştuğu belirtilmiştir.

Gelişen teknoloji, artan üretim ve tüketim, yasal bazı zorunluluklar ile birlikte endüstriler ve kuruluşlar, endüstriyel kazaların ortaya çıkma olasılığının en aza indirilmesi, can ve güvenliğinin sağlanarak kayıplarının en aza indirilmesi için önlem almaya ve müdahale yöntemleri belirlemeye başlamıştır.

1976 yılında İtalya'nın Seveso kasabasında Triklorofenol üretimi yapan bir fabrikada meydana gelen kaza sonrası toksik bulut ortama yayılarak insan sağlığı, hayvan sağlığı ve çevre problemlerine yol açmasından sonra büyük endüstriyel kazaların kontrolü ve önlenmesi için önemli direktifler ve önlemler geliştirilmiştir ve bu kapsamda Avrupa Birliği tarafından SEVESO Direktifi olarak bilinen 82/501/EEC Direktifi (SEVESO I) yayınlanmıştır. Bu tarihten sonra gerçekleşen olaylar, artan bilgi birikimi ve yaşanan kazalardan öğrenilenler ile çeşitli değişiklikler yapılarak 1996 yılında 96/82/EC (SEVESO II) Direktifi yayınlanmıştır. Daha sonra 2003 yılında 2003/105/EC (Genişletilmiş SEVESO II) Direktifi yayınlanmıştır. En son SEVESO III (2012/18/EU) Direktifi, 1 Ocak 2016 itibarıyla SEVESO II'nin yerini almak üzere yayınlanmıştır. SEVESO Direktifi'nin amacı genel olarak tehlikeli maddeler kullanan ve/veya bulunduran işletmelerde büyük kazaların önlenmesi ve oluşabilecek kazaların etkilerinin en aza indirilmesi için gerekli çalışmaların yapılması için gerekli usul ve esasların belirlenmesidir.

SEVESO III'te yer alan temel değişiklikler şu şekildedir:

- Tehlikeli maddelerin tanımlandığı EK 1 kısmı, maddelerin sınıflandırılması ile ilgili Avrupa Birliği Mevzuatına uyumlu hale getirilecektir.

Jet Yangınları, yanıcı buhar ya da sıvının boruların sınırlı boyutlu açıklıklarından sızarak tutuşması ile meydana gelen yangınlardır. Havuz Yangınları, su üzerinde, sıvı üzerinde ya da yerde havuz şeklinde toplanmış yanıcı materyallerin tutuşması sonucu meydana gelen yangınlardır. Ani Parlama Yangınları, yüksek sıcaklığa sahip, kısa süreli ve hızla hareket eden alevler ile görülmektedir. İkincil Yangınlar, depolanmış ham maddeler gibi prosesle doğrudan ilgili olmayan yanıcı materyallerin tutuşması ile ortaya çıkan yangınlardır. Ateş Topları, türbülent akış ile oluşan küresel alev kütleleridir.

Patlama, enerjinin hızlı salınımı sonucu hasara yol açan basınç dalgasıdır. Bu dalga patlamanın merkezinden uzaklaştıkça enerji azalmaktadır. Patlamalar enerjinin ortaya çıkış şekillerine göre Kimyasal Patlamalar (Enerjinin kimyasal reaksiyon sonucu ortaya çıktığı olaylar.), Fiziksel Patlamalar (Enerjinin mekanik, fiziksel yollarla ortaya çıktığı olaylar) ve Nükleer Patlamalar (Enerjinin nükleer reaksiyonlar sonucu ortaya çıktığı olaylar.) olarak sınıflandırılabilirler. Patlamalar uçan, fırlayan parçalara, sıvıların sıçrayarak havuz oluşturmalarına, yangınlara ve toksik gaz salınımlarına yol açabilmektedirler.

Toksik maddeler, vücuda alındıklarında hasara yol açabilen maddelerdir. Solunma, ten ile temas, yutma gibi yollarla kişi bu materyalleri vücuduna alabilir. Toksik maddelerin potansiyel tehlikelerinin ve maruziyet sonrası sağlık problemlerini önlemek için neler yapılması gerektiğinin bilinmesi gerekmektedir. Tehlikeli olaylardan sonra toksik bulutlar oluşabilir ve hava koşulları, rüzgar gibi etmenlerle bu tehlikeli bulutlar yayılabilmektedir ve insan sağlığı, çevre, hayvan sağlığı üzerinde istenmeyen etkilere yol açabilmektedir.

Belirlenen tehlikelerin etkilerinin önceden görülebilmesi için modelleme programları kullanılmaktadır ve yaygın olarak kullanılanlarından biri ALOHA (Areal Location Of Hazardous Atmosphere Software)'dır. Proses Tehlike Analizi Yazılımı (PHAST), BREEZE, EFFECTGIS, FLACS, CEBAM, SAFER TRACE, BLEVE Kaza Simulatörü (BIS), AUTOREAGAS, CHARM, ADORA, HAMS-GPS gibi diğer yazılımlar da modelleme amacı ile kullanılabilirler.

ALOHA programı, buhar bulutu patlamaları, kimyasal yangınlar sonucu ortaya çıkan termal radyasyon ve kimyasalların salınımı ile meydana gelen toksik hava tehlikelerinin modellenmesi amacıyla tasarlanmıştır. İçerisinde maddelerin fiziksel, kimyasal ve toksik özelliklerinin yer aldığı büyük bir kütüphanesi bulunmaktadır. Çalışılmak istenilen kimyasal bu kütüphanede yer almıyor ise o kimyasalın özellik bilgilerinin giriş yapılmasına fırsat vermektedir. Kullanımı kolaydır ve uygun olmayan girişler yapıldığında kullanıcıyı uyarmaktadır.

Bu çalışmada endüstriyel tesisler için Tehlikeler, Riskler, Tehlike Tanımlama Yöntemleri ve Tehlike Değerlendirme Modellemesi Programları irdelenerek, SEVESO direktifleri kapsamında kullanılan tehlike analizi metodolojisi HAZOP ve tehlikelerin önceden görülebilmesi için kullanılan modelleme programı ALOHA aracılığıyla yapılan örnek çalışmalar açıklanmış, kimya endüstrisinde güvenliğin artırılması ve SEVESO III Direktifi'nin Türkiye'de uygulanmasına yönelik öncelikler belirlenmiştir.



1. INTRODUCTION

Many flammable, toxic, explosive substances are stored and used for production at chemical industries. These materials can cause big hazardous accidents resulting danger to human health and/or to the environment and personal failures, equipment failures, natural disasters, nearby fires, sabotage, terrorist attacks, technical problems, maintenance problems, etc. can be the reason.

A major industrial event happened in Seveso (Italia) in 1976 because of an explosion occurred in a reactor of a chemical plant and caused human health problems and death of animals. After this accident, 82/501/EEC Directive (SEVESO I) released by the European Union for the control and prevention of major accident, SEVESO II released in 2012 and on January 2016, Seveso III replaced the SEVESO II.

Safety assessments and precautions are undertaken by the industries and organizations for determination and prevention of the hazards occurred by the accidental cases resulting injuries, deaths, economic loss, environmental problems. Risk assessment is an important study which includes the stages as hazard identification, definition, analysis and risk evaluation giving understanding of their causes, results and possibilities and simulation softwares are help us to see the effects of possible hazards.



2. TERMINOLOGY

Hazard, can be defined as dangerous material or physical situation, exist in workplace or can come from outside which has potential cause to harm human health, workplace and environment. For example, knife is tool at workplace but harm caused is cut. Three major hazards are toxic hazard, fire hazard and explosive hazard.

Hazard Identification is examination for the purpose of finding all the hazards which are inherent in the job and could cause harm in work.

Risk is the occurrence chance of losses, injuries and other unwanted results when exposed to a hazard within a specified period or in specified circumstances. Risk can be calculated as multiplying frequency with consequence.

Individual Risk is the ratio of mortality/serious injuries and the number of people exposed.

Social Risk is the relation between the expected average frequency and consequences of a hazardous incident and FN curves generally used for the expressing this relation.

Risk Management refers to coordinated activities to direct and control an organization with regard to risk. Risk Management Process includes systematic application of management policies, procedures and practices to the tasks of communicating, consulting, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk [1].

Risk Assessment is a process of identification, analysis and evaluation of the risks.

Risk Identification includes finding, recognizing and describing the risks with identification of risk sources, events, their causes and consequences.

Risk Analysis is understanding the risk character, risk level determination and likelihood.

Risk Evaluation is the determination of the whether the risk is acceptable or tolerable.

Risk Level is the magnitude of a risk expressed in terms of the combination of consequences and their likelihood [1].

Probability can be defined as a possibility of happening and shown with number between 1 (absolute certainty) and 0 (impossibility) with no unit.

Frequency is the measurement of the event happening per specified time.

Major Accident (Big Hazard Event) is an unwanted incident causing harm to human health and/or the environment.

Dispersion is the accidental release of hazardous materials.

Fire is a burning process with producing heat, light and often smoke and flames.

Thermal Radiation is a hazard because of its heating effect can cause burning injuries and/or ignite the combustible materials on the effected area depending on the exposure time.

Explosion is the blast wave resulting from a rapid release of energy.

Boiling Liquid Expanding Vapor Explosion (BLEVE) is the explosive release of pressurized liquefied gas.

Vapor Cloud Explosion is the ignition of released flammable vapor mixture with air as flammable vapor cloud producing blast overpressure.

Jet fire is the fire resulting from the combustion and ignition of a vapour, two-phase release or a flammable fluid being released from a pipe or an orifice with causing the thermal radiation.

Pool Fire is the ignition of an accumulation as pool of liquid on the water, liquid or ground.

Flash Fire is the combustion of the flammable gas cloud and air.

Secondary Fire is the ignition of the flammable substances which are not directly concerned with the process.

Fire balls are occurs because of turbulent vapour or two-phase fuel ignition in air for a short period of time.

3. MAJOR ACCIDENT (BIG HAZARD EVENT)

Major accident or **big hazard event** can be explain as an incident such a major emission, or explosion resulting from uncontrolled developments during the process and leading to important danger to human health and/or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances by SEVESO III Directive [2].

A big hazardous industrial accident happened in Seveso (Italy) in 1976 because of an explosion in a chemical reactor and toxic cloud caused human health problems and animal deaths. In 1984, an incident happened in Bhopal (India) resulting release of very toxic substance methyl isocyanate to the atmosphere and more than 2500 people died. An explosion occurred in a pyrotechnic storage area in the Netherlands in 2000 and 23 people died and almost 950 people were injured. In 2010, red toxic mud released from an industrial reservoir which collapsed and flooded several villages, people died and suffered from the toxic effect. More than hundred people died, nearly hundred people injured and large areas devastated with the explosions occurred at the warehouse which contained hazardous and flammable chemicals at Tianjin (China) in 2015.

In Turkey, 133 technological disaster was reported between 1900-2014 years with 5912 death and 278 Million Dollars economic losses [3]. One of the most big hazardous event happened after the earthquake occurred at Izmir (Turkey) in 1999 and caused fire at raw distillation unit and damage at production units at Tüpraş Petroleum Refinery causing environmental pollution and 300 Million Dollars economic losses and many people have been evacuated from the area. In 2012, hazardous fire event happened at a paint production plant and factory has become unusable.

There might be diversity in how big hazard events happen and which chemicals involve, but they share common risks which are fire, explosions and release of toxic materials. Ignition of flammable materials causes fire and has types such as flashover, boilover, torch, etc. Rapid flammable gas mixture release may cause

explosions like Unconfined Vapor Cloud Explosions (UVCEs), Boiling Liquid Expanding Vapor Explosions (BLEVEs), etc. Spreading of toxic materials to air, water or soil may causes death and/or injury of people and/or environmental damage.

Big hazard events can be happen but prevention and control of these major accidents are important for human heath, animals, environment and economy.



4. SEVESO III DIRECTIVE

Major industrial accidents occurred in recent years resulting in serious negative effects to human health, environment, economy and social life. A major industrial event happened in Seveso (Italy) in 1976 because of an explosion that occurred in a reactor of a TCP (Trichlorophenol) production chemical plant, which uses a dangerous production process among others, due to losing control of the exothermic reaction and not cooling well the reactors resulted in accidentally releasing a toxic cloud containing TCDD (2,3,7,8 – tetrachlorodibenzo – p – dioxin) to the atmosphere and caused human health problems for many people (2000 people underwent treatment because of dioxin poisoning) and death of many animals. Dioxins can accumulate through the food chain in humans and animals. After this accident, 82/501/EEC Directive (SEVESO I) was released by the European Union (EU) for the control and prevention of major accidents hazards involving dangerous substances and this started to be known as the Seveso Directive.

SEVESO I was amended into 96/82/EC Directive (SEVESO II) with the gained knowledge and lessons from later accidents. In 2003, SEVESO II was revised as the Extended SEVESO II Directive 2003/105/EC. In 2012, SEVESO II Directive was replaced with the 2012/18/EU Directive (SEVESO III) due to changes in the Union Legislation and Seveso III Directive took place of Seveso II on 1 January 2016.

SEVESO Directive aims the prevention of major accidents involving dangerous materials, decreasing the aftereffects to the human health and the environment ensuring that the necessary precautions are taken for the high level, efficient and sustainable protection.

The main changes from Seveso II to Seveso III are:

- The list of dangerous substances covered by the SEVESO Directive (Annex I), which is based on Chemicals Hazard Information and Packaging for Supply Regulations 2009 (CHIP), is organized for aligning to the EU Legislation

(Classification, Labelling and Packaging (CLP) Regulation) on the classification of dangerous. CLP Regulation entered in the force in January 2009 and provides the hazards presented by the chemical materials are clearly informed to workers and consumers in EU through classification and labelling of chemicals with basing the method of the United Nations' Globally Harmonised System (GHS).

- More effective implementation and enforcement for inspections with introducing stricter standards and new obligation for the relevant departments of government's.
- Citizen's access to true information about big hazardous accidents and more efficient participation in decision-making will ensure.
- The way of information collected, managed and shared will improve.

On 30 December 2013, SEVESO II came into force in Turkey with publishing in the Official Gazette No.28867.

In Turkey, according to Reducing The Risks Of Major Industrial Accidents Legislation (Büyük Endüstriyel Kaza Risklerinin Azaltılmasına ilişkin mevzuat – BEKRA), companies must make a statement about the dangerous materials they used and/or stored and their quantities using BEKRA Reporting System to get classification as high dangerous, low dangerous or out of scope. Turkey has 421 high dangerous and 521 low dangerous classified, total 942 SEVESO companies (December 2015) [4]. The companies also must reduce the occurrence frequency to 1×10^{-4} /year value or below determining by the quantitative techniques for each major hazard scenarios studied for the determined dangerous equipments. Operators are obliged to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment. SEVESO companies must prepare an emergency plan.

5. RESULTS OF DANGEROUS CHEMICAL RELEASE

Unwanted chemical release can happen because of equipment failures, personal failures, natural disasters, sabotage, terrorist attacks, fires, etc. and there are three types of hazards which are fire, explosion and toxic release (Table 5.1). Consequences that occurs after dangerous chemical release includes mostly dispersion, jet fire, pool fire, flash fire, secondary fire, fireballs, Boiling Liquid Expanding Vapor Explosion (BLEVE), vapour cloud explosions and cause damage due to thermal radiation from fires and overpressure effects from explosions.

Table 5.1 : Types of Hazards [5].

Type	Probability of Occurrence	Probability for Fatalities	Potential for Economic Loss
Fire	High	Low	Intermediate
Explosion	High	Intermediate	High
Toxic Release	Low	High	Low

5.1 Dispersion

Industrial facilities are not designed to leak hazardous substances, but each equipment has a potential to leak especially from joint or connection points. Dispersion is the accidental release of dangerous materials. If this material is a pressurized liquid, discharge can cause even much worse hazard. Liquid Petroleum Gas (LPG) pump mechanical seal failure can be given as a failure case example resulting with dispersion consequence.

5.2 Explosion

Explosion is a blast/shock/pressure wave which causes damage is generated by rapid release of energy. Energy is lost as the blast wave moves away from the center of the explosion. Effects of various pressure levels are given in Table 5.2.

Explosions can be classified as:

- Chemical Explosions,

- Physical Explosions,
- Nuclear Explosions.

If the energy which enables the explosion is physical accumulated by physically as mechanically compressing a gas and when this accumulated energy suddenly released in a rapid physical change as expansion of a compressed gas, a physical explosion occurs. When the energy generated by a chemical reaction, a chemical explosion can arise. If the way the accumulation of energy is nuclear, nuclear explosion can occur.

Table 5.2 : Effects of Pressure Levels [38].

Pressure (psig)	Damage by Blast
0.1	Breakage of small windows under strain
0.7 Blue zone	Minor damage to house structures
1	Partial demolition of houses, made uninhabitable
2	Partial collapse of walls and roofs of houses
3 Orange zone	Heavy machines (3000 lb) in industrial building suffered little damage; steel frame building distorted
4	Cladding of light industrial buildings ruptured
5 Red zone	Wooden utility poles snapped; tall hydraulic press (40000 lb) in buildings slightly damaged
7	Loaded train wagons overturned
10	Probable total destruction of buildings; heavy machines tool (7000 lb) moved and badly damaged
300	Limit of crater lip

5.2.1 Vapor cloud explosion

Vapor cloud explosion is the ignition of released flammable vapor, mixture of vapor, gas, aerosol or mist with air from a storage tank, process vessel, transport vessel or piping system as flammable vapor cloud producing blast overpressure. The effect of the explosion depends on the containment of the area where the explosion occurs.

The difference between gas explosion and vapor cloud explosion is about the state of material as gas or liquid at room conditions. For example, gasoline fuel is liquid and can vaporise forming a vapor cloud.

Vapor cloud explosions could be categorised with three types as Confined Explosions, Partially Confined Explosions and Unconfined Explosions. Confined Explosions, also called Internal Explosions, occur in a vessel, pipe work, etc. while Partially Confined Explosions occur in a buildings, Unconfined Explosions are the burning of clouds in open air or space [7].

Overpressure effects estimations of vapor cloud explosions can be categorised as the empirical (simplified) models, phenomenological models and computational fluid dynamics (CFD) models [8].

In 1974, a vapor cloud explosion happened in United Kingdom due to ignition of leaked large amount of cyclohexane formed as a flammable mixture resulting with deaths and injuries. After this explosion, prediction methods were developed as TNT equivalent method, TNO multi-energy method and Baker-Strehlow-Tang (BST) method to provide a non-dimensionalized blast curve to predict overpressure given the source, amount of energy generated and the standoff distance [9] and these methods can be classified as simplified methods.

Phenomenological models use differential and algebraic equations and has short running times. These methods are in between empirical methods and CFD methods in terms of complexity.

CFD models use Navier-Stroke equations to calculate overpressure field. CFD models are more accurate but more sophisticated when comparing with other methods.

5.3 Boiling Liquid Expanding Vapor Explosion (BLEVE)

Boiling Liquid Expanding Vapor Explosion (BLEVE) is an physical explosion because of released pressurized liquid above its boiling point from the ruptured vessel and if material is flammable, fireball can follow. The effect of the BLEVE depends on the container size, container weight, amount of the material contained in the vessel, temperature and pressure inside the vessel.

BLEVE can cause to the blast wave, flying fragments (missiles), splashing of some liquid to form short-lived pools, fire or toxic gas release [10].

BLEVE can create overpressure with the expansion of the vapor, the flash vaporization of the liquid, and the combustion of the vapor. Projectiles will be the effects of explosions and they can be created by the rupture and/or the vessel's itself. As a result of released materials rapid combustion, the fireball thermal radiation produced.

The events which can lead to a BLEVE are [11]:

- Fire exposure,
- Mechanical damage,
- Overfilling,
- Runaway reaction,
- Overheating,
- Vapor-space explosion,
- Mechanical failure.

5.4 Thermal Radiation

Thermal radiation can cause burning injuries and/or ignite the flammable materials nearby depending on the exposure time with its heating effect. Human skin withstands 10 kW/m^2 heat energy for approximately 8 seconds before the pain is felt in general [12]. Thermal radiation effect levels are given in Table 3.

