# Thermal Radiation Modeling and the Formulation of Active and Passive Fire Protection Strategies for Mass Hydrocarbon Storage

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**Abstract:** *Dealing with the handling and bulk storage of hydrocarbons, common incidents like fires and explosions frequently occur, severely impacting human life, property, and the environment. Spillage of liquid or liquefied gases often happens at these facilities, and if an ignition source is present, the spill can instantaneously catch fire, leading to life-threatening pool fires. Recent research on the combustion characteristics of large petroleum fires highlights the necessity of large-scale experiments to understand real tank fire behavior. Although these experiments are highly costly and require massive open spaces, worldwide collaboration is vital to advance pool fire research, fire safety design, and firefighting engineering. Radiated heat from a pool fire plays a crucial role as one of the prominent factors driving the spread of fire to nearby tanks or objects. Because radiated heat alone causes many secondary accidents and threatens life and property, it is imperative to quantify the heat transferred to objects situated at a distance. Determining this heat transfer rate is essential for taking effective measures to prevent fire propagation. Furthermore, it suggests a safe minimum distance for firefighters to operate and helps establish Acceptable Separation Distances (ASD) between storage tanks to ensure structural integrity. This thesis evaluates these heat transfer mechanisms—specifically thermal radiation—involved in open-air pool fires at mass storage facilities. The heat transfer values are calculated utilizing standard analytical approaches, including the MUDAN method, t² models, one-zone and two-zone models, alongside the Point Source Model and the Solid Flame Model. Through these models, critical parameters such as Heat Release Rate (HRR), mass burning rate, geometric view factors, and atmospheric transmissivity are evaluated for practical scenarios like LPG and gasoline tank fires. The analytical results are then utilized to recommend comprehensive fire mitigation strategies. These encompass passive fire protection measures, such as structural fire insulation and fire partitions, and active suppression systems, including Rim Seal Fire Protection, Medium Velocity Water Spray (MVWS), High Velocity Long Range (HVLR) monitors, and foam systems. Ultimately, this research provides a vital framework for optimizing facility layout, improving emergency response planning, and mitigating the catastrophic impacts of hydrocarbon pool fires.*

**Keywords**: Hydrocarbon Bulk Storage, Pool Fire Dynamics, Thermal Radiation, Heat Transfer Modeling, Acceptable Separation Distance (ASD), MUDAN Method, Fire Mitigation Strategies etc

## I. INTRODUCTION

### 1.1 Background and Motivation

In hydrocarbon processing plants, various types of crude oil, liquids, and gaseous petroleum products are stored in bulk. These materials are inherently highly flammable and volatile, often requiring storage at high pressures. Due to rapid

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industrial growth driven by globalization and technology transfer, the scale of these operations has increased significantly.

Every process industry relies on flammable materials; however, if these substances are not handled, stored, or transported with utmost precaution, they pose severe risks to human life, the environment, and property. Most fires in the process industries result from the uncontrolled escape of a combustible fluid followed by ignition. When this occurs over a horizontal fuel surface, it results in a specific and highly dangerous type of fire known as a pool fire.

### 1.2 Fundamentals of Heat Transfer

Understanding fire dynamics requires a foundational grasp of heat transfer, defined as the transmission of energy from one region to another due to a temperature gradient. The discipline of heat transfer is primarily concerned with available thermal energy (temperature) and its movement (heat flow).

