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POOL FIRES OF HYDROCARBONS STORAGE TANKS

occurrence,parameters,modeling and ccontrol

Haidar Adnan Ibrahim[1] and Prof. H . S . Syed[2]
[1]Final year student in Environmental EngineeringDepartment
[2]Associate professor in Environmental Engineering Department
[1,2]L.D Engineering College, Ahmedabad-380015

Abstract-*This paper aims to develop mathematical model to predict the potential of a large liquid hydrocarbon storage tank pool fire escalating and involving adjacent tanks, as a result of thermal loading. The exposure of a storage tank to radiant heat from an adjacent tank fire may, following ignition, result in an explosion or a fire. The point source model is simulated numerically within MATLAB environment for (i) calculation of the radiant heat flux from large, full-surface pool fires for various chemicals, various tank diameters and metrological conditions,(ii) prediction of the distribution of thermal loading over the surface of an adjacent tank ,(iii) prediction of the minimum safe separation distance between storage tanks, in order to prevent involvement of adjacent tanks. (1)By applying model for number of chemicals at same conditions has given following results ,(i) the radiant heat flux received at specific point from Heptane pool fire was greatest whereas from methanol burning was lowest,(ii) total heat radiated from heptane pool fire was highest , (ii) LPG flame length and height were highest as compared with studied products,(iii) ethanol had the highest burning durations for same fuel spill volume ,(2) The radiant heat from the flame received at particular point increase largely with pool fire diameter and wind speed ,(3) for gasoline pool fire, the minimum acceptable separation distance increases rapidly for both structures and people when the dike diameter and wind speed increase. Considering the risks associated with pool fire, Fire protection measures, such as water cooling system, foam system and personal protective equipment should be provided as well as proper layout of tanks with acceptable separation distance among them to prevent or reduce the pool fire hazards.*

Keywords-*pool fire; single point source; matlab; radiant heat flux;fraction of height radiated, Acceptable Separation Distance.*

I. INTRODUCTION

Storage tanks are usually used as containers for large volumes of flammable explosive, corrosive and toxic chemicals in petrochemical and chemical plants. When a tank fire occurs, the accident usually leads to million dollar property losses andposes risks to personnel, equipment facilities and environment[1–2].A small accident could have serious consequences [3].The results of a historical analysis show that 17% of major accidents in the chemical industry occur during storage of chemicals[4]. Fire occurs when a source of heat comes into contact with a combustible material in which combustion is started. Pool fires are either the initiators or the consequences, often both, of most process industry accidents involving fires or explosions [20]. Pool fire occurs when a flammable liquid spills onto the ground and is ignited [8]. A fire in a liquid storage tank is also a form of pool fire, as is a trench fire. The term basically represents pool of liquid fuel catching fire, but it is also used to describe burning of solid fuels, for example poly methyl methacrylate and polyethylene [10] .The main cause of damage from large open hydrocarbon fires is radiation[5].Thus; radiant heat flux causes the spread of flames from one object to another. It is necessary to determine radiant heat flux falling onto the surface of the tank In order to estimate if or when an adjacent tank may ignite due to exposure to radiant heat and the safe separation distances between storage tanks. There are many mathematical predictive tools that are used to assess the consequences of hydrocarbon pool fires. Point source model was developed using MATLAB and can be used to predict the radiant heat flux around a fire, it also can be used fairly reliably, to predict radiant heat flux beyond approximately five pool diameters from the flame [6].

II. DEFINITION, CLASSIFICATION AND OCCURRENCE

- Pool fire occurs when a flammable liquid spills onto the ground around the tank and is ignited [8], pool fires are the most frequent of process industry accidents [8, 9] ,even though pool literally means a small body of still liquid, the term pool fire represent the pool of a fuel that has caught fire [15,16],Pool fires have been classified as in (Fig.2.1). The common Sequence of events leading into pool fire in hydrocarbons storage tanks are presented in the (Fig.2.2).