Table 5.3 : Thermal Radiation Effect Levels [27].

Thermal Radiation Level (kW/m²)	Observed Effect
37.5 Red zone	Sufficient to cause damage to process equipment.
25	Minimum energy required to ignite wood at indefinitely long exposures (non-piloted).
12.5 Orange zone	Minimum energy required for piloted ignition of wood, melting of plastic.
10	Pain threshold reached after 8 seconds; second degree burns after 25 second.
4.7	Accepted value to represent injury.
4 Blue zone	Sufficient to cause pain to personnel if unable to reach cover within 20 seconds; however blistering of the skin (second degree burns) is likely; 0:lethality.
1.6	Will cause no discomfort for long exposure.

5.5 Fire

Fire is a burning process with producing heat, light and often smoke and flames. Fire cause skin burn on people when exposure due to the thermal radiation. Thermal radiation levels and related observed effects are given in previous Table 5.3.

The total heat release rate (HRR) is the amount of energy produced by the flame per unit time and it is the driving force for fire. Oxygen consumption calorimeter is the most common way to measure the HRR [13].

Flame is the visible part of a fire. Flame height may affect the fire detection system, building structures, smoke filling rates, fire ventilation and escape capabilities. Flame temperatures depends on factors as weather conditions, whether the flow is laminar or turbulent, whether the flame is adiabatic etc. [13].

Fire can be classified as:

- Jet Fire,
- Pool Fire,
- Flash Fire,
- Secondary Fire and
- Fireballs.

Jet Fire is the fire resulting from the combustion and ignition of a vapour, two-phase release or a flammable fluid being released from the limited size openings of a pipe or an orifice with causing the thermal radiation. For example, ignition of high-velocity fuel causes jet fire.

The flow discharge release rate depends on the size and shape of the leak hole, molecular weight of the gas, and pressure inside the equipment. Flame can be influenced by the atmospheric conditions with wind speed, material properties and conditions [13].

Pool Fire is the ignition of an accumulation as pool of liquid on the water, liquid or ground. The liquid burning rates and the heat radiated from flames are depend on the pool diameter.

Pool fire flame can be divided into three separate zones as ‘continuous flame zone’ which presents a visible flame just above the burner with constant temperature, ‘intermittent zone’ is the intermittent flame pockets area above the continuous zone, ‘plume zone’ is non-visible flame region. The temperature decreases as moving away from the burner [14].

Flash Fire is the ignition of the flammable material which diffused in air as gas leak, vapor cloud, combustible dust, etc. Flash fire also known as vapor cloud fire and the difference between vapor cloud fire and vapor cloud explosion is overpressure. The flash fire flame spreads both upwind and downwind direction of the ignition source after the ignition.

Secondary Fire is the ignition of the flammable substances which are not directly concerned with the process, for example stored raw materials.

Fireballs occur because of turbulent vapour or two-phase fuel ignition in air for a short period of time. For example, road tanker failure may result in fireball.

5.6 Toxic Release

Toxic materials are substances which may cause harm when they enter the body. The route of exposure which means the way of toxic material entered the body can be in different ways as inhalation, skin contact and ingestion. It is important to understand the potential hazards and how to protect yourself to prevent health problems due to exposure to toxic materials.

Toxic plume can occur after dangerous event and factors as wind speed, weather conditions may play an important role on spreading of this hazardous cloud. Table 5.4 shows the exposure limits and observed effects of toxic release.

Table 5.4 : Exposure Limits and Observed Effects of Toxic Release [15].

Concentration Level	Observed Effect
Short-Term Exposure Limit (STEL) Blue Zone	Maximum concentration of the substance to which workers can be exposed for a period up to 15 minutes without suffering (a) Intolerable Irritation (b) Chronic or irreversible tissue change (c) narcosis of sufficient degree to increase accident proneness, impair self rescue, or materially reduce worker efficiency, provided that no more than 04 excursion per day are permitted, with at least 60 minutes between the exposure periods, and provided that daily TLV is not exceeded. It should not be used to evaluate the toxic exposure up to 30 minutes.
Immediately Danger to Life and Health (IDLH) Orange Zone	An atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects from a dangerous atmosphere. If IDLH values are exceeded, all unprotected people must leave the area immediately. The maximum airborne concentration of a substance to which a worker is exposed for long as 30 minutes and still be able to escape without loss of life.
Lethal Concentration at 50% Mortality (LC50) Red Zone	LC stands for 'Lethal Concentration'. LC values usually refer to the concentration of a chemical in air but in environmental studies it can also mean the concentration of a chemical in water. For inhalation experiments, the concentration of the chemical in air that kills 50% of the test animals in a given time (usually half to four hours) is the LC50 value.
Fatal Level	Death.



6. RISK ASSESSMENT

Risk Assessment is a process of hazard identification, definition, analysis and evaluation of the risks and gives an understanding of their causes, results and possibilities.

Risk assessment may be performed by following these steps:

- Hazard identification
- Risk definition and analysis
- Risk evaluation
- Recording findings and treatment implementations
- Monitoring and review

Hazard identification is a process of defining all the hazards which are inherent in the job by identifying safety problems of plants, improve process safety and eliminate potential hazards. While hazard identification is the answer of what is wrong and what can go wrong in the process, risk assessment is the who, what, how can be effected with what frequency and possibility result of an unwanted hazard event. Common techniques that are used for hazard identification are:

- Preliminary Hazard Analysis (PHA)
- What-if Analysis
- Check-List Analysis
- Failure Modes And Effects Analysis (FMEA)
- Hazard and Operability Study (HAZOP)

Risk definition and analysis is the step for determining the who might be harmed and how, what are the risks associated with the hazards, what is the risk level and occurrence probability.

Risk evaluation is the determination of the whether the risk is acceptable or not or tolerable with comparing the risk analysis results and risk criteria. Risk evaluation assist in the desicion about risk treatment

Recording findings and treatment implementations is the step which findings are recorded, how the risks can be controlled or reduced is detected and decided to the precautions.

Risk treatment is a process of developing, selecting and implementing of controls and can involve risk source removal, changing the nature and magnitude of likelihood, changing the concequences, retaining the risk by choice, deciding not to start or doing the activity which occurs the risk [1].

Monitoring and review step if for continual checking, observing for determination the change from expected and the suitability of what implemented.

7. RISK LEVEL DETERMINATION

Risk level is the expressing the risk size with the combination of consequences and their likelihood. Risk level can be affected by the person who exposed the risk, how serious injured, is hazard well controlled.

Risk rating matrix is uses qualitative or semi-qualitative ratings of consequence and probability to combine and produce a risk level. The consequence scale/s should cover the range of different criterias depending on the context such as financial loss, safety, environment etc. [45]. Below given Table 7.1 describes likelihood ratings, Table 7.2 helps to decide to the likelihood of risk, Table 7.3 shows the risk rating matrix and Table 7.4 describes the consequence ratings. Risk ranking matrix provides easy and rapid ranking of risks but it is subjective and variations between raters can be seen.

Table 7.1 : Likelihood Rating Descriptions [17].

Rating	Criteria
Rare	May only occur in exceptional circumstances
Unlikely	The risk event could occur at some time (during a specified period), but it is unlikely
Possible	Might happen at some time; occurrence would not be unusual
Likely	Will probably occur in most circumstances
Almost certain	Is expected to occur in most circumstances

Table 7.2 : Risk Likelihood Guidance Table [17].

Descriptor	1	2	3	4	5
	Rare	Unlikely	Possible	Likely	Almost Certain
Frequency	Not expected to occur for years	Expected to occur at least annually	Expected to occur at least monthly	Expected to occur at least weekly	Expected to occur at least daily
Probability	< 1%	1-5 %	6-29%	21-50%	>50 %
	Will only occur in exceptional circumstances	Unlikely to occur	Reasonable chance of occurring	Likely to occur	More likely to occur than not

Table 7.3 : Risk Rating Matrix [17].

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost certain	Medium	High	High	Extreme	Extreme
	Likely	Medium	Medium	High	High	Extreme
	Possible	Low	Medium	Medium	High	Extreme
	Unlikely	Low	Low	Medium	Medium	High
	Rare	Low	Low	Low	Medium	High

Table 7.4 : Consequence Rating Descriptions [17].

Rating	Criteria
Insignificant/ Negligible	- Minor injury - No or basic first aid required - No lost time
Minor	- Medical or paramedical treatment - Up to four days lost time from work - Small amount of local print media coverage (< one week)
Moderate	- Treatment by hospital EMD or admission to hospital and/or four or more days lost time from work - Persistent negative local and/or state media coverage - Short term disruption to core activities (days) - Long term disruption to non-core activities (weeks) - Minor breaches of WHS (or related) legislation - Small scale investigation by regulatory bodies (local branch only) - Any notifiable incident that does not lead to injury, ie does not require medical or paramedical treatment - Uncontrolled non-hazardous chemical spill/release
Major	- Permanent impairment/disability (unable to return to work) - National and/or international negative media coverage - Medium term disruption to core activities (weeks) - Investigation by regulatory bodies with prosecution, enforceable undertakings and/or possible criminal charges or civil suits - Any notifiable incident requiring medical attention - Uncontrolled hazardous chemical spill/release
Catastrophic/ Fatality	- Fatality/s - Significant damage to reputation - Widespread ongoing negative media coverage - Long term cessation of core activities - Investigation resulting in large legislative breaches and resultant legal actions, criminal charges, civil suits - Long term extensive environmental damage

8. HAZARD IDENTIFICATION METHODS

Hazard identification methods can be classified as Qualitative Techniques and Quantitative Techniques.

Qualitative Techniques are used for identification and evaluation of potential hazardous scenarios for understanding the risk by a multidisciplinary team and uses voting and fuzzy logic to score the risk as Preliminary Hazard Analysis (PHA), What-If Analysis, Check-List Analysis, Failure Modes And Effects Analysis (FMEA), Hazard And Operability Study (HAZOP).

Quantitative Techniques provides more detailed and numerical evaluations of the risks as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Human Reliability Analysis (ERA) Event Tree, Dow Fire and Explosion Index, Dow Chemical Exposure Index.

8.1 Preliminary Hazard Analysis (PHA)

Preliminary Hazard Analysis (PHA) is simple, qualitative method to identify and assess the potential hazards and means of their corrections in a process and may help prioritizing hazards and risks. This method mostly used early in the development of a project process for providing information to specify system design and should be updated to detect new hazards.

Plant design criteria, layouts, equipment and material properties etc. informations are necessary to perform PHA method.

Results of this study can be sum up in a table form or tree diagram with containing brief descriptions of each hazard, cause, effect and correctivations.

8.2 What-If Analysis

What-If method aims to define the hazards and hazardous events by asking ‘What if...?’ questions involving examination of possible deflection from intentions. The evaluation usually starts at the input point and follows the flow of the process [18] but also can be performed for any part of the process [19].

Properties of raw materials, plant layout, operating procedures and parameters, equipment informations are necessary to perform this method. The team usually would have two or three members who has general hazard evaluation experience. Team identifies hazards and their results with recommending solutions or alternatives to reduce the risks and report the analysis results.

What-If analysis is easy to use and adaptable to specific scenarios but limited by the participant experience.

8.3 Check-List Analysis

Check-list method uses a written list of steps following each element of the process to determination of the hazards, risks and also hazard evaluation requiring parts of the system and safety needs with providing qualitative results.

This method is easy to use and can be used at any process even at preliminary design. Due to it is observation based, problems which can not readily seen may fail to notice.

8.4 Failure Modes And Effects Analysis (FMEA)

Failure Modes And Effects Analysis (FMEA) is a systematic, inductive method to determine the process failures and their consequences. Criticality analysis which identifies the importance of failure mode qualitatively or quantitatively (FMECA) can be done after FMEA.

Flow diagram, layouts, details of environmental and other parameters, historical informations are necessary to perform FMEA.

FMEA is a technique answers following questions [20];

- What can fail?
- How does it fail?
- How frequently will it fail?
- What could the effects be if the failure will occur?
- What is the safety result of failure?

FMEA report contains details of the analyzed system, how study was performed, assumptions, data sources, results, recommendations and criticality, if performed.

FMEA is not easy, it is time consuming and costs.

8.5 Fault Tree Analysis (FTA)

A failure in any part of the system can affect the other parts. Fault Tree Analysis (FTA) is used for the modelling possible combinations of equipments failures, human errors and other factors which leads to loss events. FTA uses top-down structure graphical model which looks like a tree to show pathways within a system basic events which can cause hazardous events (top events) and uses event symbols.

Following steps can be used for FTA:

- Define the system (Define the system failures and initial conditions)
- Define the top event (Specify the problem of interest)
- Construct the tree (Use symbols)
- Evaluate (Opportunities to use improvements, alternative procedures, materials etc.)
- Corrective actions

8.6 Event Tree Analysis (ETA)

Event Tree Analysis uses FTA structure to present graphically of potential hazardous event as top point and its following consequences.

Flow chart for ETA can be expressed as [21]:

- Identifying initiating events,
- Selection of safety function,
- Event tree construction,
- Quantitative risk assessment,
- Result analyzing and reporting.

8.7 Hazard and Operability Study (HAZOP)

Hazard and Operability Study (HAZOP) is an organized, structured and methodic technic, which mostly used for chemical production process, for detection and analysis of potential hazardous problems and process deviations from designed operational intents and malfunction. HAZOP study would typically be carried out by a multidisciplinary team under the leadership of a team leader with systematically following a structure which includes guide words and system diagrams in a brainstorming meeting asking a series of questions. Quality of the results of this study depends on the experience of the team members and the quality of gathered informations.

HAZOP is easy to learn but expensive and requires more participants. It is applicable to all types of systems and equipments.

8.7.1 HAZOP study steps

HAZOP study can be done in five steps respectively scope and purpose, team selection, gathering information, process review and final report [7] and may follow flow diagram given in Table 8.2.

The first step is for identifying the scope and purpose. The scope includes the node (specific area of the process) selection to be studied and hazard results to be took into consideration. The purpose is defining potential hazards and deviations of the process.

The second step is team selection to perform study. Process describe and result documentation can be done by a single person but the study must be performed by a team. The typical team would have between four and seven members from different sections in operation involving scientists, engineers, production managers, designers and safety specialists etc. The team leader should have a good knowledge about process being studied and have experience in HAZOP studies.

Process/Piping and Instrumentation Drawings/Diagrams (P&IDs) is an important document which provides informations about the equipment, piping, process flow, process control and safety design details for chemical industries and critical P&ID review helps to identify safety vulnerabilities for safer design, to determine concerns for long-term operational effectiveness, and application of positive design changes [22].

The third step is gathering informations on P&IDs, flow diagrams, layouts, equipment informations etc. Team leader should decide study nodes after data collection and create a list of guide words (Table 8.3).

The fourth step is process review. The HAZOP team should analyze the study node for potential hazardous process deflections using guide words and record causes, consequences and suggested solutions.

The final report should be prepared including all the information as guide word used, specific parameters (Table 8.1), deflections from design intentions, causes and consequences and suggested actions in table format as final stage.

Table 8.1 : HAZOP Process Parameters.

Process Parameters		
Flow	Density	Safety
Temperature	Viscosity	Contamination
Pressure	Reaction	Addition
Composition	Corrosion	Maintenance
Phase	Erosion	Sampling
Level	Relief	Inserting

Table 8.2 : HAZOP Flow Diagram.

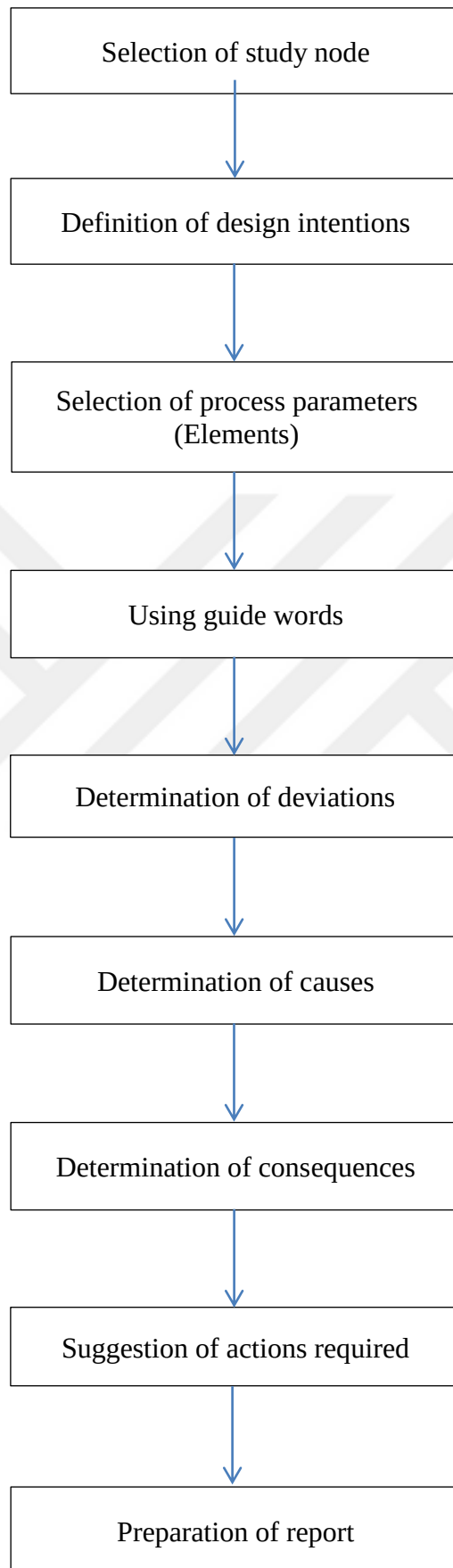


Table 8.3 : HAZOP Guide Words [20,23].

Guide word	Meaning	Example	Typical Problems
None Not No	The design aim does not happen.	No flow, No heat transfer, No reaction etc.	Blockage, Pump failure, Valve closed or jammed, Suction vessel empty, Vapour lock, Control failure etc.
More	A quantitative increase.	High pressure, High temperature, High flow rate, High volume, High viscosity, High density etc.	Blockage, Pump failure, Valve failure, High ambient temperature, Vapour lock, Reaction, Explosion, Control failure etc.
Less	A quantitative decrease.	Low pressure, Low temperature, Low flow rate, Low volume, Low viscosity, Low density etc.	Blockage, Pump failure, Leak, Sediment, Cavitation, Less ambient temperature, Heat loss, Vaporisation, Imbalance of input and output, Control failure etc.
As well as	An additional activity happens.	Contaminants as Water, Air, Lubrication oil, Corrosion products etc.	Presence of pollutants, Other products of process due to leakage etc.
Part of	Only reaching some of the design aim.	Product is not at desired ratio, Only one of four components present etc.	Pump failure, Valve failure, Control failure, Equipment failure etc.
Reverse Back	The opposite of intention.	Backflow.	Pump failure, Valve failure, Control failure etc.
Other than	Happening of activity unlike intention.	Transfer from wrong source / wrong destination, Transfer of wrong material, Production of unwanted material etc.	Control failure etc.
Early	Timing difference from planned.	A part of process starts at wrong time etc.	Control failure, Equipment damage etc.
Late	Timing difference from planned.	A part of process starts at wrong time etc.	Control failure, Equipment damage etc.

8.8 Hazard Identification Techniques Comparison

We can summarize and compare of hazard identification techniques as given in Table 8.4 according to the informations mentioned in previous sections fro their complexity, is it qualitative or quantitative technique, can be done as a team or individual, time required to study, uncertainty, report, usability for research and development, design, usability for routine operation and incident investigation.