The study of heat transfer is conducted to:

- Estimate the rate of energy flow as heat through the boundary of a system.
- Determine the temperature field under steady and transient conditions.
- Analyze material properties that modulate heat transfer, such as thermal conductivities, specific heats, fluid velocities, and surface emissivity's

| Mode | Mechanism | Characteristics in Fire Dynamics |
|---|---|---|
| **Conduction** | Transfer of heat through physical contact without appreciable molecular displacement. | In solids, heat transfers via lattice vibration and free electrons. In fluids, it relies on kinetic energy exchange during molecular collisions. |
| **Convection** | Transfer of heat within a fluid medium via the mixing of the fluid. | Includes **Free Convection** (driven by natural density differences) and **Forced Convection** (driven by external mechanical forces like wind or pumps). |
| **Radiation** | Heat transfer through space via electromagnetic waves, requiring no physical medium. | Dominates large pool fires. Thermal radiation from flames can ignite nearby materials without physical contact, making it a primary driver of fire spread. |

.Table 1: Fire spreads and impacts its surroundings

### 1.3 Pool Fire Dynamics

A pool fire is established over a horizontal fuel surface with defined boundaries, where liquid fuel depth is maintained through accumulation in a prescribed area. The thermal radiation hazards from these fires depend on fuel composition, fire geometry, duration, proximity to risk objects, and environmental ventilation.

Pool fires are generally classified by their environment:

Pool fire in the open air

- Pool fire in an enclosed area (often subject to air deficiency)
- Pool fire on the sea surface


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**Figure 1:** An Example of Open pool fire

Structure of a Pool Fire A typical pool fire consists of several fairly well-defined zones:

- The Liquid Fuel: Deep pools exhibit convective flows that affect vaporization and overall fire behavior.
- Vapor Cone: A reasonably constant-shaped zone immediately above the fuel, rich in unburned vapors.
- Luminous Flame: A surrounding zone of burning gas, maintaining a relatively constant shape.
- Turbulent Combustion: A higher region characterized by intermittent and turbulent flaming.
- Buoyant Plume: The uppermost non-reacting zone, marked by decreasing velocity and temperature.

Measurable Quantities

The behavior and danger of a pool fire are quantified using several key metrics:

- Mass Loss Rate / Burning Rate: The speed at which fuel is consumed (kg/s or mm/min).
- Heat Release Rate (HRR): The total heat energy released, generally expressed in kW or MW.
- Flame Height: The physical height of the flame, often measured at the point of 50% intermittency.
- Flame Temperature: The distribution of temperatures, typically given as mean centerline values.
- Smoke Production Rate: The volume or mass of smoke generated over time.
- Radiation: The emissive power ($kW/m^2$) or the total heat lost by radiation.

Research indicates two basic burning regimes: convectively-dominated burning for "small" pool fires (typically under 0.2 m in diameter) and radiatively-dominated burning for "large" pool fires. In large-scale incidents, radiation is the primary mechanism that threatens nearby structures and personnel.

**1.4 Objectives of the Work**

Because heat transfer plays a vital role in large-scale pool fires, calculating the heat transfer rate is essential for developing effective containment and protection strategies. The primary objectives of this study are:

- Develop Protection Strategies: Utilize calculated heat transfer data to propose specific active and passive fire protection measures tailored to mitigate hydrocarbon fire hazards.
- Define Passive Measures: Identify design and construction-stage safeguards, including structural fire insulation, safety partitions, and safe separation distances.
- Limit Fire Spread: Formulate methodologies to safely confine heat within the immediate fire zone to protect adjacent structures and equipment.
- Evaluate Active Suppression: Assess the immediate deployment and efficacy of active suppression systems, including water sprays, deluge systems, foam-based systems, $CO_2$ systems, and Dry Chemical Powder (DCP) systems.