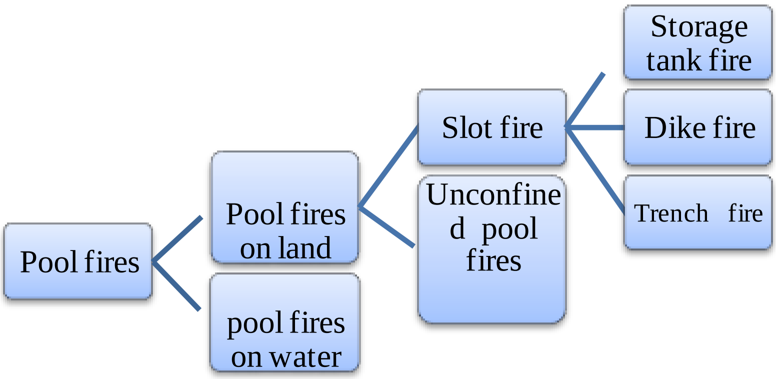

Fig.2.1. Classification of pool fires

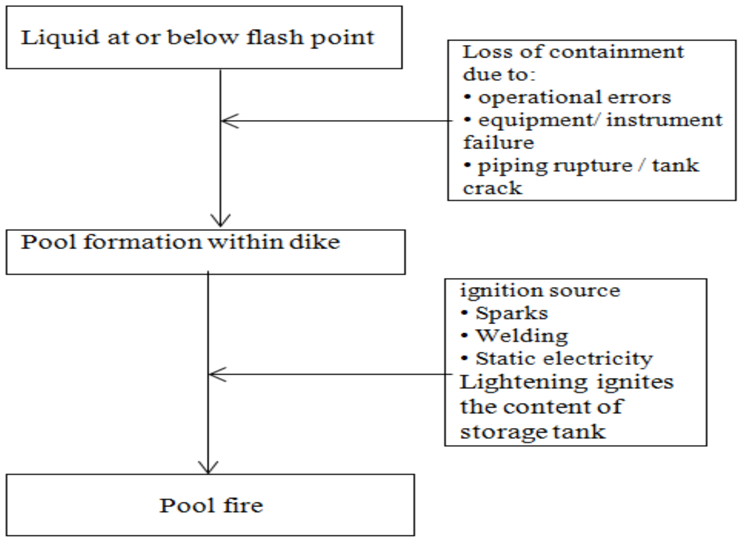

Fig.2.2. Events leading to pool fire.

III. POOL FIR MODELING AND FLAME PARAMETERS CALCULATIONS

Industrial fires can be intense emitters of heat and smoke. The radiant energy flux can be sufficiently high to damage both the structural integrity of neighboring buildings, and the physical safety ofplant personnel, and potentially people beyond the boundaries of the facility. The main cause of damage from large open hydrocarbon fires is radiation[5].Thus; radiant heat flux causes the dispersion of heat from one tank to another. the radiant heat flux falling onto the surface of the tank must be determined. For pool fires that generally have a low length-to-width ratio, it is usual to consider a point source model with a single-point source (SPS) external to the fire, The single point source model is a simple and widely-used representation of the thermal radiation emitted by a fire [12]. The flame is modeled as a single-point source located at the center of the flame as shown in (Fig 3.1).

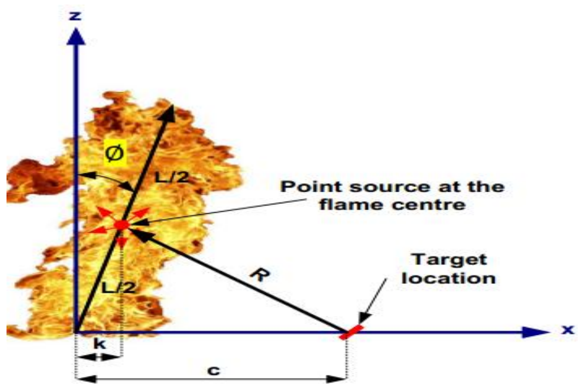

Fig.3.1. Diagram for flame as single point source model.

For this purpose a MATLAB program (SPS) was built in order to calculate the radiant heat flux, using the single-point source model to predict the possibility of hydrocarbon storage tank pool fire to damage neighboring tanks, due to expsure to radiant heat. Propertieses of number of fuels are contained in table (3.1) based on Babraukas (2002).