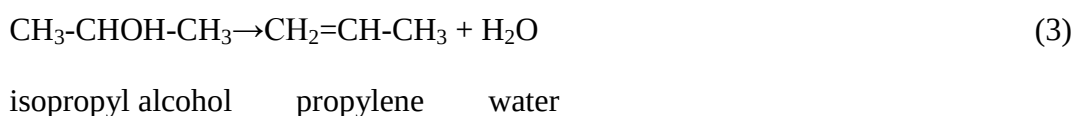
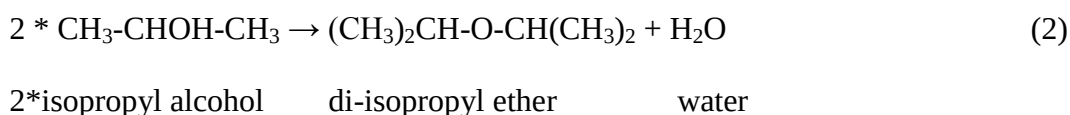
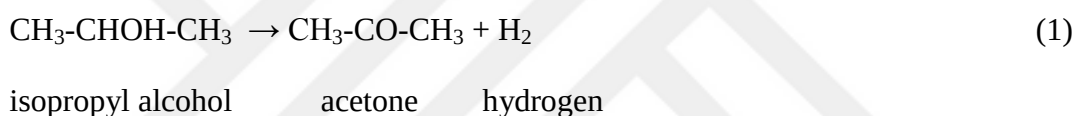
Table 8.4 : Hazard Identification Techniques Comparison.

	What-if	Check-list	FMEA	HAZOP
Complexity	Any	Low	Medium	High
Qualitative or Quantitative	Qualitative	Qualitative	Qualitative and Quantitative	Qualitative
Team or Individual	Team	Team	Team	Team
Time Required	Low	Low	Medium	Medium
Uncertainty	Medium	Low	Medium	High
Report	Low	Low	High	High
Research and Development	✓			
Design	✓	✓		
Routine Operation	✓	✓	✓	✓
Incident Investigation	✓		✓	✓

9. ACETONE PRODUCTION FROM ISOPROPYL ALCOHOL HAZOP CASE STUDY

In this section, HAZOP performed for the reaction, acetone separation and heat exchange sections of the production of acetone from isopropyl alcohol which process flow diagram is given in Figure 9.1.

An azeotropic aqueous solution of isopropyl alcohol and recycled isopropyl alcohol/water mixture is fed into V-401 surge vessel to mix. Before entering the R-401 reactor, this stream is pumped and vaporized. H-401 and stream 4 used for providing necessary heat for endothermic reaction. Below given reactions occurred over the solid catalyst:



Before entering the V-402 phase separator, the reactor's outlet stream containing acetone, hydrogen, water and isopropyl alcohol is passed through the two heat exchangers (E-402 & E-403) to cool down. In the T-401 scrubbing column, the vapor stream leaving the separator is contacted with steam & water to recover acetone. Outlet streams of separator and scrubber are mixed and sent to the two separation towers (T-402 & T-403) to separate the acetone and to recover the unused isopropyl alcohol from water for recycling back to the reactor.

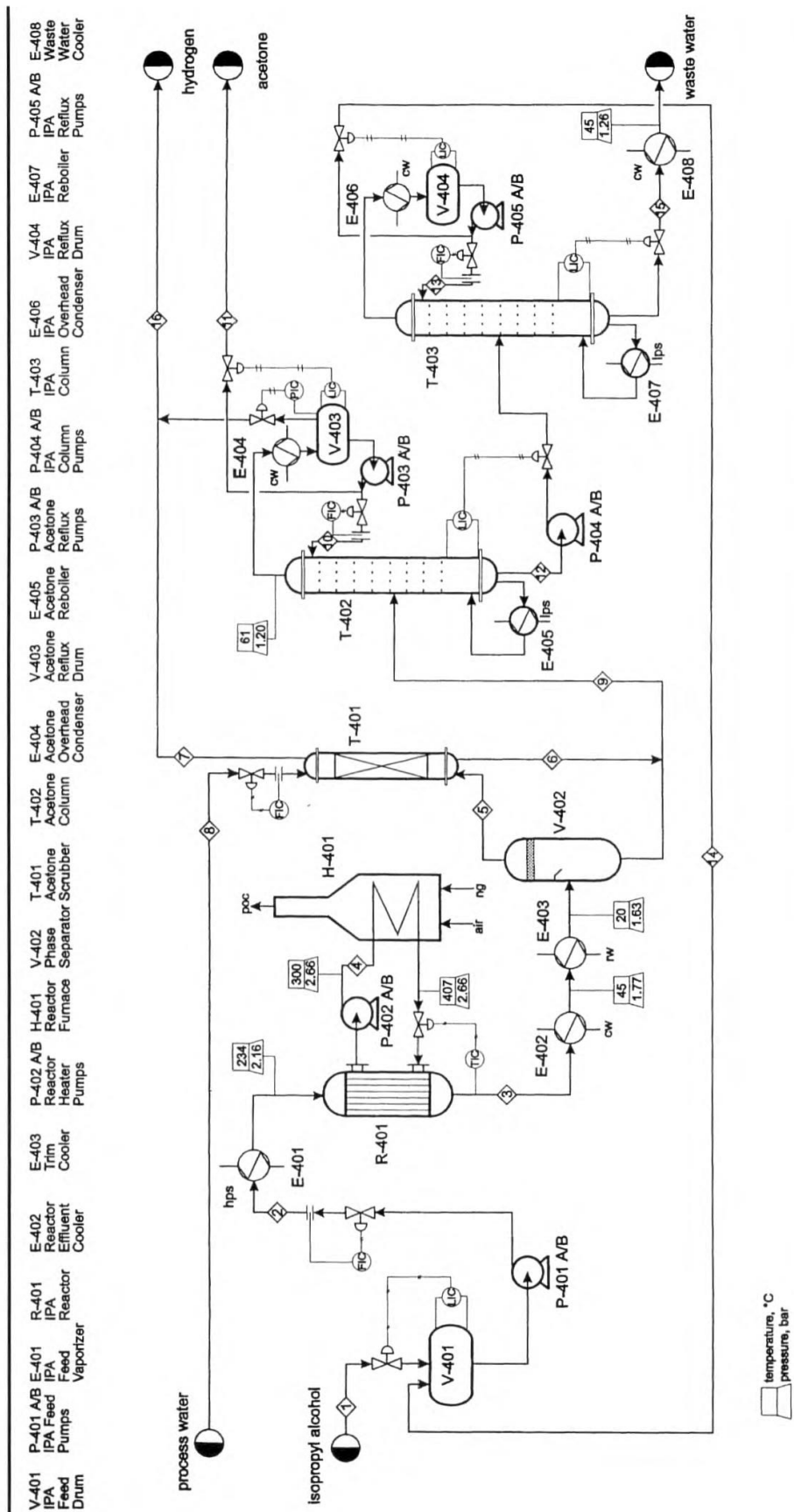


Figure 9.1 : Process Flow Diagram For The Production Of Acetone From Isopropyl Alcohol [24].

9.1 HAZOP Study For Reaction Section

Acetone was produced by the endothermic reaction in gas phase on a solid catalyst in reaction section (Figure 9.2). HAZOP study for reaction section is given in Table 9.1.

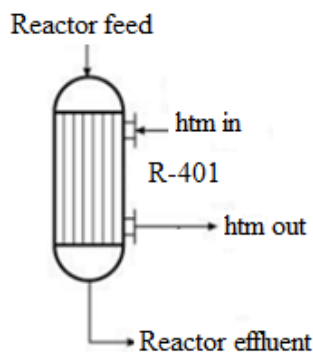


Figure 9.2 : Reaction Section of Acetone Production From Isopropyl Alcohol [24].

Table 9.1 : HAZOP Study For Reaction Section.

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
1	Less	Temperature	Less Temperature	Less heating	Less reaction, No reaction, Less quality product.	Control the temperature of Steam 4. Control the steam 4 valve.
2	More	Temperature	More Temperature	More heating, Valve control failure, H-401 control failure.	Auto ignition, Fire, Explosion.	Control the temperature of Steam 4. Control the steam 4 valve. Control the H-401. Provide high temperature sensor/alarm.
3	Less	Reactor inlet flow	Less reactor inlet flow	Tube leaks, Valve failure, Control failure.	Less reaction, Less quality product.	Provide flowmeter for tubes, Control the valve.
4	More	Reactor inlet flow	More reactor inlet flow	Valve failure, Control failure.	Unwanted operational conditions.	Control the valve. Control the control system.

Table 9.1 : HAZOP Study for reaction section (continue).

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
5	More	Pressure	More pressure	Valve failure	Explosion, Fire, High temperature, Leakage, Equipment rapture,	Control the valve.
6	Less	Pressure	Less pressure	Leakage, Less heating.	Less reaction, No reaction, Less quality product.	Control the H-401. Control the temperature of steam 4, Control the flowrate of stream 4. Control the heating steam outlet.

9.2 HAZOP Study For Acetone Separation Unit

T-402 separation towel was used to separate the acetone and recover the unused isopropyl alcohol from water for recycling back to the reactor (Figure 9.3). HAZOP study for this section is given in Table 9.3.

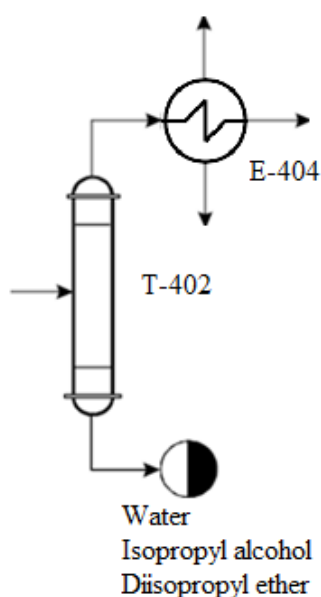


Figure 9.3 : Acetone Separation Unit [24].

Table 9.2 : HAZOP Study For Acetone Separation Unit.

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
1	Less	Temperature	Less Temperature	Less heating	Less separation.	Control the E-405.
2	More	Temperature	More Temperature	More heating, Valve control failure, E-405 control failure.	Auto ignition, Fire, Explosion.	Control the E-405. Control the valve. Provide high temperature sensor/alarm.
3	Less	Inlet Flow	Less Inlet Flow	Tube leaks, Valve failure, Control failure.	Less separation.	Provide flowmeter for tubes, Control the valve.
4	More	Inlet Flow	More Inlet flow	Valve failure, Control failure.	Unwanted operational conditions.	Control the valve. Control the control system.
5	More	Pressure	More pressure	Valve failure	Explosion, Fire, High temperature, Leakage, Equipment rapture.	Control the valve. Control the pressure gauge.
6	Less	Pressure	Less pressure	Leakage, Less heating.	Less separation.	Control the E-405. Control the inlet flowrates.

9.3 HAZOP Study For Heat Exchanger Unit

E-404 heat exchanger was used for the cool the acetone which seperated at T-402 seperation towel (Figure 9.4). HAZOP study for this section is given in Table 9.3.

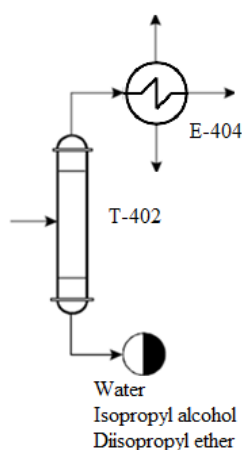


Figure 9.4 : Heat Exchanger Unit [24].

Table 9.3 : HAZOP Study For Heat Exchanger Unit.

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
1	Less	Coolant Fow	Less Coolant Flow	Pipe blockage, Pipe leak, Valve failure, Control system failure.	Unwanted outlet temperature.	Maintenance, Control the valve, Control the control system. High temperature alarm.
2	More	Coolant Fow	More Coolant Flow	Valve failure, Control system failure.	Unwanted outlet temperature, Exchanger tube leaks.	Maintenance, Control the valve, Control the control system. Low temperature alarm.
3	Less	Pressure on Tube Side	Less Pressure on Tube Side	Valve failure, Control system failure.	Unwanted outlet temperature.	Maintenance, Control the valve, Control the control system. Low pressure alarm.
4	More	Pressure on Tube Side	More Pressure on Tube Side	Valve failure, Blockage, Control system failure.	Leaks, Explosion overpressure, Pipe and unit rupture.	Maintenance, Control the valve, Control the control system. High pressure alarm.
5	Corrosion	Tube	Corrosion of Tube	Hardness of coolant.	Unwanted outlet temperature, Tube failure.	Maintenance.

10. HAZARD EVALUATION MODELS AND MODELLING SOFTWARES

In this section, general information will be given for some of below listed hazard evaluation models and modelling softwares.

AREAL LOCATION OF HAZARDOUS ATMOSPHERE (ALOHA) SOFTWARE

PROCESS HAZARD ANALYSIS (PHAST) SOFTWARE

BREEZE

EFFECTGIS

FLACS

CEBAM

SAFER TRACE

BLEVE Incident Simulator (BIS)

AUTOREAGAS

CHARM

ADORA

HAMS-GPS

10.1 Areal Location Of Hazardous Atmosphere (ALOHA) Software

Areal Location of Hazardous Atmosphere (ALOHA) is a software program designed for modelling toxic air hazards with chemical releases, thermal radiation from chemical fires and vapour-cloud explosions scenarios risk assessments for populations and environments. ALOHA is one of the integrated software applications in the Computer-Aided Management of Emergency Operations (CAMEO) software suit, which is developed by the United States Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) for afford

assistance to access, store and evaluate critical information for developing emergency plans to planners and responders.

Aloha has physical, chemical and toxicological properties data library for thousands of pure chemicals and some common chemical solutions (Library can be reached at cameochemicals.noaa.gov), but for other chemicals, users have to enter the data manually.

Aloha warns the users if the entered value is improbable or not physically possible by cross-checking.

Aloha has data for many cities in United States of America (USA) but not for other cities in the world, for other cities, data must be entered by users.

Aloha allows user to model releases on water with given chemical is soluble warning.

ALOHA gives you a chance to predict how quickly chemicals are releasing directly or from tanks, puddles and gas pipelines over time with release scenario modelling as jet fires, Boiling Liquid Expanding Vapor Explosions (BLEVEs), toxic gas clouds, vapor clouds explosions and pool fires with evaluation of different types of hazard such as toxicity, flammability, thermal radiation and overpressure. Hazard categories modeled in ALOHA are given in Table 10.1.

ALOHA can estimate hazardous chemical release threat zones including toxic, gas clouds, fire and explosions. ALOHA can display three threat zones in a single graph which shows the thermal radiation effects on people who are exposed and able to get into a shelter within 60 seconds, longer exposure duration can cause serious other effects even at lower radiation level. The red threat zone represents the worst hazard between these red, orange and yellow threat zones. The threat at point graph shows specific information about hazards at specific locations. In toxic threat zone graph, the red, orange and yellow areas represent the regions respectively predicted greatest, medium and low exposure levels where chemical concentrations are predicted to exceed the corresponding Acute Exposure Guideline Level (AEGL) values at some time after the release begins. The flammable threat zone graph shows the estimated flammable area which a vapour cloud explosion or flash fire could happen after release begins.

ALOHA can estimate the chemical cloud dispersion based on the toxicological/physical characteristics of the released material, atmospheric conditions, and specific circumstances of the release [25]. Concentration at point graph displays chemical concentration versus time. Source strength graph shows the release rate of the chemical or burn rate or evaporation rate depending on the substance and event. Other graphs as overpressure (blast force) threat zone, ALOHA's footprint, concentration by time, etc. can be given by ALOHA.

Table 10.1 : Hazard Categories Modeled In ALOHA [26].

Scenario / Source	Direct Source	Tank	Puddle	Gas Pipeline
Vapor Cloud	Toxic vapors	Toxic vapors	Toxic vapors	Toxic vapors
Vapor Cloud (flash fire)	Flammable area	Flammable area	Flammable area	Flammable area
Vapor Cloud (explosion)	Overpressure	Overpressure	Overpressure	Overpressure
Pool Fire	NA	Thermal radiation	Thermal radiation	NA
BLEVE (fireball)	NA	Thermal radiation	NA	NA
Jet Fire	NA	Thermal radiation	NA	Thermal radiation

10.2 Process Hazard Analysis (PHA) Software

Phast is industry standard process hazard analysis software developed by DNV Software to examine, estimate, understand and visualise the effects of a potential accident from the initial release to far field dispersion with modelling of pool spreading and vaporisation, liquid rainout, toxic effects, radiation, fire and explosion.

Phast applications include plant layout, inventory planning, pollution control, providing input to major accident prevention and safety management planning, emergency response plan development, safety case preparation, compliance with regulations and non-standard operations analysis.

Phast is user friendly, while new users can work on step by step, professionals can use for their own scenarios but has limitations in congested areas and urban areas.

10.3 BREEZE Incident Analyst Software

BREEZE Incident Analyst Software is developed for accidental chemical release hazard and effect modelling to toxic dispersion, fire and explosion and predicts thermal radiation exposure and temperature rise with the pool fire, jet fire and Boiling Liquid Expanding Vapor Explosion (BLEVE) models developed by the United State government, military and industry groups.

Breeze Incident Analyst Software is user friendly with providing step by step layout. From Incident Tab, user can define all the critical information needed for a model to run such as chemical information (can be selected from chemical database), meteorological data, source characteristics and result options.

Result summary file ensures the most critical results informations. With the Breeze 3D Analyst program, visualized results can be obtained with an image shows results overlaid on a map, animated results, exporting results to Google Earth or scalable vector graphics.

10.4 EFFECTGIS

EFFECTS Software calculates the effects and results of the accidental release of hazardous materials and presents in tables, graphs and on geographical maps, can be used for hazard identification, safety analysis and emergency planning.

EFFECTS has over 50 models for release, evaporation, fire, explosion, dispersion and damage accidents with storage and transportation of chemicals and has chemical database with toxic, flammable and thermodynamic properties for over 2200 chemicals and also users can enter data for their own chemicals [27].

With GIS tool, it is easy to overlay the results over GIS drawings or Google Earth. Also all data can be exported using copy-paste.

10.5 Flame Acceleration Software (FLACS)

FLACS is for modelling dispersion and explosion consequences for all typical flammable and toxic release scenarios with Computational Fluid Dynamics (CFD) and extensively used for the on/offshore explosion study, onshore building risk

assessments, gas detector optimisation, toxic dispersion calculations, dust explosions, accident investigations.

Program have been supported by small scale, medium scale and large scale experiments. But final developments are not available in the open literature.

10.6 CEBAM

CEBAM model is based on a gas phase, multi-step, finite-rate combustion CFD code for aero-propulsion applications assuming a controlled, known combustion rate without influencing by random changings and developed by the Dr. Clutter at University of Texas at San Antonio, USA [28]. The model assumed a one-step, irreversible chemical combustion reaction including fuel, air and material products.

CEBAM code model can use either Euler or Navier-Stokes form while most of other programs using Euler to solve equations during modelling explosion scenarios.

10.7 BLEVE (Boiling Liquid Expanding Vapor Explosion) Incident Simulator (BIS)

Boiling Liquid Expanding Vapor Explosion (BLEVE) is the explosive release of boiling liquid and expanding vapor from the rupture of a pressure vessel contains a pressurized liquefied gas like LPG (Liquefied Petroleum Gas) exposed to fire ending with the disastrous failure.

BLEVE Incident Simulator (BIS) is allowing to work with different hazardous scenarios with various tank sizes, fire types and tank protections and get information about hazards such as fireballs, blast, projectiles and vapor cloud explosions, critical tank behaviors, estimated tank failure or empty time, needed cooling water properties, suggested responder position and distance. Software has information data base including graphic images.

10.8 SAFER TRACE

SAFER TRACE is a software for the understandable and detailed analysis of chemical release, fire, explosion and particulate modelling with giving information about the prediction of the effected people number, protection strategy and generally

using in quantitative risk analysis, plant design, emergency plannings and regulatory requirements. The software has userfriendly interface, can show the results on map and allows to export results such as MS Office Programs [29].

10.9 AUTOREAGAS

AUTOREAGAS is using for the gas explosion safety and hazard risk assessment including the far field blast wave effects, safety distance determination, plant layout desing optimization, determination of blast loading on and inside structures, disaster planning, accident investigations and developed by the Century Dynamics Ltd. and TNO of the Netherlands [30]

10.10 Complex Hazardous Air Release Software (CHARM)

Complex Hazardous Air Release Software (CHARM) is an air dispersion model software for accidental air dispersion and transport of hazardous chemical release, BLEVE, pool fire, jet fire, vapor cloud explosion [31].