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## II. LITERATURE REVIEW

| SL/No | Name of Literature | Year of Publication | Key Focus / Methodology |
|---|---|---|---|
| 1 | Thermal Radiation from Large Pool Fires, Kevin B. McGrattan, Howard R. Baum, Anthony Hamins. Fire Safety Engineering Division Building and Fire Research Laboratory. | 2024 | Investigates thermal radiation characteristics and models for large-scale pool fires. |
| 2 | Large-Scale Pool Fires by Thomas Steinhaus, Stephen Welch, Richard Carvel and Jose L. Torero, BRE Centre for Fire Safety Engineering. | 2023 | Provides experimental data and fundamental modeling approaches for large-scale pool fires. |
| 3 | Heat Release Rates of Burning items in Fire by Hyeong-Jin Kim and David G. Lilley, 38th Aerospace Sciences Meeting & Exhibit 10-13 January 2000 | 2022 | Focuses on Heat Release Rate (HRR) calculations and fire growth models (e.g., $t^2$ model). |
| 4 | K.S. Mudan and P.A. Croce. SFPE Handbook, chapter Fire Hazard Calculations for Large Open Hydrocarbon Fires. National Fire Protection Association, Quincy, Massachusetts, 2nd edition, 1995 | 2000 | Establishes fundamental fire hazard calculations using Point Source and Solid Flame models for hydrocarbon fires. |

Table 2: Literature Review

### 2.1 Identified Literature Gap (Based on research)

Lacks integration with modern active mitigation strategies (e.g., specific foam application rates) in high-density refinery layouts and real-time wind effect modeling.

High cost of experiments limits extensive scenario testing; gap exists in computational validation (CFD/zone models) for specific multi-tank farm configurations.

Primarily focuses on general burning items rather than the specific complexities of large-scale open hydrocarbon pool fires and boil-over scenarios in refineries.

Traditional models often oversimplify thermal radiation footprints in confined spaces; needs updating with modern quantitative risk assessment (QRA) tools and 3D modeling.

## III. SYSTEM DOMAIN

**3.1 The system domain of this project is petroleum refinery.** The petroleum refining industry converts crude oil into more than 2500 refined products, including liquefied petroleum gas, gasoline, kerosene, aviation fuel, and diesel fuel, fuel oils, lubricating oils, and feed stocks for the petrochemical industry. Petroleum refinery activities start with receipt of crude for storage at the refinery, include all petroleum handling and refining operations, and they terminate with storage preparatory to shipping the refined products from the refinery.

Crude oil and its derivatives are potentially hazardous materials. The degree of the hazard is characterized essentially by volatility and flash points.

Classification of these materials by the Institute of Petroleum, based (except for liquefied petroleum gases L.P.G.) on closed cup flash points, is as follows:-

**Class 0:-** Liquefied Petroleum Gases.

**Class 1:-** Liquid which have flash points below 21º C.

**Class 2 (a):-** Liquid which have flash points from 21º C up to and include 55º C handled below flash point.

**Class 2 (b):-** Liquid which have flash points from 21º C up to and include 55º C handled above flash point.

**Class 3 (a):-** Liquid which have flash points from 55º C up to and include 100º C handled below flash point.

**Class 3 (b):-** Liquid which have flash points from 55º C up to and include 100º C handled above flash point.

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**Unclassified: -** Liquid which have flash point above 100º C

**3.2 Storage of gaseous and liquid petroleum products:**

**Class 'A' (flash point below 22.8 C)**

- Floating Roof

**Figure 2**: Fixed pressure type tank

- Non-pressure fixed roof with internal floating deck
- Pressure fixed roof type

**Class 'B' (flash point between 22.8 and 65.6 C)**

- Floating roof
- Non- pressure fixed roof with internal floating deck
- Non-pressure fixed roof with atmospheric vents.

**Class 'C' (Flash point above 65.6 C)**

Non-pressure' fixed roof with atmospheric vents (Tanks which contain heavy fuel oils or bitumen's are insulated and heated.)

The largest quantities of chemical are found in storage facilities, which may be chemical plants or in other storage terminals. The prevention of loss in storage is extremely important. Loss of containment from storage of toxic chemicals could have serious effect. The effect of chemical release is very harmful for human life and environment. The best example of effect of chemical release is Bhopal Gas Disaster, which was the worst disaster which has ever occurred in the chemical industry.