Table 3.1. Fuels Properties based on Babraukas (2002)

Fuel	***Maximum Mass Burning rate***	***Empirical Constant***	***Heat of Combustion***	***Fuel Density***	***Fraction of heat radiated***
	m_{max} $(Kg.m^{-2}.s^{-1})$	k_β (m^{-1})	ΔH_c $(KJ.kg^{-1})$	ρ $(Kg.m^{-3})$	X_r
Benzene	0.085	2.700	40,100	874	0.35
Butane	0.078	2.700	45,700	573	0.30
Ethanol	0.015	100.00	26,800	794	0.20
Gasoline	0.055	2.1	43,700	740	0.18
Hexane	0.074	1.9	44700	650	0.31
Heptane	0.101	1.1	44600	675	0.32
LPG	0.099	1.4	46000	585	0.26
Methanol	0.017	100.00	20000	796	0.19

The key property to characterize the fuel and the affects flame behaviour is mass burning rate per unit pool fire surface area per unit time and calculated by equation"(1)" :

$$mb = m_{max}\ (1 - \exp(-k_\beta\,.\,d)(1)$$

Where: m_{max} :is the maximum mass burning rate of fuel per unit surface area obtained from table(3.1), d: The burning pool diameter , k_β : empirical constant is obtained from table (3.1)

According to equation "(1)," mass burning rate for particular fuel is function to pool fire diameter , as illustrated for gasoline and hexane versus different pan diameter, d=(1,1.2,2.5,4,8) , Using SPS model, mass burning rate is calculated for each diameter for both fuel.

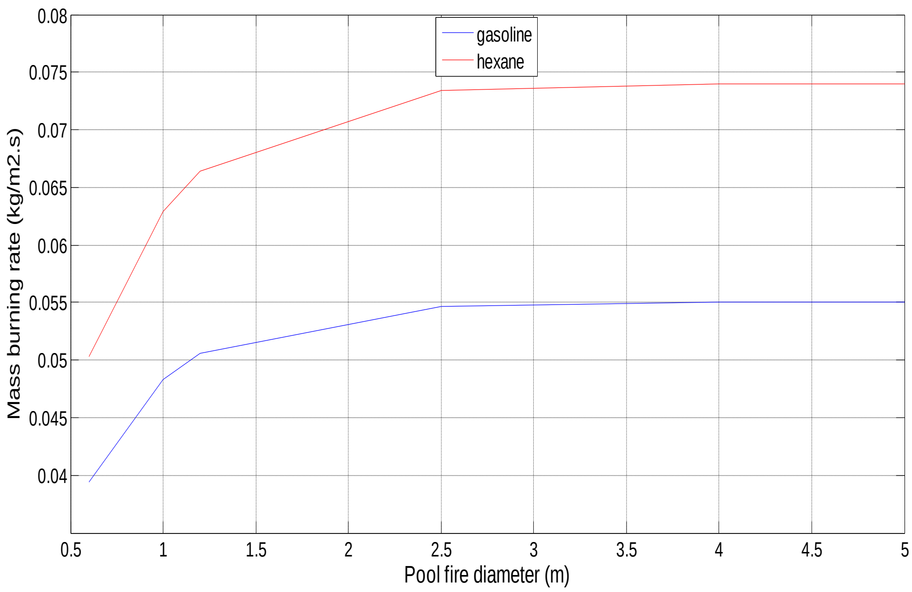

Fig.3.2. A comparison of the mass burning rate of the gasoline and hexane fire and pool fire diameter

From (Fig.3.2), it can be seen that the mass burning rate approaches the maximum mass burning rate at approximately (4 m) diameter for both hexane and gasoline pool fire. As the pool diameter increases, it reaches a size at which the flame is said to have become optically thick and any further increase in pool diameter does not produce an increase in emitted radiation.

- The radiant heat flux (q) ($Kw.m^{-2}$) received at a particular location is estimated using the following equation:

q=Q/ (4.pi.R^2) (2)

Where: Q: is the total radiative energy output of the fire (kW), R: is the distance from the single-point source to the target (m).

- The Distance between the Point Source and the target:

The distance(R) from the hypothetical single-point source location at the center of the flame (Fig.2.3) to the target is determined as follows:

$$R = \sqrt{(C-K)^2 + \left(\frac{L}{2}\cos(\emptyset)\right)^2} \quad (3)$$

Where: K: is the horizontal distance from pool center to the flame center (m), C: is the horizontal distance from the pool center to the target (m), L: is the flame length (m), Ø: is the flame tilt (degrees).

- The total radiative heat of the fire is calculated as follows:

$$Q_r = H_{rr} . X_r \quad (4)$$

H_{rr} : Is the heat release rate of the fire (kW) and X_r : is the fraction of heat radiated.