10.11 Atmospheric Dispersion Of Reacting Agents (ADORA)

Atmospheric Dispersion of Reacting Agents (ADORA) is for environmental impact assessment, air quality assessment, accidental discharge of hazardous chemicals which react with air, moisture or each other, chemical warehouses, rail cars, tank fires, explosions, pool fires, forest fires, petroleum product burns [32].

10.12 HAMS-GPS

HAMS-GPS is Windows based program for such as Health, Safety and Environment Management Studies including risk assessment, accident analysis, plume, puff, spill pool evaporation dispersion modelling, emergency management planning and control, percent and absolute fatality, injury computations, vapour cloud explosion, BLEVE, mechanical explosion, dust explosion, pool fire, jet fire, flash fire, fireball, explosion prevention [33].

11. COMPARISON OF ALOHA SOFTWARE

We can summarize and compare of Aloha, Phast and Breeze as given in Table 11.1 according to the informations mentioned in previous sections.

Table 11.1 : Comparison of Aloha, Phast and Breeze.

Properties	ALOHA	PHAST	BREEZE
Userfriendly	✓	✓	✓
Results can be shown on maps	✓	✓	✓
Graphical outputs	✓	✓	✓
Chemical database	✓	✓	✓
Discharge and dispersion models	✓	✓	✓
Explosion models	✓	✓	✓
Toxicity models	✓	✓	✓
Flammability models	✓	✓	✓
Release from tanks	✓	✓	✓
Release from puddles	✓	✓	✓
Release from pipelines	✓	✓	✓

According to study carried out for consequence analysis of n- Butanol Main storage tank 2 inch leakage for 1 hour duration, it was seen that while Phast gives more specific and realistic results compearing with real inputs for distance to concentration results, ALOHA results are more approximate due to it requires very less inputs and therefore its assumptions derivates from practical scenarios in range $\pm 10\%$ [34].

Dense gas dispersion models comparison study was performed for three chlorine reilcar accidents simulations using ALOHA, PHAST, TRACE, HGSYSTEM (A hazard-assessment software developed at Shell), SLAB (For effects of dense clouds from evaporating pools), SCIPUFF (Focused on power plant steck pulme and included specialized algorithm for dense gas behavoir in ground) and downwind chlorine concentrations were calculated. It is mentioned that while PHAST and TRACE have adequate source emissions modules, ALOHA has simplified source emissions module, HGSYSTEM ans SCIPUFF have limited source emissions capabilities, with no specific capabilities dor chlorine, SLAB has no source emissions module [35].

PHAST and ALOHA softwares were used to model and simulate the accident scenario of a LPG truck tanker which truck tanker hit a divider and overturned, a crack in the bottom pipe caused LPG leakage for about twenty minutes form a large vapor cloud which got ignited creating a fireball and BLEVE for results of fireball, jet flame radiation and explosion overpressure and simulations results were correlated with the actual damage data from the accident site. Comparison of estimated fireball and jet fire simulations diameters are given in Table 11.2 [36].

Table 11.2 : Estimated Fireball And Jet Fire Simulations Diameters [36].

	Fireball		Jet Fire	
	ALOHA	PHAST	ALOHA	PHAST
5 kW/m²	457 m	350 m	60 m	91 m
12.5kW/m²	289 m	220 m	36 m	71 m
37.5 kW/m²	156 m	50 m	12 m	53 m

ALOHA is limited to assessing hazards of chemicals that become airborne. ALOHA incorporates the models for assessing the hazards of chemicals which becomes airborne with estimating the rate of release and vaporization of chemicals from containment. PHAST solves the dispersion of accidental chemical release into the atmosphere with using validated Unified Dispersion Model (UDM) [36].

For the calculation of the chemical release and the released toxic gases dispersion, ALOHA, MEMPLEX (Distributed from Keudal av-Technik GmbH for estimation of hazard zones), BREEZE, TRACE, SAM (Lohmeyer GmbH for real time simulation of the dispersion from the hazardous materials after release from the chemical plants or by transport accidents) simulation models were used, chlorine railway accident results and ammoniac railway accident scenarios results are assessed. None of the models is found to be more conservative than others in all scenarios since the input requirements differ from the model to model [37].

ALOHA is not convenient at stable atmospheric conditions and it is not take into account chemical reactions [25].

A study performed for the providing an overview of the algorithms used by EPIcode and ALOHA to calculate evaporation rates and downwind plume concentrations and differences on results was observed. EPIcode is simple screening tool while ALOHA is more complex model with details. Both EPIcode and ALOHA use the Gaussian

plume model but they use different algorithms for the pool evaporation, ALOHA uses more complex algorithm than EPIcode. It is mentioned that user skills and expertises can have a strong influence on the differences between these models [38].

While ALOHA is considered convenient to use for specific area estimation due to its origins, user friendliness and conservative modelling results, PHAST and other softwares may be used for difficult or unusual cases [39].





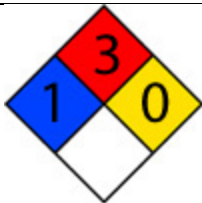
12. HAZOP AND ALOHA CASE STUDIES

In this section, different case studies were worked with HAZOP and ALOHA for an experimental set-up system for acetone and for vessel containing LPG with different leak hole diameters.

12.1 Acetone

Acetone is a colourless liquid which evaporates easily, flammable, readily soluble in water, ethanol, ether etc. and used for making drugs, plastics, fibers and other chemicals. Acetone can readily ignite under almost all ambient conditions. Acetone properties are given in the Table 12.1.

Table 12.1 : Acetone Properties [40, 41].

Name:	Acetone, β -ketopropane, Dimethyl ketone, Dimethylformaldehyde, DMK, Propanone, 2-propanone, propan-2-one.
Molecular formula:	CH_3COCH_3
Molar mass:	58.08 g/mol
Vapor pressure:	247 kPa at 20°C
Melting point:	-94.6°C
Boiling point:	56°C at 101 kPa
Flash point:	-20°C
Auto ignition temperature:	465 °C
Explosive limits:	2.5 (LEL)–13.0 (UEL) vol.%
NFPA 704 Fire Diamond Rating	

Acetone can be produced using different processes as given in below:

- Dehydrogenation of isopropyl alcohol
- As co-product in the process for phenol from cumene.

- Direct oxidation of propylene
- Hydration of propylene to give 2-propanol which is oxidized to acetone.

NFPA 704 Fire Diamond is Standard System For The Identification of The Hazards of Materials For Emergency Response and developed by the National Fire Protection Association to inform about hazards associated with the material. The label contains four coloured diamond shapes and each colored diamond associated with different type of hazard. Blue represents the health hazard (Table 12.2), red represents flammability hazard (Table 12.3), yellow represents instability (reactivity) (Table 12.4) and white represents special hazards (Table 12.5). Explanation of acetone fire diamond values are given in Table 12.6.

Table 12.2 : Health Hazard Values Descriptions [42].

Health Hazard Values	Description
4 – Deadly	Materials that under emergency conditions can be lethal.
3 – Extreme Danger	Materials that under emergency conditions can cause serious injury.
2 – Dangerous	Materials that under emergency conditions can cause temporary incapacitation or residual injury.
1 – Slight Hazard	Materials that under emergency conditions can cause significant irritation.
0 – No Hazard	Materials that offer no hazard beyond that of ordinary combustible material.

Table 12.3 : Flammability Hazard Values Descriptions [42].

Flammability (fire) Hazard Values (Flash points)	Description
4 – Below 73°F	All liquids and gases with a flash point below 73°F and a boiling point 100°F.
3 – Below 100°F	All liquids and gases with a flash points at or below 73°F and a boiling point at or above 100°F and those liquids having flash point at or above 73°F and below 100°F.
2 – Below 200°F	All liquids with a flash points at or above 100°F and below 200°F or solids that readily give off vapors.
1 – Below 200°F	All liquids, solids and semi solids with flash points at or above 200°F.
0 – Will not burn	Materials that will not burn, including any material that will not burn in air when exposed to a temperature of 1500 for a period of 5 minutes.

Table 12.4 : Reactivity Values Descriptions [42].

Reactivity Values	Description
4 – May Detonate	Materials readily capable of detonation or explosive reaction at normal temperatures and pressures. Includes materials that are very sensitive to heat, shock, or light.
3 – Explosive	Materials which when heated and under confinement are capable of detonation and which may react violently with water.
2 – Unstable	Materials which will undergo a violent chemical change at elevated temperatures and pressures but do not detonate.
1 – Normally stable	Materials which are normally stable but may become unstable in combination with other materials or at elevated temperatures and pressures.
0 – Stable	Materials that in themselves are normally stable, even under fire conditions.

Table 12.5 : Special Hazards Descriptions [42].

Special Hazards	Description
W	Water Reactive. Reacts with water in an unusual or dangerous manner.
OX	Oxidizer. Allows chemical to burn without an air supply.
SA	Simple asphyxiant gas.
CRY	Cryogenic material.
COR	Corrosive material.
POI	Poisonous material.
	Radiation warning signal.

Table 12.6 : Acetone Fire Diamond Values Descriptions.

Diamond	Hazard	Value	Description
	 Health	1	Can cause significant irritation.
	 Flammability	3	Can be ignited under almost all ambient temperature conditions.
	 Instability/Reactivity	0	Normally stable, even under fire conditions.
	 Special		

12.2 Case Study One: An Experimental Set-Up System For Acetone

Based on the experimental study carried out by Y.M. Chang et al. (2011) (Figure 12.1), 20 L stainless steel spherical tank which contains 15.8 L pure acetone is examined for HAZOP (Table 12.7) and ALOHA performed for case of BLEVE, tank

explodes and chemical burns in a fireball according to parameters given in Table 12.8 and thermal radiation threat zone results are given in Figure 12.1.

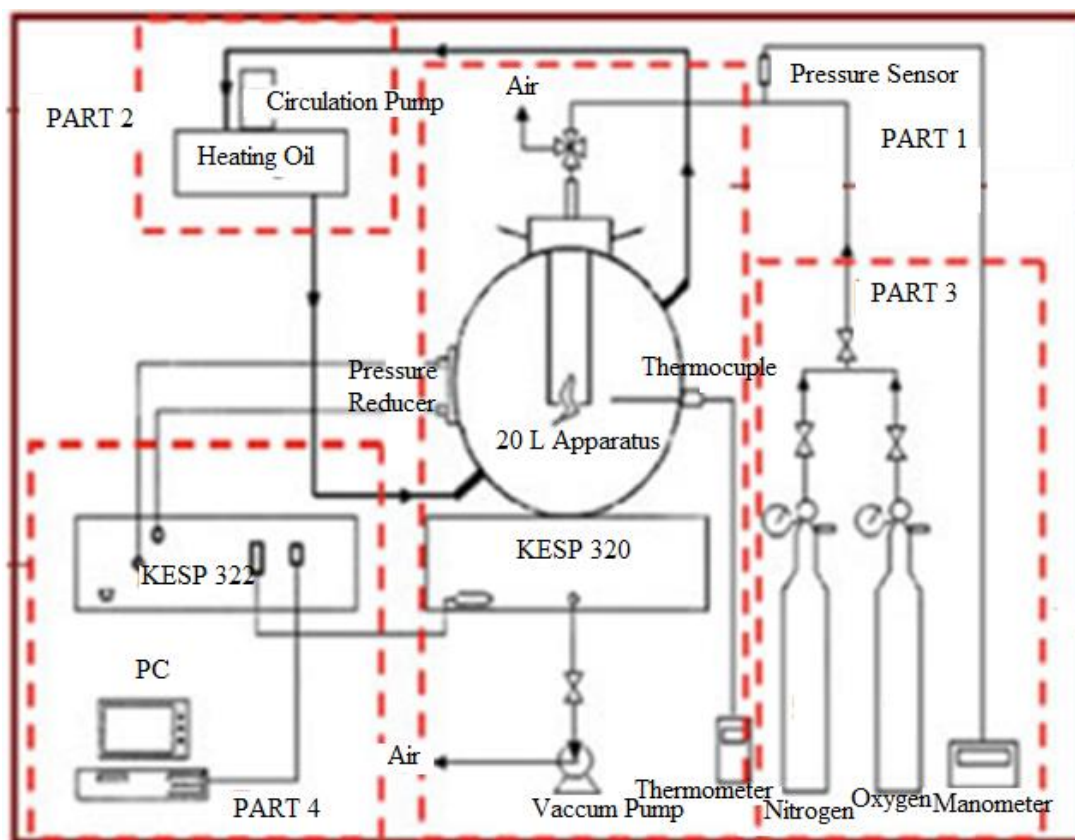


Figure 12.1 : Schematic Diagram Of The Experimental Set-Up And Its Control System [43].

Table 12.7 : HAZOP For Case Study One.

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
1	Less	Initial temperature	Less initial temperature	No acetone vapour	No generation and no well-mixed gas phase	Valve control
2	Less	Initial pressure	Less initial pressure	No acetone vapour	No generation and no well-mixed gas phase	Pressure sensor
3	Less	Heating oil	Less heating oil	Less initial temperature	No generation and no well-mixed gas phase	Valve control
4	No	Ignition	No ignition	No electric current	No explosion	Electric supply control
5	More	Heating oil	More heating oil	More initial temperature	Early explosion	Valve control

Table 12.8 : ALOHA Input Parameters For Case Study One.

Input Parameters	
Chemical Name:	Acetone
Wind:	3.3 meters/second from South
Ambient Weather:	22.7° C temperature 77% relative humidity Partly cloudy
Tank Properties:	Spherical Tank 20 L volume 200° C intertal temperature 79% full Tank contains liquid
Scenario:	BLEVE, tank explodes and chemical burns in fireball.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from fireball

Red : 23 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 33 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 51 meters --- (2.0 kW/(sq m) = pain within 60 sec)

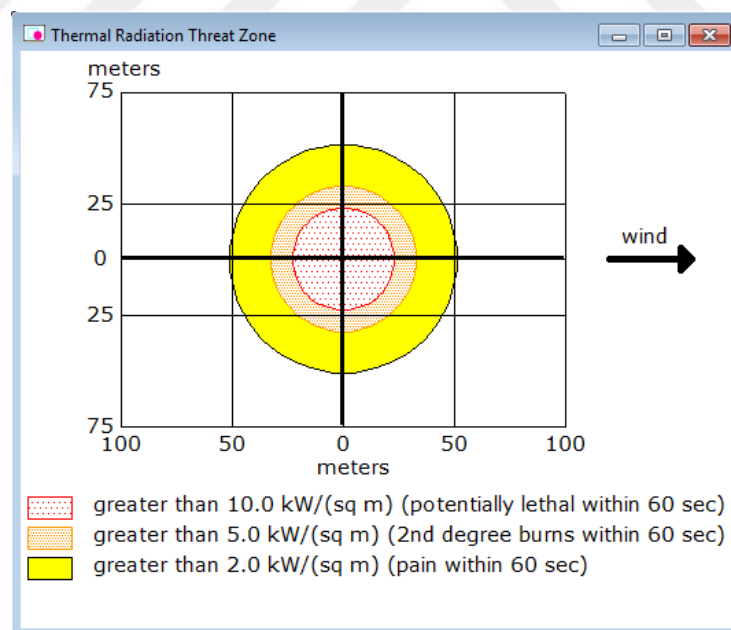


Figure 12.2 : ALOHA Thermal Radiation Threat Zone Results For Case Study One.

On the plot at Figure 12.2, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 23 meters in all directions and potentially lethal within 60 seconds

which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 33 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 51 meters in all directions and pain within 60 seconds results in slight injury.

12.3 Liquid Petroleum Gas (LPG)

Liquid Petroleum Gas (LPG) is butane and propane flammable gases mixtures with including very small quantities of other gasses. Butane, propane and LPG properties are given in Table 12.9 [45]. LPG is gas at standart temperature and pressure and generally supplied pressurised in steel pressure vessels.

LPG leakage accumulates in low ground areas. Due to its flammability, even small leaks can cause serious consequences.

LPG release causes hazards mostly occuring with dispersion, jet fire, fireball and BLEVE with causing thermal radiation from fires and overpressure effects from explosions in general [44].

HAZOP study performed for a LPG containing vessel and shared in Table 12.10.

Table 12.9 : Butane, Propane and LPG Properties [45].

	Butane	Propane	LPG
Molecular formula:	C_4H_{10}	C_3H_8	Mixture of C_3H_8 and C_4H_{10}
Molar mass:	58.12 g/mol	44.09 g/mol	53.19 g/mol
Vapor pressure:	2.60 kg/m^3 at 38°C	12.30 kg/m^3 at 38°C	5.51 kg/m^3 at 38°C
Melting point:	-138°C	-190°C	-154°C
Boiling point:	$-0,5^\circ\text{C}$	-42°C	-13°C
Flash point:	-60°C	-105°C	-74°C
Auto ignition temperature:	430°C	510°C	454°C
Low explosive limit:	1.55%	2.15%	1.96%
High explosive limit:	8.5%	9.6%	9%

Table 12.10 : HAZOP Study For A LPG Containing Vessel.

No	Guide word	Element	Deviation	Possible causes	Consequences	Action Required
1	Less	Temperature	Less Temperature	Less heating.	Less pressurisation	Control the heating device.
2	More	Temperature	More Temperature	More heating, Valve control failure, Heat exchanger control failure.	Auto ignition, Fire, Explosion.	Control the heat exchanger. Control the valve. Provide high temperature sensor/alarm.
3	Less	Gas Amount	Less Gas Amount	Vessel leaks, Valve failure, Control failure.	Unwanted leaking. Dispersion.	Provide gas level sensor. Control the valve.
4	More	Gas Amount	Gas Amount	Valve failure, Control failure.	Unwanted pressurisation.	Control the valve. Control the control system.
5	More	Pressure	More pressure	Valve failure.	Dispersion, Fire, Leakage.	Control the valve. Control the pressure gauge.
6	Less	Pressure	Less pressure	Leakage.	Unwanted operational conditions. Dispersion.	Control the heat exchanger. Control the valve.

12.4 Case Study Two: Butane Horizontal Cylindrical Tank Bottom Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters respectively 0.25 meters and 0.5 meters for the butane horizontal cylindrical tank for thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.4.1 Butane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.11.

Table 12.11 : Butane Horizontal Cylindrical Tank With 0.25 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 163 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 235 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 356 meters --- ($2.0 \text{ kW}/(\text{sq m})$) = pain within 60 sec

On the plot at Figure 12.3, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 163 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the $5 \text{ kW}/\text{m}^2$ thermal radiation extends 235 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the $2 \text{ kW}/\text{m}^2$ thermal radiation extends 356 meters in all directions and pain within 60 seconds results in slight injury.

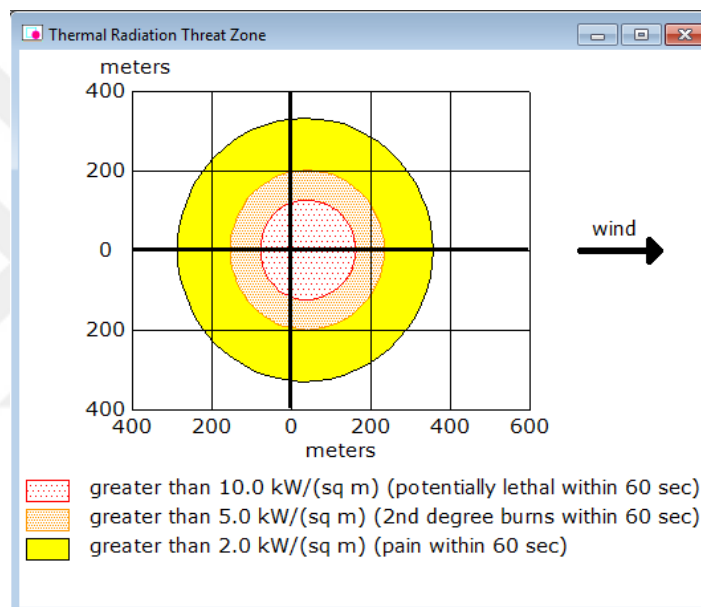


Figure 12.3 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole.