**3.3 Storage of gases**

- High pressure horizontal tanks
- High pressure spherical storage tanks
- Cryogenic liquid storage tanks
- Liquefied Natural Gas (LNG) Tanks
- Transportation through Pipelines

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**Figure 3**: Storage facility

## IV. PROBLEM DESCRIPTION

### 4.1 Leaks

Most fires at the bulk storage of hydrocarbons result from uncontrolled escape of a combustible fluid, followed by ignition. There is a large number of situations which might result in are lease from a pipeline or a process plant. In heat transfer assessment it is not possible to in all types of leak scenarios. It is, however, important to select the typical situation.

Leak causes may be divided in two categories:

Leak due to a component failure.

Leak due to maloperation

**Figure 4**: Leaks in process plant

### 4.2 Rupture of vessel or tank

In the case of rupture of vessel or tank the contents will be released almost immediately. In addition to the supply lines may feed the leak until successful isolation has been done.

### 4.3. Fire hazard

**Pool Fires vs. Spill Fires**

Pool Fires: Defined as flames burning over a horizontal liquid fuel surface with distinct physical boundaries (confinement). If fuel remains available, they can burn for long periods at high rates.

Spill Fires: Occur when a liquid fuel release is unconfined and spreads along a surface. The fuel layer thickness depends on fluid flow rather than physical barriers.

Spill Fire Characteristics: Because the fuel layer is thin, heat transfers more easily to the ground (substrate). As a result, spill fires are generally shorter in height and duration, have a larger effective diameter, and produce more soot due to poor air entrainment.

**Large Pool Fires**

Definition of "Large": A pool fire is considered "large" once it becomes optically thick, typically starting at a diameter of 3 meters and potentially reaching 10-100 meters (such as in bulk storage tank fires).

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Visual Structure: Large pool fires are divided into two distinct sections: the "luminous band" of flame just above the pool surface, and the upper plume where smoke obscures the flames.

Soot Production: The amount of soot increases with the size of the fire but stabilizes at a constant level for pool diameters beyond 2-3 meters.

Radiative Heat Transfer: Radiation controls the burning rate for fires larger than one meter. However, thick vapor and soot near the surface cause "radiative energy blockage," reducing the heat directed back to the fuel by 25-35%, which limits the mass burning rate.

Smoke Shielding: In large fires, the outer surface is heavily cloaked by thick black smoke. This shield significantly lowers the fire's external radiation loss (dropping as low as 3% for fires over 30 meters).

Intermittent Hot Spots: The smoke shield is not perfectly solid. Turbulence causes it to open randomly, exposing highly luminous "hot spots" (about 20% of the fire's surface) that release sudden pulses of intense radiation.

Evolution of Fires: Depending on the release environment and ignition timing, an initial spill can evolve into various burning regimes, including pool fires, vapor cloud fires, jet flames, or even fireballs.

### 4.4 Fire Ball Hazard

**Figure 5**: Fireball demonstration

Large release of liquefied hydrocarbon burn as a fire ball under certain conditions. The large release of hydrocarbon forms a vapour Cloud above the upper flammability limit (UFL) and therefore is not able to explode. The burning starts around the outer edges and grows larger and results in a fireball. The preceding event for fireball may be a pool fire enveloping a pressurized storage tank containing liquefied gases or a jet fire impinging on the storage tank. After some time the tank will rupture due to intense heating.

### 4.5 Heat Impact on Human Body

The changes occurring during cremation were watched and documented in 15 undissected bodies to be cremated. It was found that at temperatures between 670 and 8108C the body showed the ‘‘pugilistic attitude’’ after about 10 minutes. After 20 minutes the calvaria was free from any soft tissue and fissures of the tabula externa could be noticed. The body cavities became visible after approximately 30 minutes, so that the organs were exposed. Forty minutes after cremation had started, the internal organs were severely shrunken and showed a net-like or sponge-like structure. After about 50 minutes the extremities were destroyed to an extent leaving only the torso which broke apart after 1–1.5 hours. The complete incineration of a human body took about 2–3 hours.