- The heat release rate (H_{rr}) :

The heat release rate for the fire (H_{rr}) is calculated as below [18]:

$$H_{rr} = m_b . \Delta H_c . A_f \quad (5)$$

ΔH_c: is the heat combustion of fuel ($kJ.kg^{-1}$) obtained from table 1 in (Appendix1), A_f :is the surface area of the burning pool (m^{-2}).

- The fraction of heat radiated (X_r) :

The fraction of heat radiated is defined as the fraction of the total energy released by combustion, which leaves the flame as radiation [14]. The fraction of heat radiated is independent of the heat release rate of the fire [15].

- Pool fire flame height (heskestad)H_f (m):

$$H_f = 0.235\, H_{rr}^{\frac{2}{5}} - 1.02d \quad (6)$$

- Flame length (Pritchard and Binding, 1992) $f_l\,(m)$ [21]:

$$f_l = d.615.d_m^{0.305}.d_{ws}^{-0.03} \quad (7)$$

Where: dm: dimensionless Burning Rate, dws: dimensionless Wind Speed (dws>=1).

Flame length is the distance from the base of the flame to the highest point at which can be seen to emerge from the upper section of the plume [6] as shown in (Fig.3.3).

- Flame tilt (Pritchard and Binding, 1992) [16]:

$$\frac{\tan\emptyset}{\cos\emptyset} = 0.666.(Fr)^{0.333}.(Re)^{0.117} \quad (8)$$

- Estimating pool fire burning duration:

$$\boldsymbol{t_b} = 4.V/(\pi.v.d^2) \quad (9)$$

T_b = burning duration of pool fire (sec), V = volume of liquid (m^3), D = pool diameter (m),v = regression rate (m/sec).

The parameters describing the flame geometry are dependent on fuel properties presented in table (3.1).

According to the mentioned equations, A MATLAB program (SPS) was developedin order to calculate the radiant flame parameter for fuels listed in table (3.1).

❖ For fuels listed in table (3.1), prediction of pool fire flame parameters at same pool fire diameter and same input data and conditions in table (3.2).

Table 3.2: Input data and conditions

Wind speed U_a ***(m.s***$^{-1}$***)***	2
The burning pool diameter d (m)	2.5
Gravitational acceleration (m.s^{-2}***)***	9.81
Air density ρ_a ***(kg.m***$^{-3}$***)***	1.205
The relative humidity (%)	75
Ambient temperature (℃)	15

Parameters values for fuels fire flame at measured point (5m) from the center of pan are calculated by single point source model on matlab and presented in table (3.3).

Table 3.3: Flame parameters obtained by model

Fuel	q ***(Kw.m***$^{-2}$***)***	***Q (kw)***	H_{rr} ***(kw)***	f_l ***(m)***	H_f ***(m)***	t_b ***(Sec)***
Benzene	82.9912	5849.1	16712	7.1444	8.9389	1047.4
Butane	70.1660	5243.2	17477	6.9536	9.1465	748.27
Ethanol	2.600	394.66	1973.3	4.1384	2.3382	5391.7
Gasoline	22.9117	2112.5	11736	6.2209	7.4242	1370.5
Hexane	64.2201	4990	16097	6.8231	8.7678	894.70
Heptane	101.6126	6623.5	20698	7.3907	9.9653	680.74
LPG	87.4876	5636.6	21679	7.4266	10.199	601.89
Methanol	2.2647	317.10	1669	4.304	2.021	4769.4

From table(3.3) , it can be seen that (i) the radiant heat flux received at specific point from Heptane burning is greatest and from methanol burning is lowest, that's means that Heptane tank fire is most dangerous on the adjacent tanks due to thermal loading so, minimum acceptable separation distance between tanks should be more than other fuels at same conditions , (ii) LPG fire flame length and flame height is greater than other fuels, (iii) The greatest heat radiated is from heptane flame ,(iv) Ethanol fire has the highest burning durations for same spill volumes of fuel.

❖ The following calculation shows the estimation of the radiant heat flux received at different points which their horizontal distance from pan center C= (4, 5, 6, 8, 10, 13). The calculation was conducted for: gasoline, LPG and butane, the required input data are listed in the table 3.1. Despite applying the same conditions: at 4m from the center of the pan, the radiant heat flux for the LPG pool fire was 260 kW. m^{-2}, whereas, for butane was 200 kWm^{-2} and for the gasoline pool fire, it was 70 kWm^{-2}.