12.4.2 Butane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.12.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 293 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 438 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 679 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.12 : Butane Horizontal Cylindrical Tank With 0.5 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

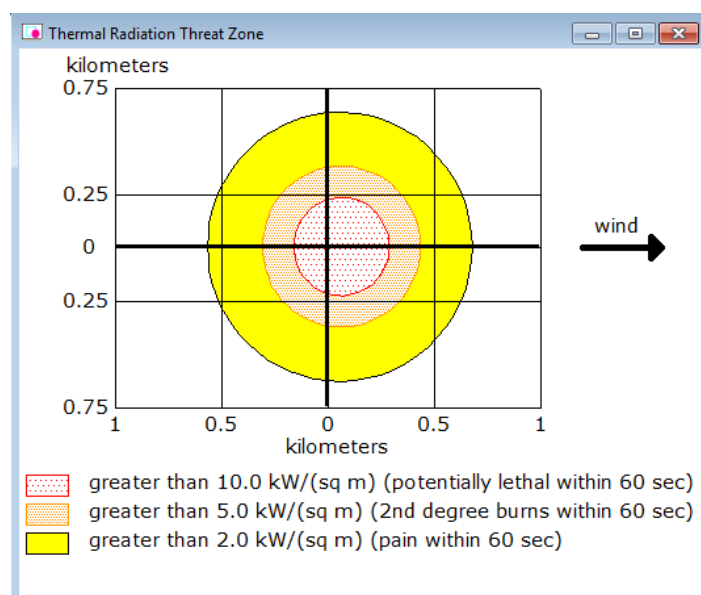


Figure 12.4 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole.

On the plot at Figure 12.4, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60

seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 293 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 438 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 679 meters in all directions and pain within 60 seconds results in slight injury.

12.4.3 Butane horizontal cylindrical tank bottom leak hole diameter comparison results

The studies performed at the same conditions but with different diameters of bottom leak hole for butane horizontal cylindrical tank, thermal radiation from jet fire. It can be seen from Table 12.13 that increase in the leak hole diameter for two times at these conditions causes almost two times increase in the red threat zone, almost two times increase in the orange threat zone and almost two times increase in the yellow threat zone.

Table 12.13 : Butane Horizontal Cylindrical Tank Bottom Leak Hole Diameter Comparison Results.

Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m)) = potentially lethal within 60 sec)	163 meters	293 meters
Orange (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)	235 meters	438 meters
Yellow (2.0 kW/(sq m)) = pain within 60 sec)	356 meters	679 meters

12.5 Case Study Three: Butane Horizontal Cylindrical Tank Top Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters at the top of the vessel for butane horizontal cylindrical tank as

thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.5.1 Butane horizontal cylindrical tank with 0.25 meters diameter top leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.14.

Table 12.14 : Butane Horizontal Cylindrical Tank With 0.25 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the top of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 150 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 216 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 326 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.15, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 150 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays

the 5 kW/m^2 thermal radiation extends 216 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 326 meters in all directions and pain within 60 seconds results in slight injury.

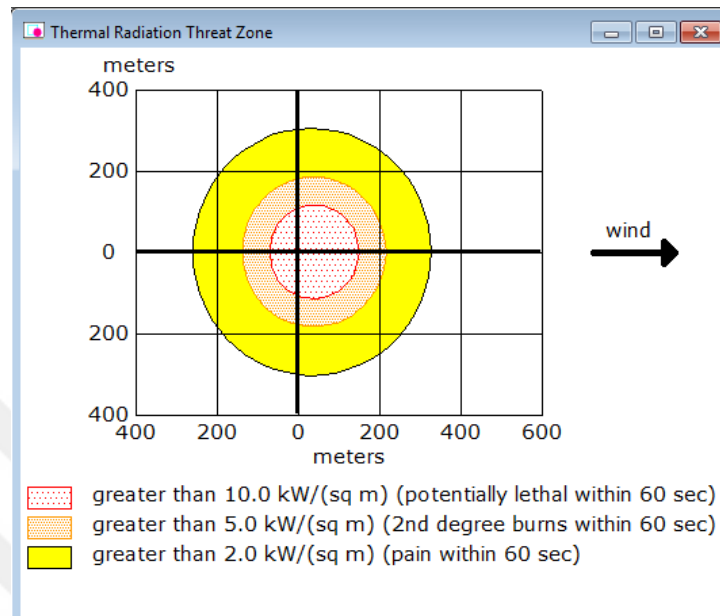


Figure 12.5 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.25 m Diameter Top Leak Hole.

12.5.2 Butane horizontal cylindrical tank with 0.5 meters diameter top leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.15.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 265 meters --- (10.0 kW/(sq m)) = potentially lethal within 60 sec)

Orange: 395 meters --- (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)

Yellow: 611 meters --- (2.0 kW/(sq m)) = pain within 60 sec)

On the plot at Figure 12.6, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 265 meters in all directions and potentially lethal within 60 seconds

which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 395 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 611 meters in all directions and pain within 60 seconds results in slight injury.

Table 12.15 : Butane Horizontal Cylindrical Tank With 0.5 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the top of the tank

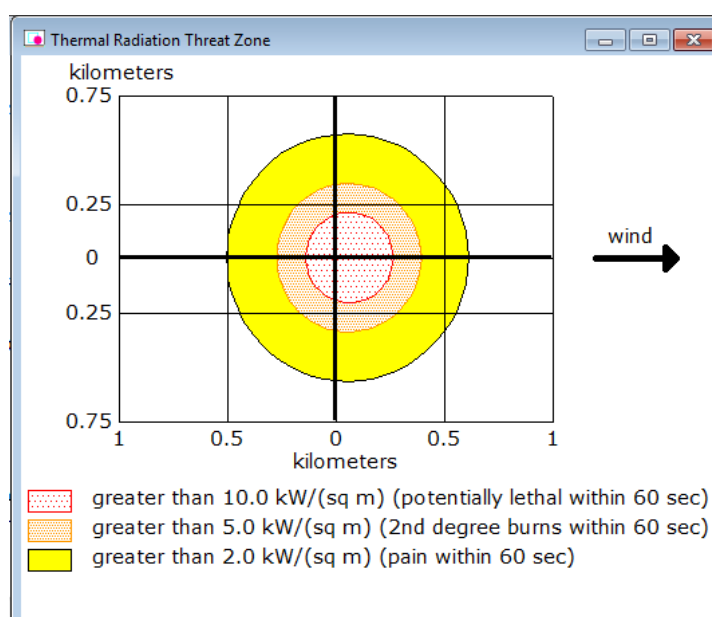


Figure 12.6 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.5 m Diameter Top Leak Hole.

12.5.3 Butane horizontal cylindrical tank top leak hole diameter comparison results

The studies performed at the same conditions but with different diameters of top leak hole for butane horizontal cylindrical tank, thermal radiation from jet fire. Comparison results are given in Table 12.16.

Table 12.16: Butane Horizontal Cylindrical Tank Top Leak Hole Diameter Comparison Results.

Thermal Radiation Thread Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	150 meters	265 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	216 meters	395 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	326 meters	611 meters

12.6 Butane Horizontal Cylindrical Tank Bottom and Top Leak Hole Diameter Comparison Results

We can summarize the thermal radiation threat zone results comparison of the leak locations as given in Table 12.17 for bottom and top leak holes according to the above studies which performed under the same conditions except for the leak location.

Table 12.17 : Butane Horizontal Cylindrical Tank Bottom and Top Leak Hole Diameter Comparison Results.

Thermal Radiation Thread Zone	Bottom Leak Hole		Top Leak Hole	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	163 meters	293 meters	150 meters	265 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	235 meters	438 meters	216 meters	395 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	356 meters	679 meters	326 meters	611 meters

12.7 Case Study Four: Butane Horizontal Cylindrical Tank With Bottom Leak Hole Filling Rate Comparison

This study aims to compare the thermal radiation threat zone effects of butane horizontal cylindrical vessel with leak hole at the bottom of the tank and have different tank filling rates under the same conditions. In the section 12.4, studies were performed for the 80% filling ratio and in this section 50% filling ratio studied for same conditions for butane horizontal cylindrical vessel with different bottom leak hole diameters and results assessed for comparison.

12.7.1 Butane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 50% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.18.

Table 12.18: Butane Horizontal Cylindrical Tank With 0.25 Meters Diameter Bottom Leak Hole and 50% Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 161 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 232 meters --- ($5.0 \text{ kW}/(\text{sq m}) = 2\text{nd degree burns within 60 sec}$)

Yellow: 352 meters --- ($2.0 \text{ kW}/(\text{sq m}) = \text{pain within 60 sec}$)

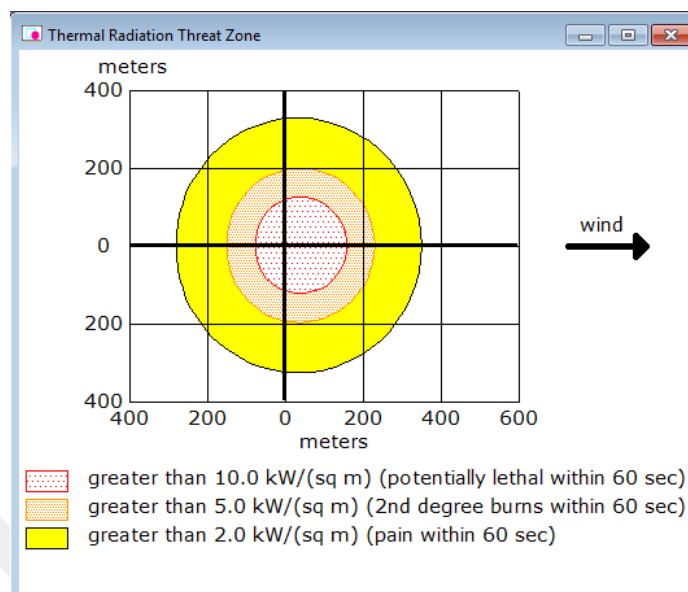


Figure 12.7 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 50% Filling Ratio.

On the plot at Figure 12.7, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 161 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the $5 \text{ kW}/\text{m}^2$ thermal radiation extends 232 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the $2 \text{ kW}/\text{m}^2$ thermal radiation extends 352 meters in all directions and pain within 60 seconds results in slight injury.

12.7.2 Butane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 50% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.19.

Table 12.19 : Butane Horizontal Cylindrical Tank With 0.5 Meters Diameter Bottom Leak Hole and 50% Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 289 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 432 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 671 meters --- (2.0 kW/(sq m) = pain within 60 sec)

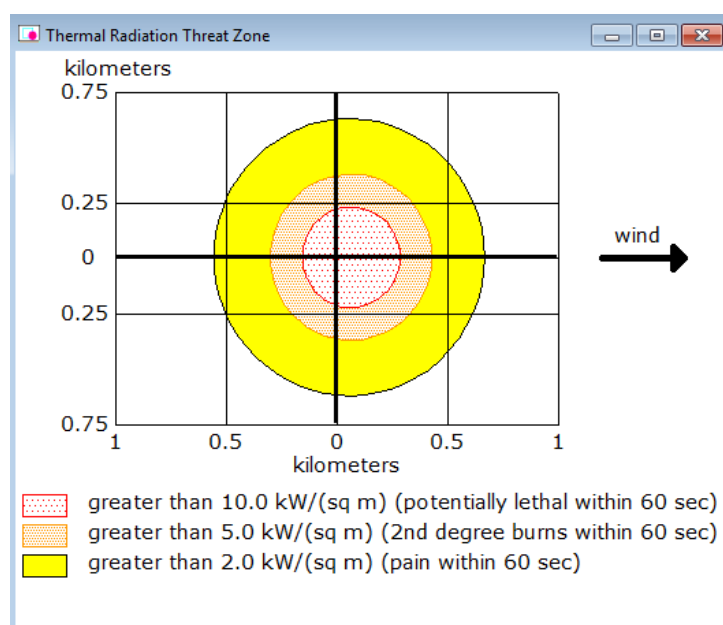


Figure 12.8 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 50% Filling Ratio.

On the plot at Figure 12.8, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 289 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 432 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 671 meters in all directions and pain within 60 seconds results in slight injury.

12.7.3 Butane horizontal cylindrical tank with bottom leak hole comparison results for %50 and 80% filling ratios

Comparison the thermal radiation threat zone results of butane horizontal cylindrical tank with leak hole at the bottom of the tank and have different tank filling rates respectively 80% and 50% under the same conditions are given in Table 12.20.

Table 12.20 : Butane Horizontal Cylindrical Tank Bottom Leak Hole Diameters and Filling Rates Comparison Results.

Thermal Radiation Threat Zone	80% Full		50% Full	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red ($10.0 \text{ kW}/(\text{sq m})$ = potentially lethal within 60 sec)	163 meters	293 meters	161 meters	289 meters
Orange ($5.0 \text{ kW}/(\text{sq m})$ = 2nd degree burns within 60 sec)	235 meters	438 meters	232 meters	432 meters
Yellow ($2.0 \text{ kW}/(\text{sq m})$ = pain within 60 sec)	356 meters	679 meters	352 meters	671 meters

12.8 Case Study Five: Butane Horizontal Cylindrical Tank With Bottom Leak Hole Wind Rate Comparison

This study aims to compare the thermal radiation threat zone effects of butane horizontal cylindrical vessel with leak hole at the bottom of the tank and have

different wind rates under the same conditions. In the section 12.4, studies was performed for the 15 meters/second from South East and in this section 30 meters/second from South East studied for same conditions for butane horizontal cylindrical vessel with different bottom leak hole diameters and results assessed for comparison.

12.8.1 Butane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.21.

Table 12.21 : Butane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 197 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 263 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 388 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.9, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 197 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 263 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 388 meters in all directions and pain within 60 seconds results in slight injury.

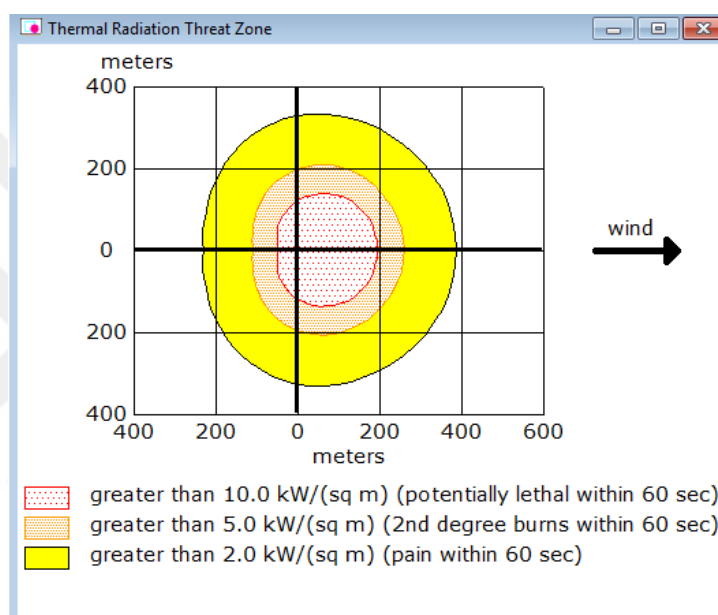


Figure 12.9 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

12.8.2 Butane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a horizontal cylindrical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.22.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 357 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 480 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 722 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.22 : Butane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

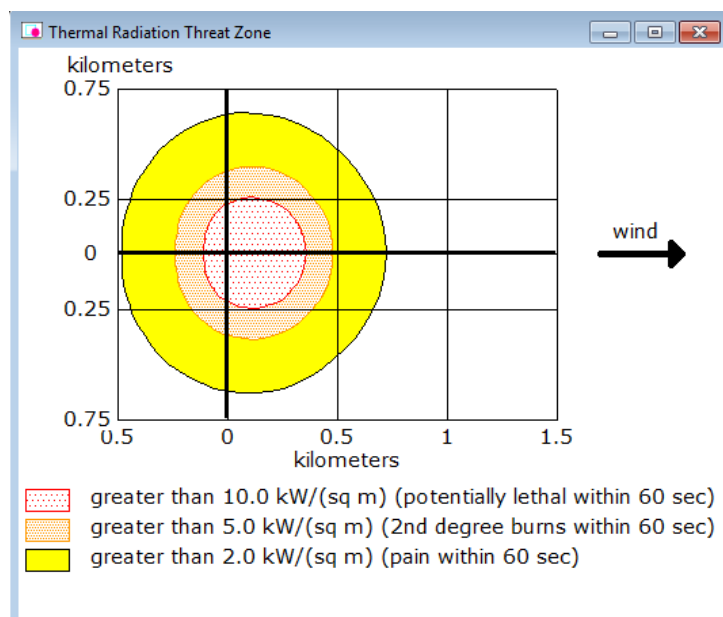


Figure 12.10 : ALOHA Thermal Radiation Threat Zone Results For Butane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

On the plot at Figure 12.10, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 357 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 480 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 722 meters in all directions and pain within 60 seconds results in slight injury.

12.8.3 Butane horizontal cylindrical tank with bottom leak hole wind rate comparison results

Comparison the thermal radiation threat zone results of butane horizontal cylindrical tank with leak hole at the bottom of the tank and have different wind rates respectively 15 meters/second from South East and 30 meters/second from South East under the same conditions are given in Table 12.23 for Red Thermal Threat Zone, Orange Thermal Threat Zone and Yellow Thermal Threat Zone.

Table 12.23 : Butane Horizontal Cylindrical Tank Bottom Leak Hole Diameters and Wind Rates Comparison Results.

	15 meters/second		30 meters/second	
Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red ($10.0 \text{ kW}/(\text{sq m})$ = potentially lethal within 60 sec)	163 meters	293 meters	197 meters	357 meters
Orange ($5.0 \text{ kW}/(\text{sq m})$ = 2nd degree burns within 60 sec)	235 meters	438 meters	263 meters	480 meters
Yellow ($2.0 \text{ kW}/(\text{sq m})$ = pain within 60 sec)	356 meters	679 meters	388 meters	722 meters

12.9 Case Study Six: Butane Spherical Tank Bottom Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters respectively 0.25 meters and 0.5 meters for the butane spherical tank for thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.9.1 Butane spherical tank with 0.25 meters diameter bottom leak hole

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.24.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 165 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 238 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 361 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.24 : Butane Spherical Tank With 0.25 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

On the plot at Figure 12.11, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60

seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 165 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 238 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 361 meters in all directions and pain within 60 seconds results in slight injury.

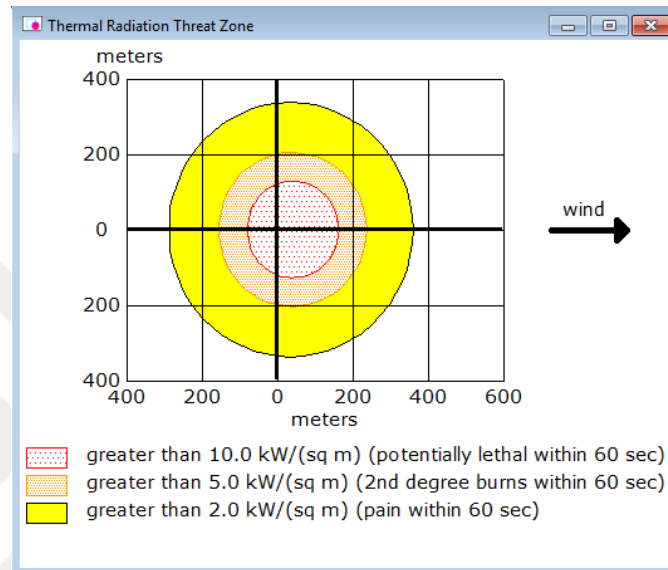


Figure 12.11 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.25 m Diameter Bottom Leak Hole.

12.9.2 Butane spherical tank with 0.5 meters diameter bottom leak hole

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.25.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 297 meters --- (10.0 kW/(sq m)) = potentially lethal within 60 sec)

Orange: 444 meters --- (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)

Yellow: 689 meters --- (2.0 kW/(sq m)) = pain within 60 sec)

On the plot at Figure 12.12, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60

seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 297 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 444 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 689 meters in all directions and pain within 60 seconds results in slight injury.