Firefighting involves performing strenuous muscular activity in a hot and hostile environment while wearing heavy and restrictive PPE. As a result of this combination of stressors, firefighters experience heat stress. Heat stress, and the resulting elevation in body temperature, has a myriad of effects on the human body, most notably: hastening the onset of muscular fatigue, promoting dehydration, increasing cardiovascular strain, and interfering with cognitive function. Firefighters are vaguely aware of all these effects – that is, every firefighter knows that firefighting leads to muscular fatigue, profuse sweating, high heart rates, and, at times, trouble concentrating on multiple tasks simultaneously. Heat stress leads to the early onset of

muscular fatigue and hence may be a contributing factor to these injuries through changes in the firefighters' biomechanics associated with walking and balancing.

**4.5 Separation Distance:**

The main principle is to separate all critical process equipment by satisfying sufficient distances to any possible fire caused by failure of a process equipment so that the incident radiation flux onto relevant process equipment is below a critical value.

This section presents a step by step method for determining the Acceptable Separation Distance (ASD) from a large fire. There are two ASD criteria – one for buildings and one for people. The ASD for buildings is the distance between the building and the fire at which the thermal radioactive flux is less then 31.5 kW/m2 (10,000 Btu/h/ft2 ). For people, the flux level is 1.4 kW/m2 (450 Btu/h/ft2). Hence, a fire due to leakage of hydrocarbon fuel for any process equipment in any process area must not cause higher heat fluxes onto nearest process equipment for a given assumed safe separation distance.

## V. METHODOLOGY PROBLEM FORMULATION

**5.1 Industrial fires can be intense emitter's of heat, smoke, and other combustion products.**

This is particularly true if the fuel is a petroleum based substance, with a high heat of combustion and sooting potential. The radiant energy flux can be sufficiently high to threaten both the structural integrity of neighboring buildings, and the physical safety of fire fighters, plant personnel, and potentially people beyond the boundaries of the facility. The assumption that the fire is unobscured by smoke, that is, a person watching the fire from a distance sees the entire extent of the combustion region. In reality, large fires of most combustible liquids and gases generate an appreciable amount of smoke. Depending on the fuel and the size of the fire, up to 20 % of the fuel mass is converted to smoke particulate in the combustion process. This smoke shields much of the luminous flame region from the viewer, and it is this luminous flame region that is the source of most of the thermal radiation. This shielding effect is most pronounced for fires that are tens or hundreds of meters in diameter because of the decreased efficiency of combustion at these scales.

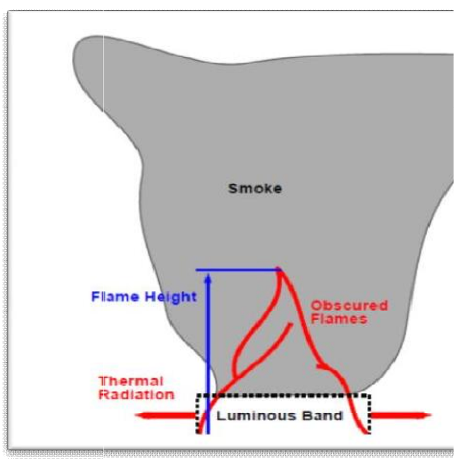


Figure 6: Flame Height calculation

Predicting the thermal radioactive flux from a fire of leaking combustible gases is more complicated than that of a liquid fuel fire because there are a number of potential fire scenarios to consider. With a liquid fuel fire, the dynamics of the fire is more understood and predictable than with a gaseous fuel. Rather than develop a separate methodology for estimating thermal radiation for each potential gaseous fire scenario, it is preferable to employ a simple procedure which encompasses a wide variety of scenarios, removes most of the geometrical parameters from the calculation, and remains conservative. Such a method is known as the "point source" radiation model. All that it requires is an estimate of the total heat release rate of the fire, and the fraction of that energy that is emitted as thermal radiation. The point source method is accurate in the