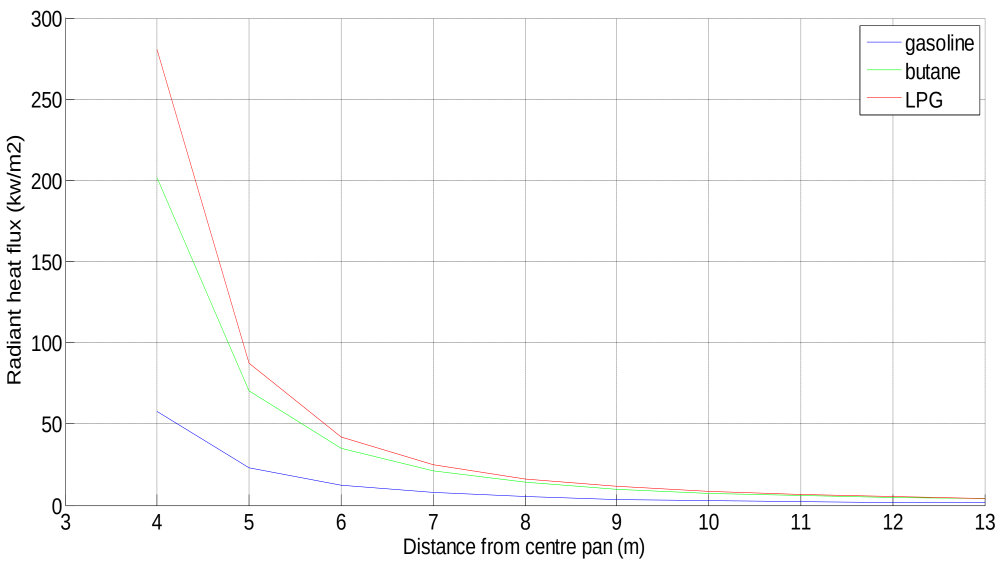

Fig.3.3.Radiant heat flux predictions of the single-point source model for butane, gasoline and LPG.

❖ Effect of pool fire diameter on radiant heat flux:

The pool fire characteristics depend on diameter of fire which occurring in the fuel tanks. Detailed example for gasoline fuel for different pool fire diameter values (2.5, 5,7.5,10,12) at (5m) distance from the center pan and wind speed is constant(2 m/s). By plotting the resulted radiant heat flux that obtained by model as function to pool fire diameter valuesusing MATLAB, the graph (3.4) is obtained.From graph, the radiant heat flux received at particular point from the center pan increase with fire diameter largely, so the higher dike diameter, the higher minimum acceptable separation distance between tanks in the storage farms.

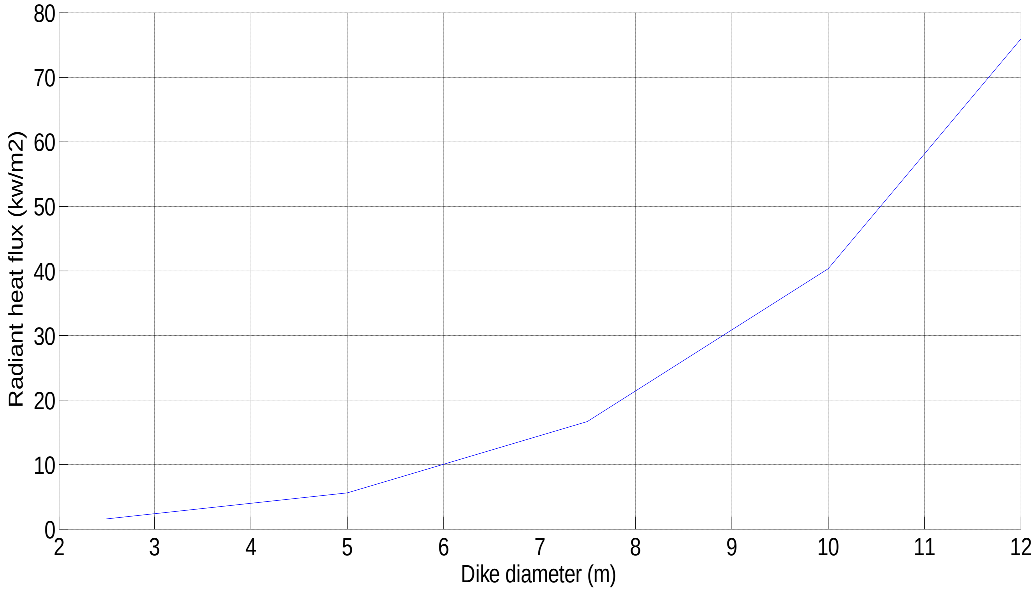

Fig.3.4. Effect of dike diameter on radiant heat flux.