Table 12.25 : Butane Spherical Tank With 0.5 Meters Diameter Bottom Leak Hole
Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

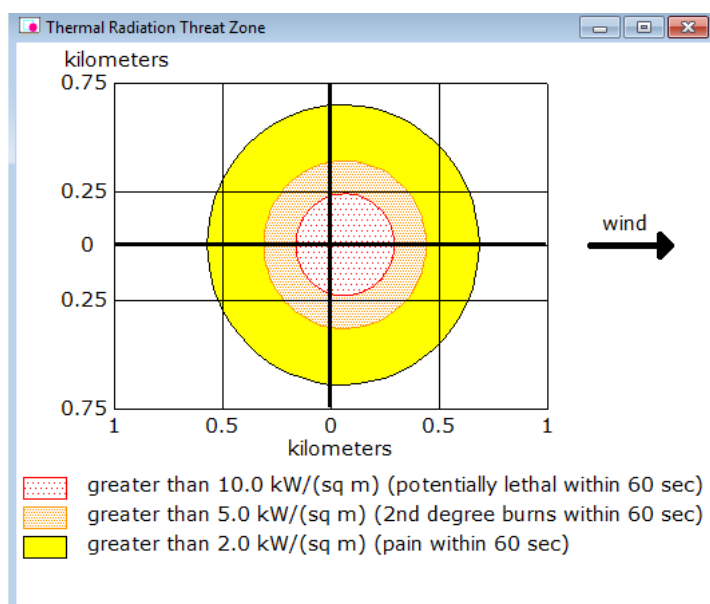


Figure 12.12 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.5 m Diameter Bottom Leak Hole.

12.9.3 Butane spherical tank bottom leak hole diameter comparison results

The studies performed at the same conditions but with different diameters of bottom leak hole for butane spherical tank, thermal radiation from jet fire and comparison given in Table 12.26.

Table 12.26 : Butane Spherical Tank Bottom Leak Hole Diameter Comparison Results.

Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	165 meters	297 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	238 meters	444 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	361 meters	689 meters

12.10 Case Study Seven: Butane Spherical Tank Top Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters at the top of the vessel for butane spherical tank as thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.10.1 Butane spherical tank with 0.25 meters diameter top leak hole

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.27.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 150 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 216 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 326 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.27 : Butane Spherical Tank With 0.25 Meters Diameter Top Leak Hole
Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the top of the tank

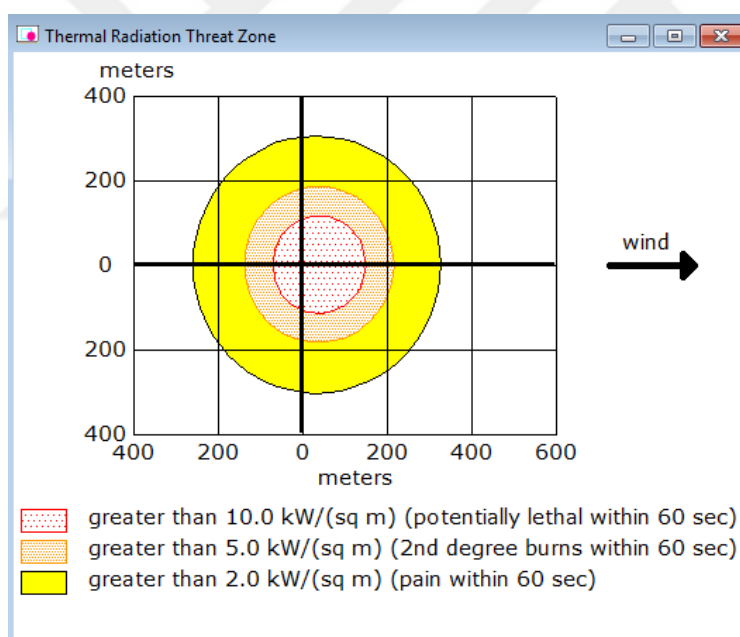


Figure 12.13 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.25 m Diameter Top Leak Hole.

On the plot at Figure 12.13, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 150 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m² thermal radiation extends 216 meters in all directions and 2nd degree

burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 326 meters in all directions and pain within 60 seconds results in slight injury.

12.10.2 Butane spherical tank with 0.5 meters diameter top leak hole

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.28.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 265 meters --- (10.0 kW/(sq m)) = potentially lethal within 60 sec)

Orange: 395 meters --- (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)

Yellow: 611 meters --- (2.0 kW/(sq m)) = pain within 60 sec)

Table 12.28 : Butane Spherical Tank With 0.5 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the top of the tank

On the plot at Figure 12.14, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 265 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays

the 5 kW/m² thermal radiation extends 395 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m² thermal radiation extends 611 meters in all directions and pain within 60 seconds results in slight injury.

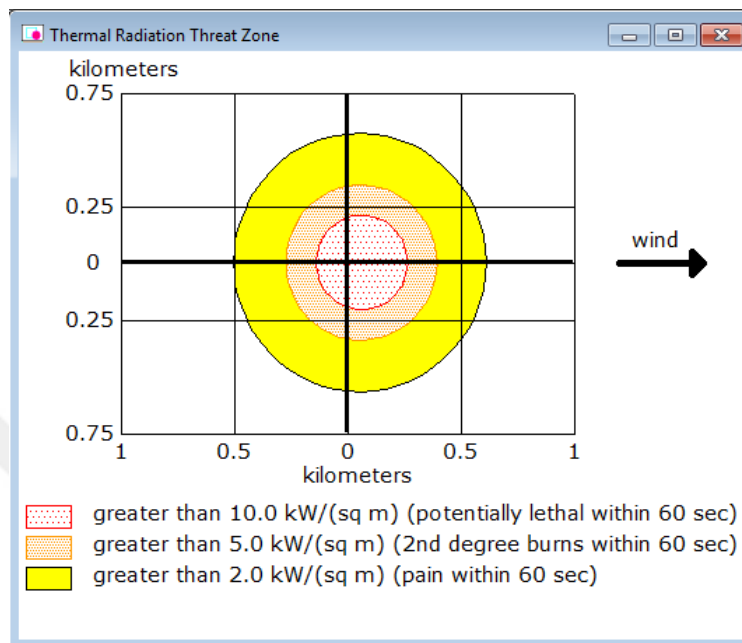


Figure 12.14 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.5 m Diameter Top Leak Hole.

12.10.3 Butane spherical tank top leak hole diameter comparison results

The studies performed at the same conditions but with different diameter top leak hole for butane spherical tank, thermal radiation from jet fire and comparison given in Table 12.29 for Red Thermal Thread Zone, Orange Thermal Thread Zone and Yellow Thermal Thread Zone.

Table 12.29 : Butane Spherical Tank Top Leak Hole Diameter Comparison Results.

Thermal Radiation Thread Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	150 meters	265 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	216 meters	395 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	326 meters	611 meters

12.11 Case Study Eight: Butane Spherical Tank With Bottom Leak Hole Filling Rate Comparison

This study aims to compare the thermal radiation threat zone effects of butane spherical vessel with leak hole at the bottom of the tank and have different tank filling rates under the same conditions. In the section 12.9, studies was performed for the 80% filling ratio and in this section 50% filling ratio studied for same conditions for butane spherical vessel with different bottom leak hole diameters and results assessed for comparison.

12.11.1 Butane spherical tank with 0.25 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a spherical tank which contains butane with 50% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.30.

Table 12.30 : Butane Spherical Tank With 0.25 Meters Diameter Bottom Leak Hole and %50 Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C intertal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 163 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 235 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 356 meters --- ($2.0 \text{ kW}/(\text{sq m})$) = pain within 60 sec)

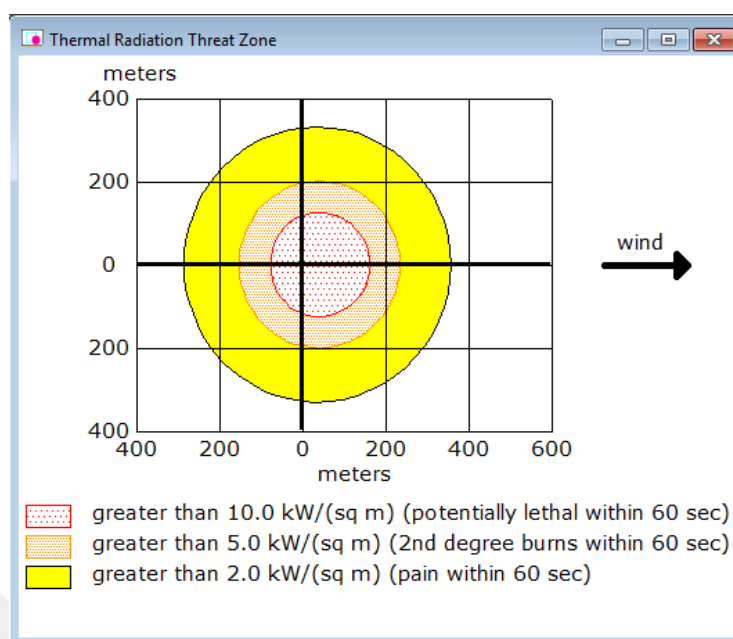


Figure 12.15 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and %50 Filling Ratio.

On the plot at Figure 12.15, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 163 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the $5 \text{ kW}/\text{m}^2$ thermal radiation extends 235 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the $2 \text{ kW}/\text{m}^2$ thermal radiation extends 356 meters in all directions and pain within 60 seconds results in slight injury.

12.11.2 Butane spherical tank with 0.5 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a spherical tank which contains butane with 50% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.31.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 292 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 437 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 678 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.31 : Butane Spherical Tank With 0.5 Meters Diameter Bottom Leak Hole and %50 Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

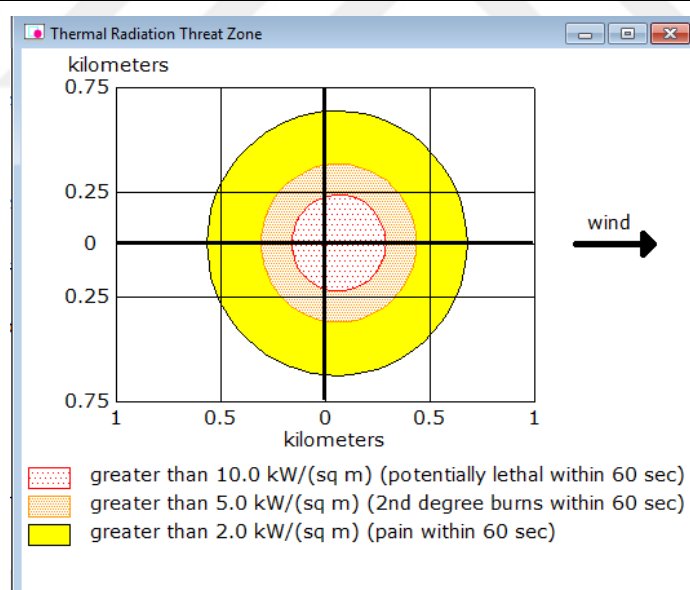


Figure 12.16 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and %50 Filling Ratio.

On the plot at Figure 12.16, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 292 meters in all directions and potentially lethal within 60 seconds

which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 437 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 678 meters in all directions and pain within 60 seconds results in slight injury.

12.11.3 Butane spherical tank with bottom leak hole comparison results for %50 and 80% filling ratios

Comparison the thermal radiation threat zone results of butane spherical vessel with leak hole at the bottom of the tank and have different tank filling rates as 50% and 80% under the same conditions are given in Table 12.32.

Table 12.32 : Butane Spherical Tank Bottom Leak Hole Diameters and Filling Rates Comparison Results.

Thermal Radiation Threat Zone	80% Full		50% Full	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	165 meters	297 meters	163 meters	292 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	238 meters	444 meters	235 meters	437 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	361 meters	689 meters	356 meters	678 meters

12.12 Case Study Nine: Butane Spherical Tank With Bottom Leak Hole Diameters and Wind Rate Comparisons

This study aims to compare the thermal radiation threat zone results of butane spherical vessel with leak hole at the bottom of the tank and have different wind rates under the same conditions. In the section 12.9, studies was performed for the 15 meters/second from South East and in this section 30 meters/second from South East studied for same conditions for butane spherical vessel with different bottom leak hole diameters and results assessed for comparison.

12.12.1 Butane spherical tank with 0.25 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.33.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 199 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 267 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 394 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.33 : Butane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

On the plot at Figure 12.17, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 199 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m² thermal radiation extends 267 meters in all directions and 2nd degree burns within 60 seconds results in serius injury. The yellow theat zone shows the 2

kW/m^2 thermal radiation extends 394 meters in all directions and pain within 60 seconds results in slight injury.

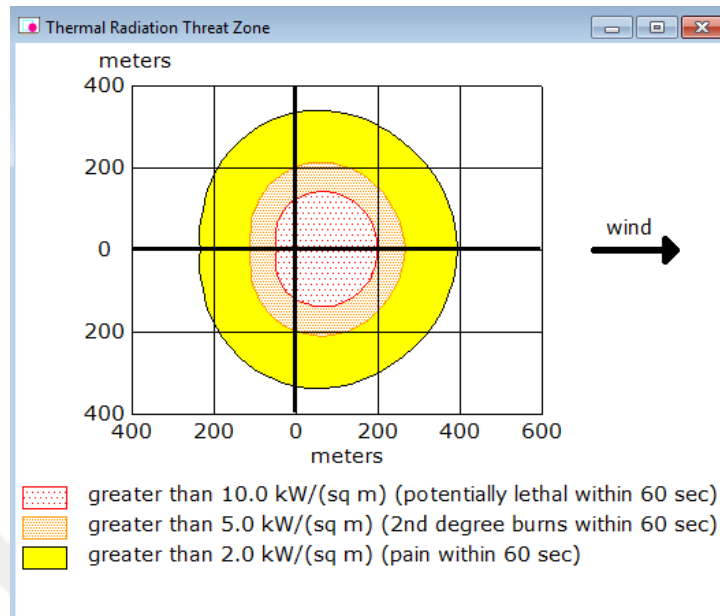


Figure 12.17 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

12.12.2 Butane spherical tank with 0.5 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a spherical tank which contains butane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.34.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 361 meters --- ($10.0 \text{ kW}/(\text{sq m})$) = potentially lethal within 60 sec)

Orange: 486 meters --- ($5.0 \text{ kW}/(\text{sq m})$) = 2nd degree burns within 60 sec)

Yellow: 732 meters --- ($2.0 \text{ kW}/(\text{sq m})$) = pain within 60 sec)

On the plot at Figure 12.18, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal

radiation extends 361 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m² thermal radiation extends 486 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m² thermal radiation extends 732 meters in all directions and pain within 60 seconds results in slight injury.

Table 12.34 : Butane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Butane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

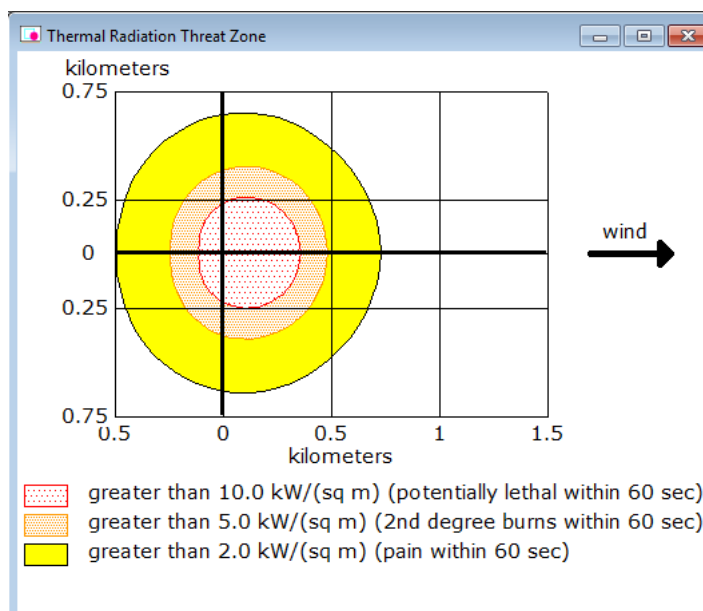


Figure 12.18 : ALOHA Thermal Radiation Threat Zone Results For Butane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

12.12.3 Butane spherical tank with bottom leak hole diameters and wind rate comparison results

Comparison the thermal radiation threat zone results of butane spherical vessel with leak hole at the bottom of the tank and have different wind rates as 30 meters/second from South East and 15 meters/second from South East under the same conditions are given in Table 12.35.

Table 12.35 : Butane Spherical Tank Bottom Leak Hole Diameters and Wind Rates Comparison Results.

Thermal Radiation Threat Zone	15 meters/second		30 meters/second	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	165 meters	297 meters	199 meters	361 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	238 meters	444 meters	267 meters	486 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	361 meters	689 meters	394 meters	732 meters

12.13 Case Study Ten: Propane Horizontal Cylindrical Tank Bottom Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters respectively 0.25 meters and 0.5 meters for the propane horizontal cylindrical tank for thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.13.1 Propane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.36.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 220 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 306 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 464 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.36 : Propane Horizontal Cylindrical Tank With 0.25 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

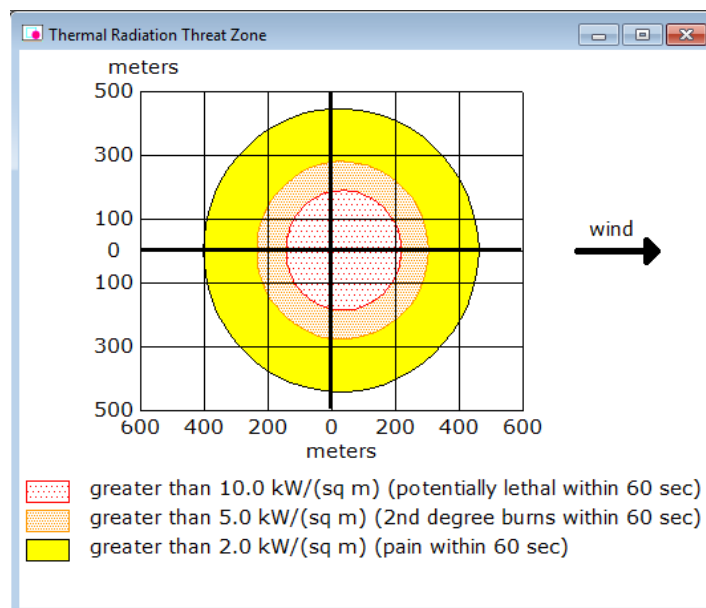


Figure 12.19 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole.

On the plot at Figure 12.19, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 220 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 306 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 464 meters in all directions and pain within 60 seconds results in slight injury.

12.13.2 Propane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.37.

Table 12.37 : Propane Horizontal Cylindrical Tank With 0.5 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 402 meters --- ($10.0 \text{ kW}/(\text{sq m})$) = potentially lethal within 60 sec)

Orange: 569 meters --- ($5.0 \text{ kW}/(\text{sq m}) = 2\text{nd degree burns within 60 sec}$)

Yellow: 868 meters --- ($2.0 \text{ kW}/(\text{sq m}) = \text{pain within 60 sec}$)

On the plot at Figure 12.20, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 402 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the $5 \text{ kW}/\text{m}^2$ thermal radiation extends 569 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the $2 \text{ kW}/\text{m}^2$ thermal radiation extends 868 meters in all directions and pain within 60 seconds results in slight injury.

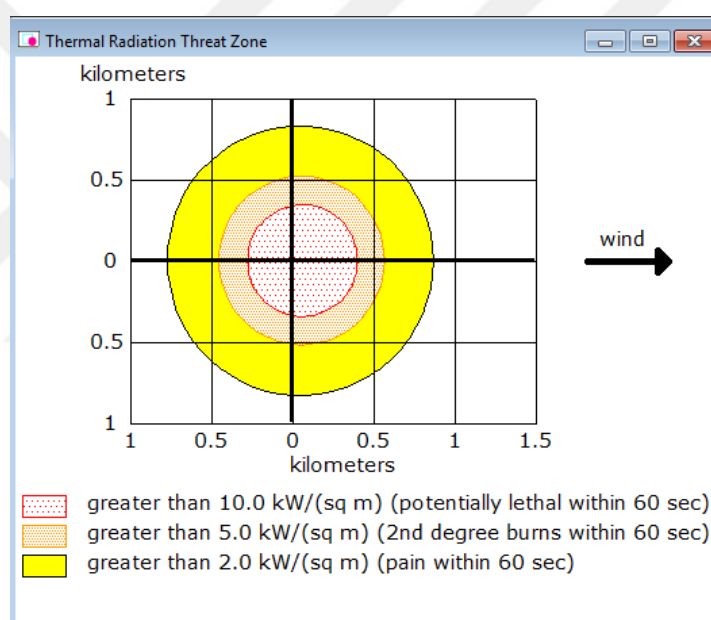


Figure 12.20 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole.