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far-field, but is considered overly conservative within a few fire diameters because it assumes that all of the radiative energy from the fire is emitted at a single point rather than distributed over an idealized shape (usually a cone or cylinder) meant to represent the fire. For liquid fuel fires, however, the point source model may be too conservative because these fires are more predictable and there is much more experimental data available to validate a more detailed model. A popular method of estimating radiation flux from large liquid pool fires is the "solid flame" radiation model. In this case, the fire is idealized as a solid vertical cylinder emitting thermal radiation from its sides. This model is relatively simple, but it does require estimates of the diameter and height of the cylinder, plus an estimate of the emissive power.

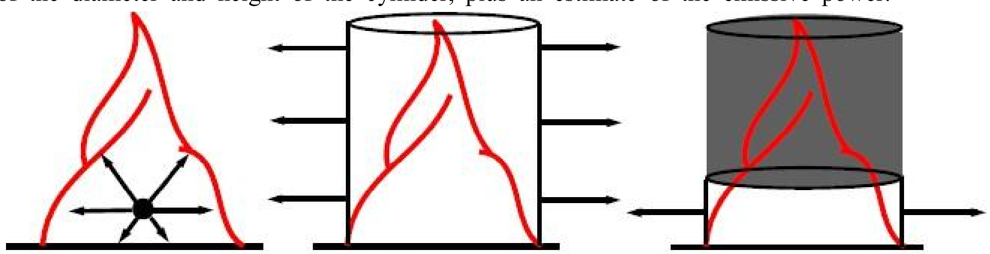


Figure 7: Types of Thermal Radiation Models

**Heat Transfer Calculation Method:**

Two different methods can be used when predicting incident heat flux on to a target from flame plume, namely the 'Point Source Model' and 'Solid Flame Model' where the other methods are far more simple and less accurate at locations close to the fire.

**Point Source Model:**

The 'Point Source Model' is the method which simplifies the problem significantly by assuming that the flame plume is represented by a point source of thermal energy. Further, it assumes that the certain specified fraction of the release energy is released by radiation.

However, the accuracy of the result may be insufficient, especially in the near field of a large pool fire. The radiative heat flux to a target, , may be expressed in the following ways:

Where,

ERR = energy released by radiation (kW)

x = distance from a flame center (m)

F = fraction of heat released as radiation

M= burning rate (kg/s)

H= heat of combustion of the fuel (kj/kg)

The 'Point Source Model' has been used successfully for flame which have a large flame height to diameter ratio (i.e. jet fires and diffusive flare fires from comparatively small openings compared to flame height) except very close to the fire. In the near field the point source model will overestimate the incident heat flux, which is a great disadvantage when predicting safe distances for process equipment and human beings. Further, this method is unable to include the effect of wind (e.g. flame tilt and flame drag) satisfactorily.

**1-Point Source Model:** Capacity or volume of a LPG tank is 150. Due to rupture in the tank an instantaneous spill occurs at storage site. There is a colony 100m away from the storage site, in the event of fire calculate the thermal radiation flux from fire plume to the house of the colony and to people residing in the colony. Would they be exposed to extensive heat flux (no dyke wall is present)?

Sol:

Diameter of spill = **122.474 m**

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Area of Fire = **17780.9724**

Mass Burning Rate for LPG = 0.10 kg/-s Heat of Combustion = 46000 kJ/kg HRR (Heat Release Rate) = Burning Rate q" (f) = m" (f) … (equ.1)

= 46000 0.10

= 4600 kw/

Now, Total HRR = (4600) *(Total Area) Q = (4600) * (17780.97245)

Q = 54.192 kW/

Thermal Radiation Flux to a target 150m away:

And, Where,

F= Fraction of the radiated heat Also, from equation 1,

Q= HRR

From above,

Zz = **24.91 kw/m$^2$**

Similarly, Thermal Radiation Flux to a target 90m away,

34.4 kw/m$^2$

And, also Thermal Radiation Flux to a target 60m away,

43.4 kw/m$^2$

The above value can meet acceptable distance criteria for building or structure but not for the human being or any other organism.