❖ Wind effect on flame tilt and radiant heat flux :

When estimating radiant heat flux on a nearby object, it is important to take into account the effect of wind on the flame, as the wind causes the flame to tilt and move over the edge of the pool. It is essential to know theangle at which a flame will tilt and radiant heat received to target. Applying model for gasoline pool fire for various wind
Speed values (0.05, 0.5, 1, 2, 3,6,10 m/s) at (5m) distance from the center pan and diameter of pan is constant(2.5 m). The resulted radiant heat flux and flame tilt are plotted versus wind speed as shown in (Fig .3.5) and (Fig3.6) respectively.

From (Fig.3.5), the radiant heat flux received at particular point around the tank pool fire increase with wind speed so, it is important to take into account the wind speed and direction in determination of minimum acceptable separation distance between tanks in the storage farms.

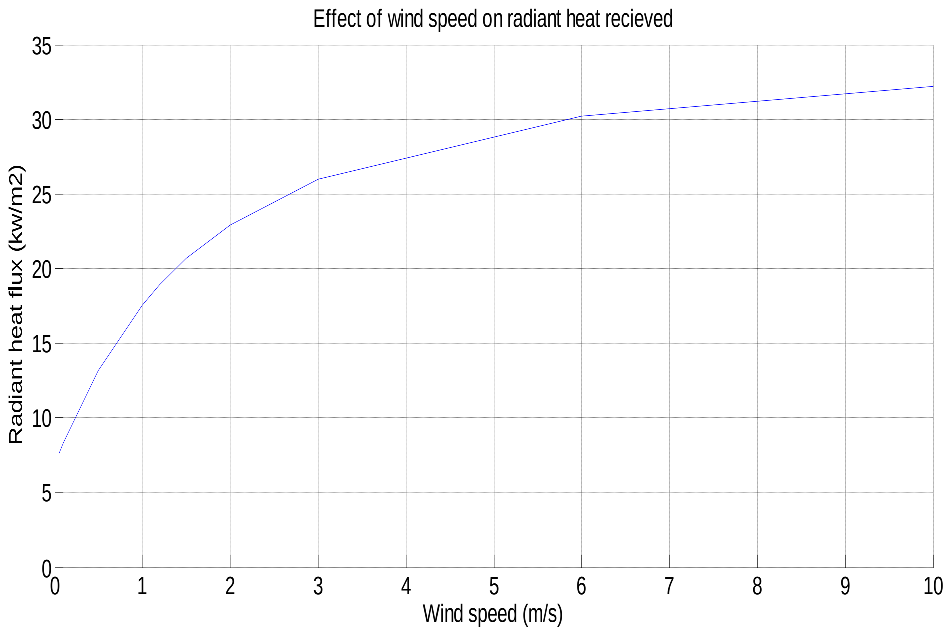

Fig.3.5. Effect of wind speed on radiant heat flux.

