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An Evaluation of the Heat Transfer Assessment Involved in a Pool Fire Occurring at a Mass Storage Facility for Hydrocarbon Substances

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Abstract: *Results of recent researches of large pool fires are reviewed. Researches on combustion characteristics of large petroleum fires have been conducted by many research groups. To do large fire experiments costs very much and huge open space is taken, but it is important to conduct large scale experiments for obtaining information of large real tank fires. Therefore, in order to promote large pool fire research, understandings of combustion characteristics of petroleum for fire safety design and fire fighting engineering. Worldwide collaboration is very important Dealing with handling and storage of hydrocarbons, common incidents like fire and explosion may occur. That may influence human, property and environment. Spillage of liquid or liquefied gases occurs often at bulk storage of hydrocarbons. In case of spill, if ignition source is present there, the spill will take no time in catching fire the consequences may be life threatening accident. The heat radiated from a fire play a crucial role in spreading fire to the nearby tank or other object. Radiated heat is one of the prominent factors affecting spread of fire. Many accident occurs due to radiated heat only and threatens life and property. So it is necessary to know how much heat would be transferred to some object or tank situated at some distance from the fire, so that effective measures can be taken to prevent the spread of fire from one place to another place. The value of heat transfer rate will also suggest a minimum distance at which a fire fighter can fight fire safely. A separation distance can be fixed between two storage based on these values. Value of heat transfer is calculated by some standard methods like MUDAN method, t2 model for heat transfer calculations, one zone and two zone models etc.*

Keywords: Fire hazard, conduction, Convection, radiation, pool fire, Crude Oil, LPG MUDAN method T_2 model Zone model etc

I. INTRODUCTION

In hydrocarbon processing plants different type of crude oil, liquids and gaseous petroleum products which are highly inflammable, volatile in nature are required to be stored in bulk with due care. Some Hydrocarbons are stored at high pressure which requires utmost precaution during carrying out the operation of process units as well as storage of products to avoid any occurrence involving fire.

There have been numerous incidents in the oil gas and petroleum industries involving bulk storage tanks. In today's world industrial growth seems to be higher than ever before due to globalization, sharing of knowledge and transfer of technology around the world. Every industry involves some processes and operation, without use of any flammable material in any form, a process cannot have accomplished.

II. POOL FIRE

Pool fires are defined as flames established over horizontal fuel surfaces. Generally, these surfaces have defined boundaries and if a liquid fuel is involved its depth is established through the accumulation of fuel in the prescribed area. Various types of pool fire may occur when a liquid fuel is released depending upon the environment of the release and mode of release.

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It is convenient to classify pool fire into the following types:

- Pool fire in the open air
- Pool fire in an enclosed area
- Pool fire on the sea surface

A pool fire in open air may take place when there is ignition of a liquid spill which is released on a horizontal fuel surface in open air. If this spill takes place on the sea surface a pool fire on sea surface may occur. likewise if the liquid fuel is released within in an enclosed Area, which may suffer air deficiency, may occur.

Figure 1: An Example of Open pool fire.

The structure of most pool fires may be split into a number of fairly well-defined zones:

The liquid fuel itself in deep pools, there may be significant convective flow within the fuel which may affect the fuel vaporization rate and hence influence the 'external' characteristics of the fire. The interaction between the fuel and the vessel which surrounds it may also have a significant influence over the burning behavior.

Above the fuel there is a reasonably constantly-shaped conical zone, rich in unburned fuel vapors. Surrounding the cone of vapor is a zone of luminous flame, also with a reasonably constant shape. Above this zone is a further combustion region, but here there is intermittency and obvious turbulence in the flaming.

Finally, there is the non-reacting buoyant plume, which is generally turbulent in nature and is characterized by decreasing velocity and temperature with height and lateral position.

Each individual zone has been extensively described and numerous studies have described the different parameters controlling the behavior of each zone and their interactions.