**2-Solid Flame Model Analysis**

**Facility:** 15m high gasoline tank (Diameter: 20m, Capacity: 1500).

**Containment:** Situated inside a rectangular dyke measuring 60m x 40m.

**Exposure Target:** An educational building located 80m away, parallel to the 60m dyke wall.

**Calculations & Results**

**Heat Release Rate (HRR):** Evaluated to determine the base thermal output.

**Calculated Heat Transfer:** The incident heat flux on the target is calculated as **11.80 kW/m²** (using Equation 2 and intermediate factors, e.g., 0.711).

**Conclusion on Separation Distance**

**Structural Safety:** The calculated heat flux of 11.80 kW/m² meets the acceptable distance criteria for the **building or structure**.

**Human Safety Risk:** This value is **not acceptable** for human beings.

**Mitigation Requirement:** To meet the acceptable exposure limits for humans as per the Department of Housing and Urban Development (HUD), the View Factor must be reduced to **0.014**.

3 **Facility & Layout Dimensions**

- **Dyke Dimensions:** 60m x 40m
- **Equivalent Diameter of Dyke:** 48m
- **Target Distance (S):** 80m (Distance between the fire and the exposed target)
- **Gasoline Storage:** 1500 m³ inside a 20m diameter tank (Height = 15m)

**Flame Geometry & Characteristics**

- **Height of Luminous Zone (H):** 15.4m (For pool diameter > 20m)
- **Total Flame Height:** 52.60m
- **Breadth of Flame (W):** 60m (Width in front of the target object)

**Key Radiation Variables**

- **Calculated View Factor:** 0.166 (Derived using H = 15.4m, W = 60m, and S = 80m from standard reference tables 5.1 & 5.2)
- **Average Surface Emission Power:** 100 (for gasoline)
- **Atmospheric Transmissivity:** Calculated considering relative humidity of the atmosphere (%) and distance from the flame surface to the exposed target (m).

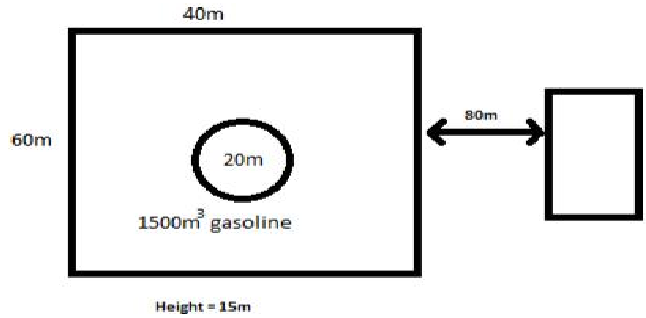


Figure 8: Solid Frame Models

## VI. SOLUTION DOMAIN

### 6.1 Fire Protection:

It is the theory practice of reducing life and property loss by fire, fire extinguishment, fire control and fire prevention. Fire protection is provided by proper building design, by installing appropriate extinguishment and detection device in buildings, by establishing adequate fire fighting systems etc.

Two types of fire protection are distinguished:

- Passive: Passive fire protection is represented by fire walls, fire and flame retardant treatments and the like.
- Active: Active fire protection is represented by sprinklers and other automatic and manual fire suppression systems.

Figure 9: Geodesic roof tank

### 6.2 Tank Protection Systems:

Tank is a container which is used to store a liquid with capacity of more than 1000 litres. Tanks are used to store both Raw materials and finished products. All the tanks shall be protected with the help of M.V.W.S(medium velocity water spray) which are manually operated. The

M.V.W.S mainly is used as an exposure protection i.e. protecting the tank from the radiated heat evolved from the fire of adjacent tank. The flow rate for M.V.W.S on tanks is 10.2 lpm/m.