12.13.3 Propane horizontal cylindrical tank bottom leak hole diameter comparison results

The studies performed at the same conditions but with different diameters of bottom leak hole for propane horizontal cylindrical vessel, thermal radiation from jet fire. It can be seen from Table 12.38 that increase in the leak hole diameter for two times at these conditions causes almost two times increase in the red threat zone, almost two

times increase in the orange threat zone and almost two times increase in the yellow threat zone.

Table 12.38 : Propane Horizontal Cylindrical Tank Bottom Leak Hole Diameter Comparison Results.

Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	220 meters	402 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	306 meters	569 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	464 meters	868 meters

12.14 Case Study Eleven: Propane Horizontal Cylindrical Tank Top Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters at the top of the vessel for propane horizontal cylindrical tank as thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.14.1 Propane horizontal cylindrical tank with 0.25 meters diameter top leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.39.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 205 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 284 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 431 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.39 : Propane Horizontal Cylindrical Tank With 0.25 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the top of the tank

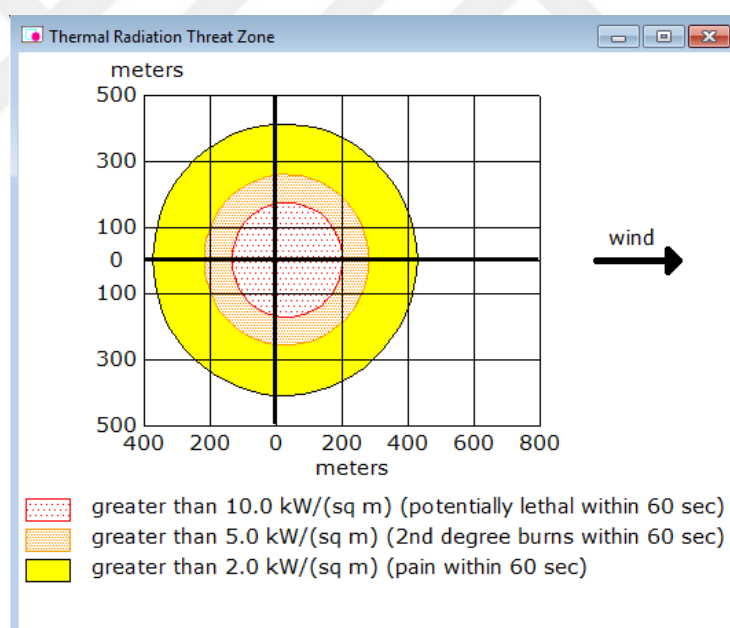


Figure 12.21 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.25 m Diameter Top Leak Hole.

On the plot at Figure 12.21, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 205 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays

the 5 kW/m² thermal radiation extends 28 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m² thermal radiation extends 431 meters in all directions and pain within 60 seconds results in slight injury.

12.14.2 Propane horizontal cylindrical tank with 0.5 meters diameter top leak hole

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.40.

Table 12.40 : Propane Horizontal Cylindrical Tank With 0.5 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the top of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 351 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 495 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 753 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.22, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60

seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 351 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 495 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 753 meters in all directions and pain within 60 seconds results in slight injury.

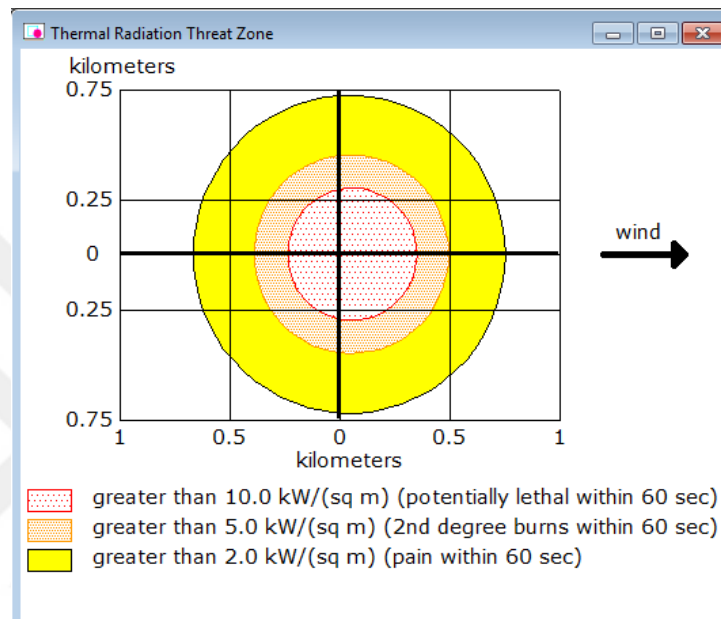


Figure 12.22 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.5 m Diameter Top Leak Hole.

12.14.3 Propane horizontal cylindrical tank top leak hole diameter comparison results

The studies performed at the same conditions but with different diameters respectively 0.25 m diameter and 0.5 m diameter of top leak hole for propane horizontal cylindrical vessel, thermal radiation from jet fire. Comparison results are given in Table 12.41 for Red Thermal Radiation Threat Zone (10.0 kW/(sq m)) = potentially lethal within 60 sec), Orange Thermal Radiation Threat Zone (5.0 kW/(sq m)) = 2nd degree burns within 60 sec) and Yellow Thermal Radiation Threat Zone (2.0 kW/(sq m)) = pain within 60 sec) and 0.25 m diameter and 0.5 m diameter of top leak hole.

Table 12.41 : Propane Horizontal Cylindrical Tank Top Leak Hole Diameter Comparison Results.

Thermal Radiation Thread Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	205 meters	351 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	284 meters	495 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	431 meters	753 meters

12.15 Propane Horizontal Cylindrical Tank Bottom and Top Leak Hole Diameter Comparison Results

We can summarize the thermal radiation threat zone results comparison of the leak locations as given in Table 12.42 for bottom and top leak holes according to the above studies which performed under the same conditions except for the leak location for Red Thermal Radiation Thread Zone (10.0 kW/(sq m) = potentially lethal within 60 sec), Orange Thermal Radiation Thread Zone (5.0 kW/(sq m) = 2nd degree burns within 60 sec) and Yellow Thermal Radiation Thread Zone (2.0 kW/(sq m) = pain within 60 sec).

Table 12.42 : Propane Horizontal Cylindrical Tank Bottom and Top Leak Hole Diameter Comparison Results.

Thermal Radiation Thread Zone	Bottom Leak Hole		Top Leak Hole	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	220 meters	402 meters	205 meters	351 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	306 meters	569 meters	284 meters	495 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	464 meters	868 meters	431 meters	753 meters

12.16 Case Study Twelve: Propane Horizontal Cylindrical Tank With Bottom Leak Hole Filling Rate Comparison

This study aims to compare the thermal radiation threat zone effects of propane horizontal cylindrical vessel with leak hole at the bottom of the tank and have different tank filling rates under the same conditions. In the section 12.13, studies was performed for the 80% filling ratio and in this section 50% filling ratio studied for same conditions for butane horizontal cylindrical vessel with different bottom leak hole diameters and results assessed for comparison.

12.16.1 Propane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 50% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.43.

Table 12.43 : Propane Horizontal Cylindrical Tank With 0.25 Meters Diameter Bottom Leak Hole and 50% Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 220 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 305 meters --- ($5.0 \text{ kW}/(\text{sq m}) = 2\text{nd degree burns within 60 sec}$)

Yellow: 463 meters --- ($2.0 \text{ kW}/(\text{sq m}) = \text{pain within 60 sec}$)

On the plot at Figure 12.23, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 220 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the $5 \text{ kW}/\text{m}^2$ thermal radiation extends 305 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the $2 \text{ kW}/\text{m}^2$ thermal radiation extends 463 meters in all directions and pain within 60 seconds results in slight injury.

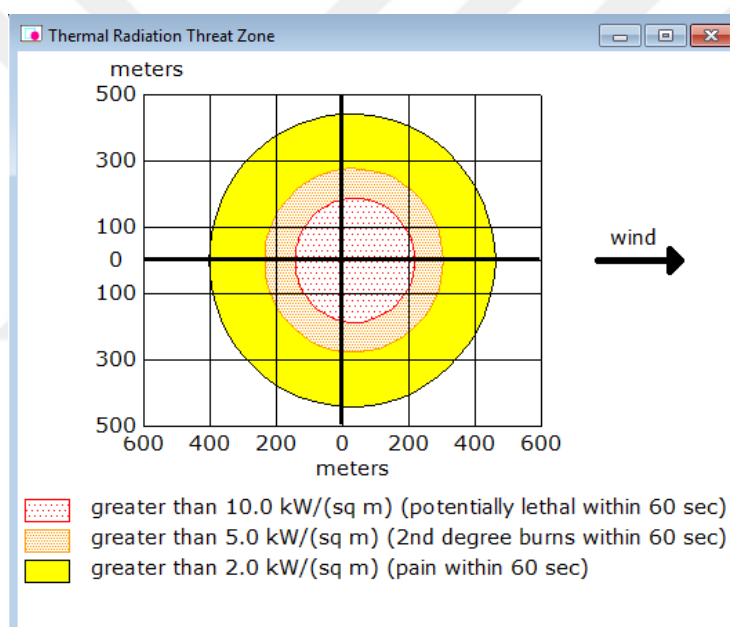


Figure 12.23 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 50% Filling Ratio.

12.16.2 Propane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 50% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.44.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 356 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 503 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 766 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.44 : Propane Horizontal Cylindrical Tank With 0.5 Meters Diameter Bottom Leak Hole and 50% Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

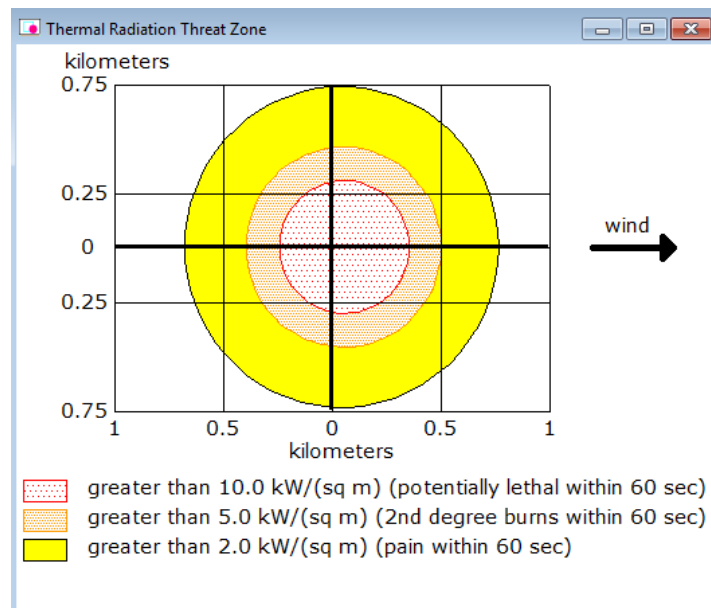


Figure 12.24 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 50% Filling Ratio.

On the plot at Figure 12.24, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 356 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 503 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 766 meters in all directions and pain within 60 seconds results in slight injury.

12.16.3 Propane horizontal cylindrical tank with bottom leak hole comparison results for %50 and 80% filling ratios

Comparison the thermal radiation threat zone results of propane horizontal cylindrical vessel with leak hole at the bottom of the tank and have different tank filling rates as 50% and 80% under the same conditions are given in Table 12.45.

Table 12.45 : Propane Horizontal Cylindrical Tank Bottom Leak Hole Diameters and Filling Rates Comparison Results.

Thermal Radiation Threat Zone	80% Full		50% Full	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red ($10.0 \text{ kW}/(\text{sq m})$ = potentially lethal within 60 sec)	220 meters	402 meters	220 meters	356 meters
Orange ($5.0 \text{ kW}/(\text{sq m})$ = 2nd degree burns within 60 sec)	306 meters	569 meters	305 meters	503 meters
Yellow ($2.0 \text{ kW}/(\text{sq m})$ = pain within 60 sec)	464 meters	868 meters	463 meters	431 meters

12.17 Case Study Thirteen: Propane Horizontal Cylindrical Tank With Bottom Leak Hole Wind Rate Comparison

This study aims to compare the thermal radiation threat zone effects of propane horizontal cylindrical vessel with leak hole at the bottom of the tank and have different wind rates under the same conditions. In the section 12.13, studies was

performed for the 15 meters/second from South East and in this section 30 meters/second from South East studied for same conditions for propane horizontal cylindrical vessel with different bottom leak hole diameters and results assessed for comparison.

12.17.1 Propane horizontal cylindrical tank with 0.25 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.46.

Table 12.46: Propane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 245 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 333 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 493 meters --- (2.0 kW/(sq m) = pain within 60 sec)

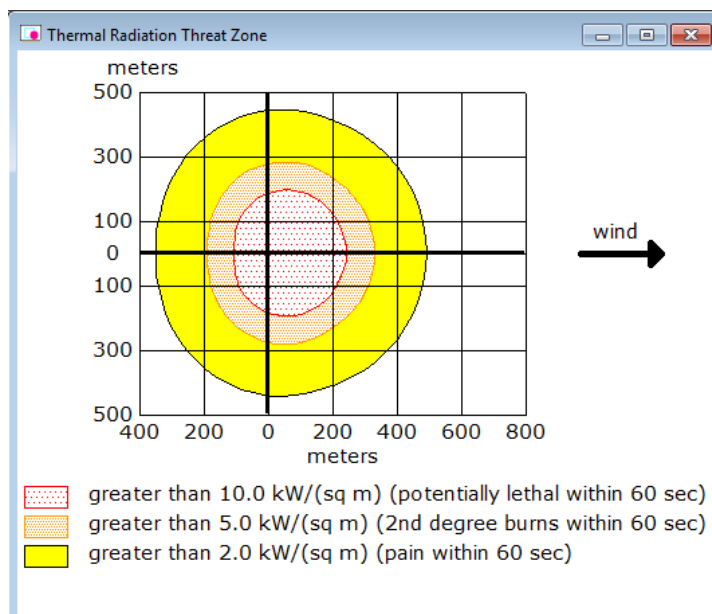


Figure 12.25 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

On the plot at Figure 12.25, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 245 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 333 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 493 meters in all directions and pain within 60 seconds results in slight injury.

12.17.2 Propane horizontal cylindrical tank with 0.5 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a horizontal cylindrical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.47.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 446 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 602 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 913 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.47 : Propane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Horizontal Cylindrical Tank 4.5 meters diameter 11.5 meters length 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

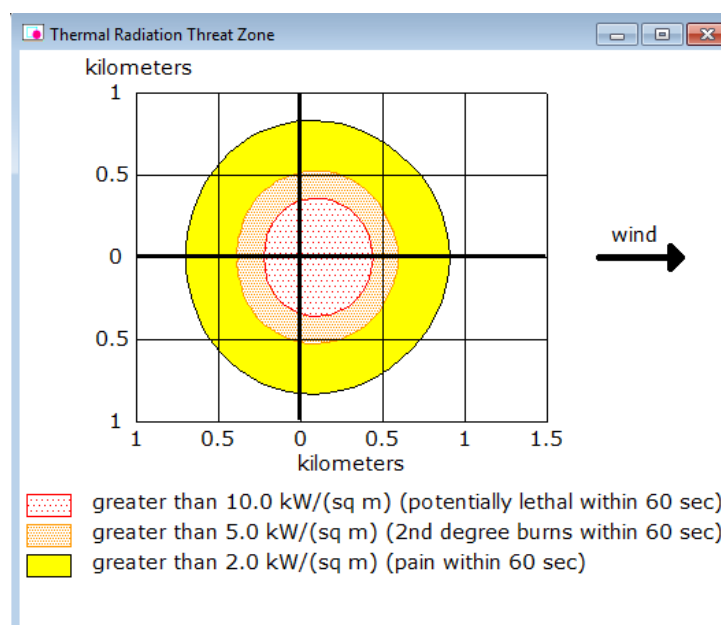


Figure 12.26 : ALOHA Thermal Radiation Threat Zone Results For Propane Horizontal Cylindrical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

On the plot at Figure 12.26, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 446 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 602 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 913 meters in all directions and pain within 60 seconds results in slight injury.

12.17.3 Propane horizontal cylindrical tank with bottom leak hole wind rate comparison results

Comparison the thermal radiation threat zone results of propane horizontal cylindrical vessel with leak hole at the bottom of the tank and have different wind rates as 30 meters/second from South East and 15 meters/second from South East under the same conditions are given in Table 12.48 for Red Thermal Radiation Thread Zone (10.0 kW/(sq m)) = potentially lethal within 60 sec), Orange Thermal Radiation Thread Zone (5.0 kW/(sq m)) = 2nd degree burns within 60 sec) and Yellow Thermal Radiation Thread Zone (2.0 kW/(sq m)) = pain within 60 sec).

Table 12.48 : Propane Horizontal Cylindrical Tank Bottom Leak Hole Diameters and Wind Rates Comparison Results.

Thermal Radiation Thread Zone	15 meters/second		30 meters/second	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m)) = potentially lethal within 60 sec)	220 meters	402 meters	245 meters	446 meters
Orange (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)	306 meters	569 meters	333 meters	602 meters
Yellow (2.0 kW/(sq m)) = pain within 60 sec)	464 meters	868 meters	493 meters	913meters

12.18 Case Study Fourteen: Propane Spherical Tank Bottom Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters respectively 0.25 meters and 0.5 meters for the propane spherical tank for thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.18.1 Propane spherical tank with 0.25 meters diameter bottom leak hole

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.49.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 221 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 307 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 465 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.49 : Propane Spherical Tank With 0.25 Meters Diameter Bottom Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

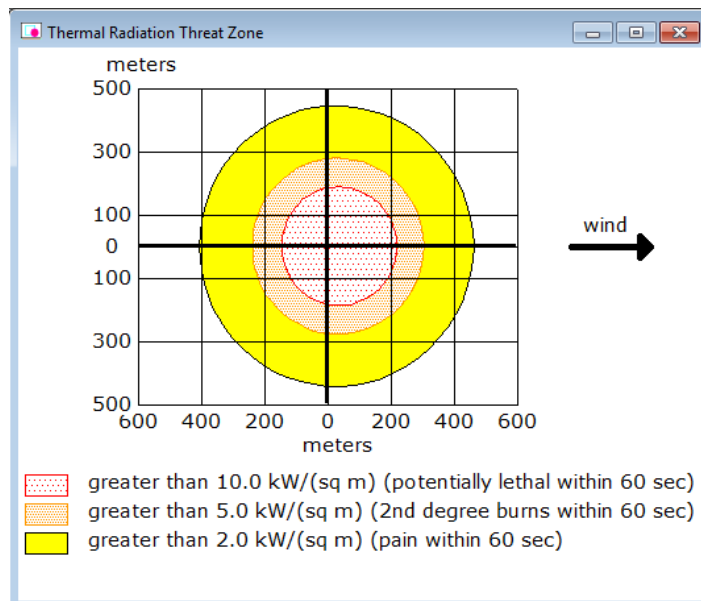


Figure 12.27 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.25 m Diameter Bottom Leak Hole.

On the plot at Figure 12.27, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 221 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 307 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 465 meters in all directions and pain within 60 seconds results in slight injury.