The resulting pool is then quantified via a number of "measurable quantities." The main "measurable quantities" associated to a pool fire are:

Burning rate or mass loss rate: these are closely related to the HRR. Mass loss rate is generally expressed in terms of kg/s.. Historically, burning rate has been expressed in terms of a 'regression rate' given in mm/min (i.e. the surface is lowered by a number of mm per minute as the fuel is consumed in the fire).

Heat release rate (HRR): the total amount of heat energy released by the fire, generally expressed in kilowatts (kW) or megawatts (MW). For pool fires this is sometimes expressed in terms of HRR per unit area (i.e. kW/m2). Occasionally this is taken to mean the convective HRR only, but this convention is best avoided as it can be a source of confusion.

Flame height: generally expressed in meters (m). The flame tip is often taken to be the point of 50% intermittency.

Flame temperature: actually a distribution of temperatures, often given as mean centerline values, with radial variations.

Smoke production rate: may be expressed in m3/s or kg/s.

Radiation: described either as the emissive power at a given point in space (kW/m2) or as the sum of all heat lost by radiation (kW), the latter often expressed as a percentage of the HRR.

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A number of physical characteristics of the pool fire then control these "measurable quantities".

These physical characteristics vary from the very simple to the complex. A simple abbreviated list will include:

- Pool geometry (diameter, depth, substrate)
- Fuel composition
- Ventilation conditions (wind, forced or restricted ventilation, etc.)
- Surrounding geometry.

Nature of the bounding materials, i.e. those used to construct the lip of liquid pool fire trays.

Physical characteristics associated with the pool fire will have a direct impact on the different zones and this impact is generally defined by means of "measurable quantities."

It is important to note that "zones" and "measurable quantities" are a practical way to describe a pool fire that has been found useful to breakdown a very complex problem but do not correspond to the fundamental physical parameters controlling the combustion and different transport processes

These will be discussed as follows.

Early experiments with pools of liquid fuels showed that there are two basic burning regimes for pool fires: Radiatively-dominated burning for pools with "large" diameters and convectively dominated burning for pools with 'small' diameters. "Large" pool fires are difficult to define and potential definitions will be discussed throughout. Nevertheless, diameters smaller than 0.2 m will always fall in the category of "small" pool heat transfer play a vital role in large scale pool fires. Increase in heat transfer rate will result in fire in the nearby are it has combustible material. So it is customary to calculate heat transfer rate so that effective measures can be taken to confine the heat in the area involving fire to save nearby object.

III. OPERATIVE SYSTEM FOR CALCULATIONS

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

3.1 STORAGE OF GASEOUS AND LIQUID PETROLEUM PRODUCTS:

Class 'A' (flash point below 22.8 C)

Floating Roof

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Figure 2: Fixed pressure type tank

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

IV. PROBLEM FORMULATION

Industrial fires can be intense emitters 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.

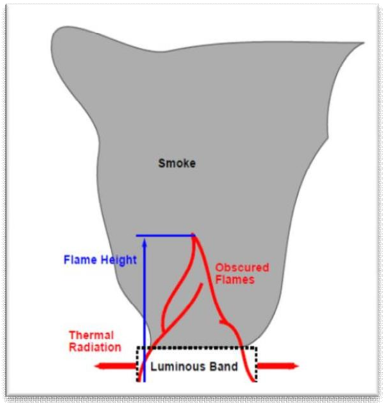

Figure 2: Flame Height calculation

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 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

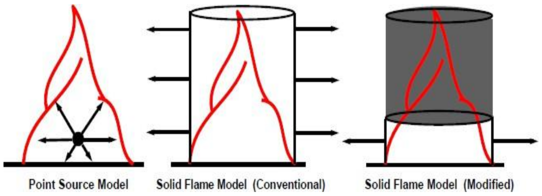

Figure 3: Types of Thermal Radiation Models

Heat Transfer Calculation Method:

Two different methods can be used when predicting incident heat flux onto 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.

Example: 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**

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.

V. 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.

VI. 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 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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