Figure 10: Rim Seal Fire Protection System

**6.3 Foam System:**

The foam is used to make a barrier between the liquid surface on fire and the air. By doing so it cuts off the oxygen supply and hence extinguishes the fire. The foam solution used in refinery and depots are mainly of two types:

**AFFF:**

AFFF or the Aqueous Film Forming Foam is water soluble foam solution. It is mechanical foam which is mixed with water and air to form foam.

**AR-AFFF:**

Alcohol Resistant Aqueous Film Forming Foam is used on liquids which are miscible with water. AFFF if used on such liquids will disintegrate as the water in the foam will mix with the liquid. The AR-AFFF forms a layer of poly-propylene between the liquid surface and the foam.

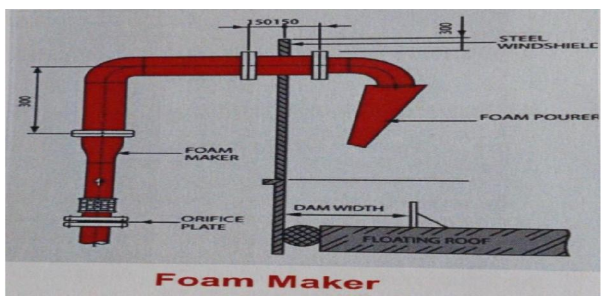


Figure 11: Foam Maker

| Description | Foam Application Rate of |
|---|---|
| Cone Roof | 5 lpm/m |
| Floating roof tank | 12 lpm/m |
| Floating roof sinking case | 8.1 lpm/m |

Table 3: Foam application rate

| Tank Diameter (m) | Minimum no of Foam |
|---|---|
| Upto20 | 2 |
| >20 up to 25 | 3 |
| >25 up to 30 | 4 |
| >30 up to 35 | 5 |
| >35 up to 40 | 6 |
| >40 up to 45 | 8 |
| >45 up to 50 | 10 |

Table 4: Installation criteria for foam discharge outlet

| Powder type | Effective against fire in: |
|---|---|
| A | Cellulosic materials, flammal |
| B | Liquid fires |
| C | Electrical equipment's |
| D | Metal fires (each metal may |

Table 5 Dry chemical powders

## VII. APPLICATION

Point Source Model and Solid Flame Model are the two models to calculate heat flux to object situated at some distance from fire. The value of heat flux is of great importance in the measures taken for active and passive fire protection. These two models can be applied for pool fire in bulk storage of Hydrocarbons like:

- Oil Refinery.
- Petrochemical Plants.
- LNG storage area.
- LPG bottling plant.
- Petroleum depots and terminals.
- Lube Oil installation.

These two models can be used for only pool fires in open air. Based on the value obtained from these models acceptable separation distance for humans and structures can be calculated easily. The calculated separation distance can be applied for the construction of new structure or tank or separation distance for the employees to assemble. These two models play a very important role in the disastrous situations to assume the hot zone, warm zone and cold zone. And also to find at what distance will be the incident command post.

## VIII. CONCLUSION

There are number of hazards which may occur in oil industry like leakage of flammable liquid from the storage vessel, ignition of pool of liquid in the ground level etc. The leakage may result during mal-operation like overfilling of tank contents and component failure like rupture of pipes, valves, flange or instrument connections.

The heat can be transmitted by three method conduction, convection and radiation in above scenario radiation from the pool fire is assumed to be predominant due to radiation effect heat flux (kw/m2) can be

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estimated. Based on the HUD Guidelines heat flux shall not be more than 1.4 kw/m2 for human beings and 31.5 kw/m2 in case of building structure.

The heat released by liquid pool fire can be calculated by different types of methods available like point source model, one zone & two zone method, solid flame model etc.

In this report we emphasized on the point source and solid flame model for the calculation of heat release rate, total heat generated, height of flame and acceptable separation distance (ASD) for any structure and human beings. Both the models have their own limitation,

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