12.18.2 Propane spherical tank with 0.5 meters diameter bottom leak hole

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.50.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 402 meters --- (10.0 kW/(sq m)) = potentially lethal within 60 sec)

Orange: 570 meters --- (5.0 kW/(sq m)) = 2nd degree burns within 60 sec)

Yellow: 870 meters --- ($2.0 \text{ kW}/(\text{sq m})$) = pain within 60 sec)

Table 12.50 : Propane Spherical Tank With 0.5 Meters Diameter Bottom Leak Hole
Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

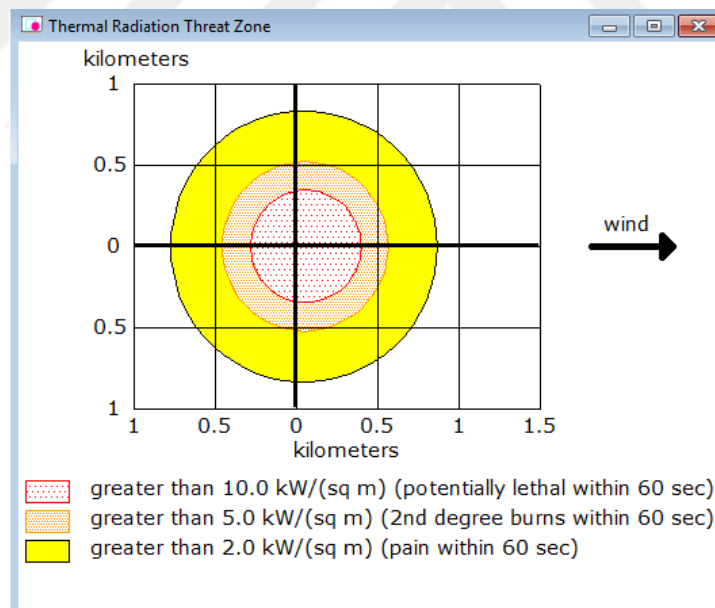


Figure 12.28 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.5 m Diameter Bottom Leak Hole.

On the plot at Figure 12.28, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the $10 \text{ kW}/\text{m}^2$ thermal radiation extends 402 meters in all directions and potentially lethal within 60 seconds

which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 570 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 870 meters in all directions and pain within 60 seconds results in slight injury.

12.18.3 Propane spherical tank bottom leak hole diameter comparison results

The studies performed at the same conditions but with different diameters of bottom leak hole for propane spherical vessel, thermal radiation from jet fire and comparison given in Table 12.51.

Table 12.51 : Propane Spherical Tank Bottom Leak Hole Diameter Comparison Results.

Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red ($10.0 \text{ kW}/(\text{sq m})$ = potentially lethal within 60 sec)	221 meters	402 meters
Orange ($5.0 \text{ kW}/(\text{sq m})$ = 2nd degree burns within 60 sec)	307 meters	570 meters
Yellow ($2.0 \text{ kW}/(\text{sq m})$ = pain within 60 sec)	465 meters	870 meters

12.19 Case Study Fifteen: Propane Spherical Tank Top Leak Hole Diameter Comparison

In this section, two studies performed at the same conditions but with different leak hole diameters at the top of the tank for propane spherical tank as thermal radiation from jet fire scenario to see the effects of leak diameter on thermal radiation threat zone.

12.19.1 Propane spherical tank with 0.25 meters diameter top leak hole

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.52.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 205 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 284 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 431 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Table 12.52 : Propane Spherical Tank With 0.25 Meters Diameter Top Leak Hole
Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the top of the tank

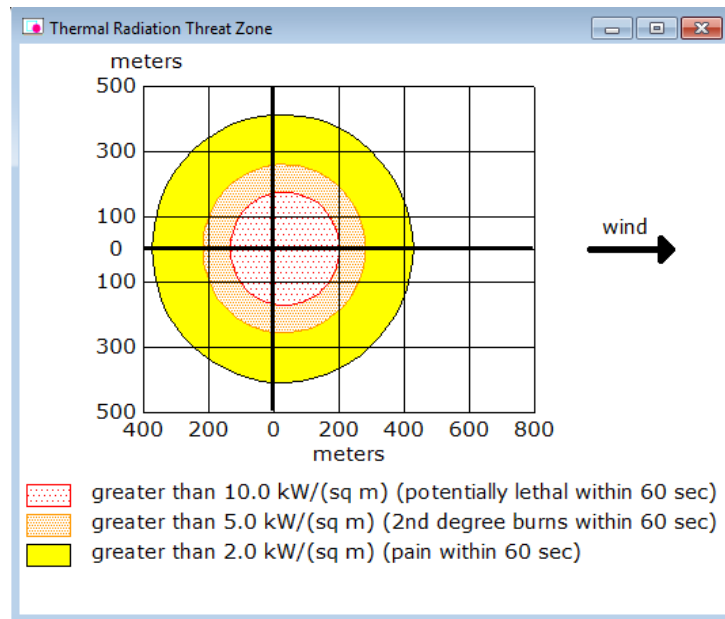


Figure 12.29 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.25 m Diameter Top Leak Hole.

On the plot at Figure 12.29, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 205 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 284 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 431 meters in all directions and pain within 60 seconds results in slight injury.

12.19.2 Propane spherical tank with 0.5 meters diameter top leak hole

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the top that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.53.

Table 12.53 : Propane Spherical Tank With 0.5 Meters Diameter Top Leak Hole Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the top of the tank

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 351 meters --- ($10.0 \text{ kW}/(\text{sq m})$) = potentially lethal within 60 sec)

Orange: 495 meters --- ($5.0 \text{ kW}/(\text{sq m})$) = 2nd degree burns within 60 sec)

Yellow: 753 meters --- ($2.0 \text{ kW}/(\text{sq m})$) = pain within 60 sec)

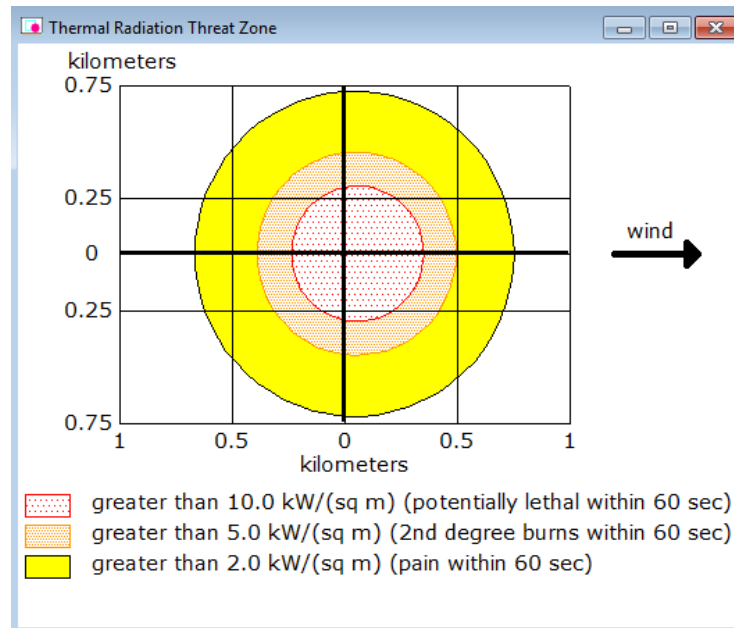


Figure 12.30 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.5 m Diameter Top Leak Hole.

On the plot at Figure 12.30, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 351 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 495 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 753 meters in all directions and pain within 60 seconds results in slight injury.

12.19.3 Propane spherical tank top leak hole diameter comparison results

The studies performed at the same conditions but with different diameters respectively 0.25 m diameter and 0.5 m diameter top leak hole for butane spherical vessel, thermal radiation from jet fire and comparison given in Table 12.54 for Red Thermal Radiation Threat Zone (10.0 kW/(sq m)) = potentially lethal within 60 sec), Orange Thermal Radiation Threat Zone (5.0 kW/(sq m)) = 2nd degree burns within 60 sec) and Yellow Thermal Radiation Threat Zone (2.0 kW/(sq m)) = pain within 60 sec).

Table 12.54 : Propane Spherical Tank Top Leak Hole Diameter Comparison Results.

Thermal Radiation Threat Zone	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	205 meters	351 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	284 meters	495 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	868 meters	753 meters

12.20 Case Study Sixteen: Propane Spherical Tank With Bottom Leak Hole Filling Rate Comparison

This study aims to compare the thermal radiation threat zone effects of propane spherical vessel with leak hole at the bottom of the tank and have different tank filling rates under the same conditions. In the section 12.18, studies was performed for the 80% filling ratio and in this section 50% filling ratio studied for same conditions for propane spherical vessel with different bottom leak hole diameters and results assessed for comparison.

12.20.1 Propane spherical tank with 0.25 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a spherical tank which contains propane with 50% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.55.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 220 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 305 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 463 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.31, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60

seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 220 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 305 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m^2 thermal radiation extends 463 meters in all directions and pain within 60 seconds results in slight injury.

Table 12.55 : Propane Spherical Tank With 0.25 Meters Diameter Bottom Leak Hole and %50 Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

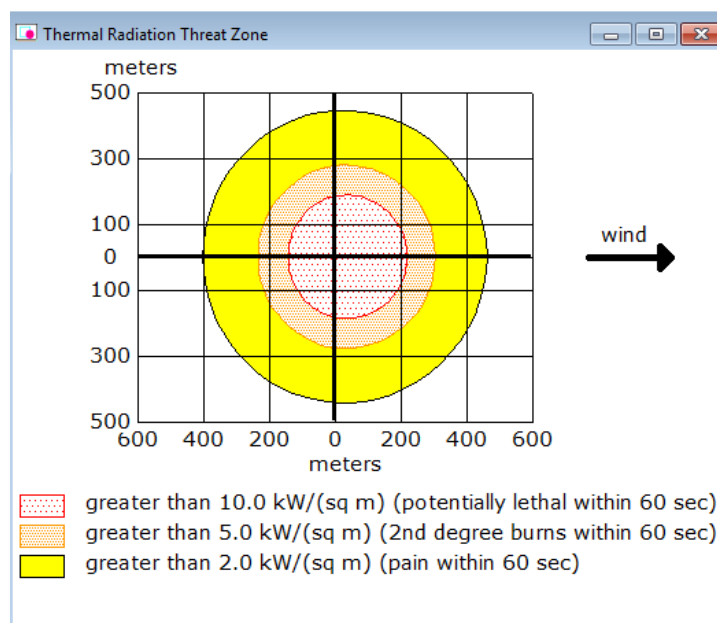


Figure 12.31 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and %50 Filling Ratio.

12.20.2 Propane spherical tank with 0.5 meters diameter bottom leak hole and %50 filling ratio

In this study, it is assumed that a spherical tank which contains propane with 50% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire. ALOHA input parameters are given in Table 12.56.

Table 12.56 : Propane Spherical Tank With 0.5 Meters Diameter Bottom Leak Hole and %50 Filling Ratio Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	15 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 50% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

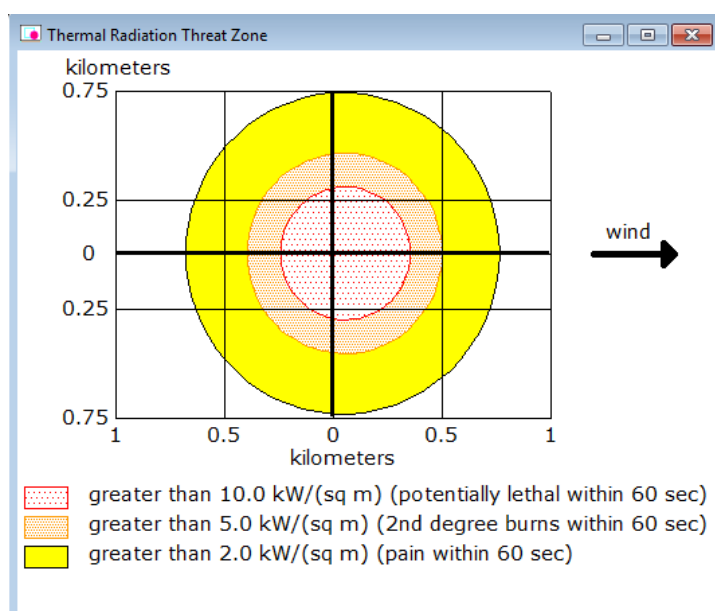


Figure 12.32 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and %50 Filling Ratio.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 356 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 503 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 766 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.32, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 220 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m² thermal radiation extends 305 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m² thermal radiation extends 463 meters in all directions and pain within 60 seconds results in slight injury.

12.20.3 Propane spherical tank with bottom leak hole comparison results for %50 and 80% filling ratios

Comparison the thermal radiation threat zone results of propane spherical vessels with leak hole at the bottom of the tank and have different tank filling rates as 50% and 80% under the same conditions are given in Table 12.57 for Red Thermal Radiation Thread Zone, Orange Thermal Radiation Thread Zone and Yellow Thermal Radiation Thread Zone.

Table 12.57 : Propane Spherical Tank Bottom Leak Hole Diameters and Filling Rates Comparison Results.

Thermal Radiation Thread Zone	80% Full		50% Full	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	221 meters	402 meters	220 meters	356 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	307 meters	570 meters	305 meters	503 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	465 meters	870 meters	463 meters	766 meters

12.21 Case Study Seventeen: Propane Spherical Tank With Bottom Leak Hole Diameters and Wind Rate Comparisons

This study aims to compare the thermal radiation threat zone results of propane spherical vessel with leak hole at the bottom of the tank and have different wind rates under the same conditions. In the section 12.18, studies was performed for the 15 meters/second from South East and in this section 30 meters/second from South East studied for same conditions for propane spherical vessel with different bottom leak hole diameters and results assessed for comparison.

12.21.1 Propane spherical tank with 0.25 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.25 meters circular leak hole at the bottom that the chemical escaped and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.58.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 246 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 333 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 494 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.33, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m^2 thermal radiation extends 246 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m^2 thermal radiation extends 333 meters in all directions and 2nd degree burns within 60 seconds results in serius injury. The yellow theat zone shows the 2 kW/m^2 thermal radiation extends 494 meters in all directions and pain within 60 seconds results in slight injury.

Table 12.58 : Propane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C internal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.25 meters leak hole at the bottom of the tank

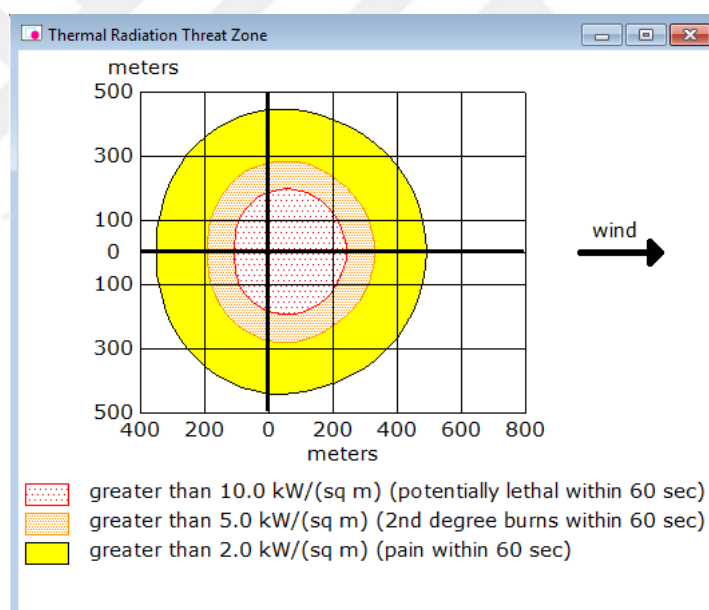


Figure 12.33 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.25 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

12.21.2 Propane spherical tank with 0.5 meters diameter bottom leak hole and 30 meters/second from south east wind

In this study, it is assumed that a spherical tank which contains propane with 80% filling ratio has 0.5 meters circular leak hole at the bottom that the chemical escaped

and burned as a jet fire and wind rate is 30 meters/second from South East. ALOHA input parameters are given in Table 12.59.

Table 12.59 : Propane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind Study ALOHA Input Parameters.

Input Parameters	
Chemical Name:	Propane
Wind:	30 meters/second from South East
Ambient Weather:	23° C temperature 70% relative humidity Clear
Tank Properties:	Spherical Tank 7 meters diameter 183 m ³ volume 21° C intertal temperature 80% full Tank contains liquid
Scenario:	The chemical escaped from the tank and burned as a jet fire.
Leak Properties:	0.5 meters leak hole at the bottom of the tank

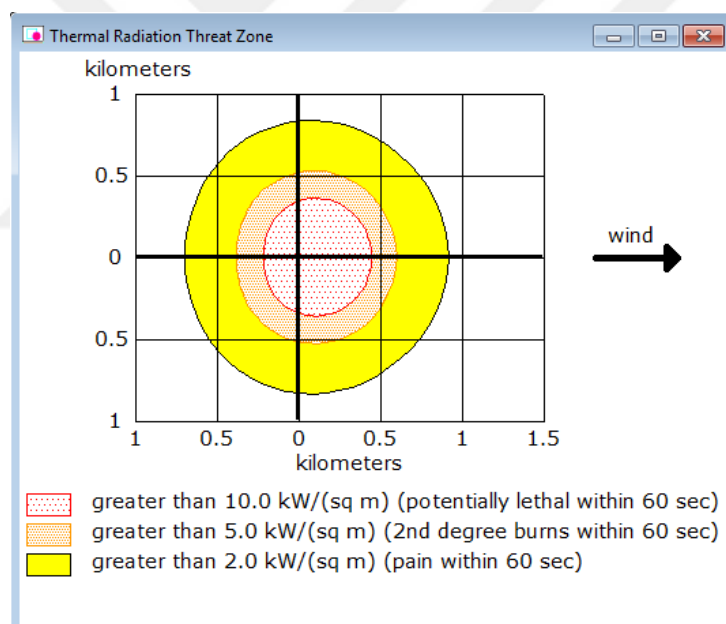


Figure 12.34 : ALOHA Thermal Radiation Threat Zone Results For Propane Spherical Tank With 0.5 m Diameter Bottom Leak Hole and 30 meters/second from South East Wind.

THREAT ZONE RESULTS:

Threat Modeled: Thermal radiation from jet fire

Red : 447 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 603 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 915 meters --- (2.0 kW/(sq m) = pain within 60 sec)

On the plot at Figure 12.34, the red, orange and yellow areas represent the damaged regions respectively potentially lethal within 60 seconds, 2nd degree burns within 60 seconds, pain within 60 seconds. The red threat zone shows the 10 kW/m² thermal radiation extends 471 meters in all directions and potentially lethal within 60 seconds which means will cause the loss of lives in this area. The orange threat zone displays the 5 kW/m² thermal radiation extends 603 meters in all directions and 2nd degree burns within 60 seconds results in serious injury. The yellow threat zone shows the 2 kW/m² thermal radiation extends 915 meters in all directions and pain within 60 seconds results in slight injury.

12.21.3 Propane spherical tank with bottom leak hole diameters and wind rate comparison results

Comparison the thermal radiation threat zone results of propane spherical vessels with leak hole at the bottom of the tank and have different wind rates as 30 meters/second from South East and 15 meters/second from South East under the same conditions are given in Table 12.60.

Table 12.60 : Propane Spherical Tank Bottom Leak Hole Diameters and Wind Rates Comparison Results.

Thermal Radiation Threat Zone	15 meters/second		30 meters/second	
	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole	0.25 m Diameter Leak Hole	0.5 m Diameter Leak Hole
Red (10.0 kW/(sq m) = potentially lethal within 60 sec)	221 meters	402 meters	246 meters	447 meters
Orange (5.0 kW/(sq m) = 2nd degree burns within 60 sec)	307 meters	570 meters	333 meters	603 meters
Yellow (2.0 kW/(sq m) = pain within 60 sec)	465 meters	870 meters	494 meters	915 meters



13 CONCLUSION

Big hazardous events can happen because of a technical failures, personal failures, natural disasters, terrorist attacks, sabotages, fires and consequences as fire, explosion and toxic release can be dangerous to the human health, environment and cause economic loss. Determination, prevention and control of these consequences are very important.

National software with including necessary informations about Turkey as atmospheric data etc. should be prepared and should be used by the SEVESO companies which locates in Turkey.

Engineering students must have a knowladge about the tools to apply scientific laws to design and operation of hazardous technologies safely and environmentally.

Fault detection and diagnosis studies must be go forward.



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