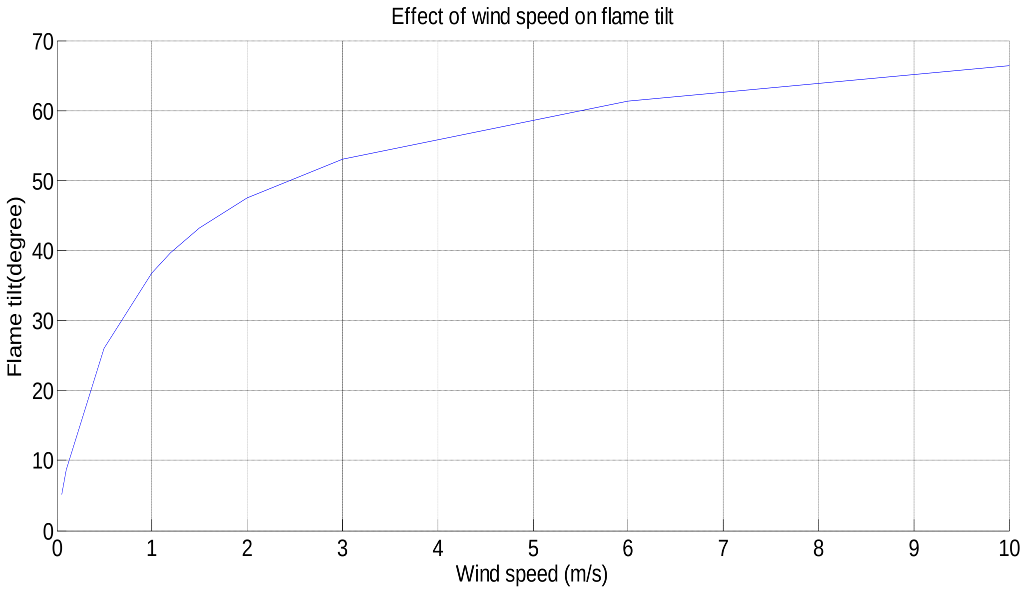

Fig.3.6.Effect of wind speed on radiant heat flux.

(Fig.3.6) shows the significant effect of wind speed on flame tilt, as you see flame tilt increase rapidly with increased wind speed.

- Combined effect of wind speed and pool diameter on radiant heat flux :

Since, the radiant heat flux increase with pool diameter or wind speed separately, Combined effect of wind speed and pool diameter on radiant heat flux is studied for different values and got the graph (Fig3.7) ,It can be noticed from graph above, the radiant heat flux received at particular point from the center pan increase largely with fire diameter and wind speed so, and both factors must be considered in layout of any storage facility.

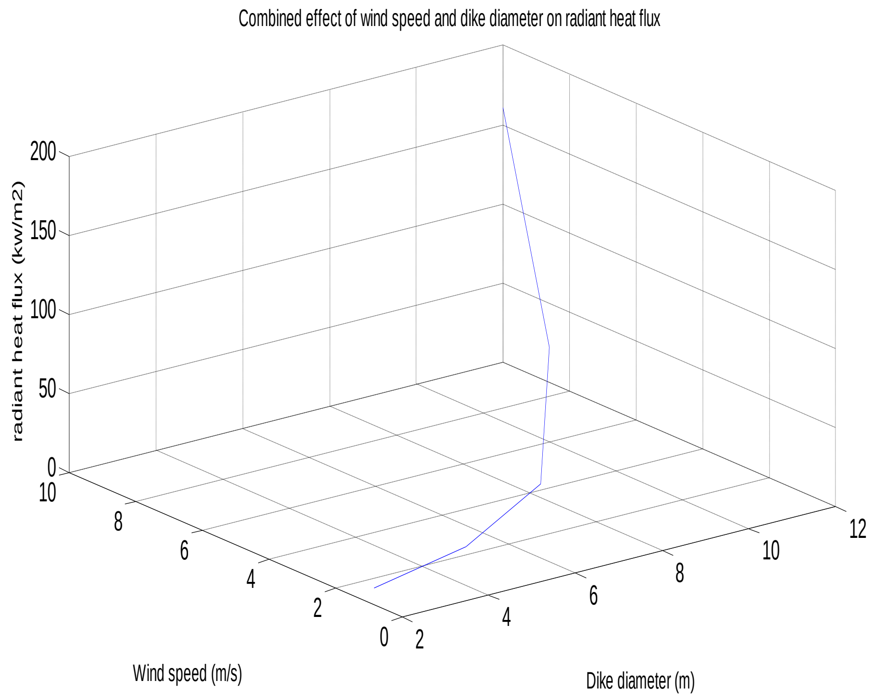

Fig.3.7.Combined Effect of wind speed and dike diameter on radiant heat flux.

So, the radiant heat flux received at particular point from the center pan extremely increase when fire diameter and wind speed increase so, it is obviously that both factors must be considered in layout of any storage facility tanks.

❖ Determining the Acceptable Separation Distance (ASD):

Acceptable Separation Distance between tanks is a common approach used to reduce risks of fire propagation between adjacent tanks and to allow sufficient time for users' evacuation and fire -fighting procedures .There are two ASD criteria, The ASD for buildings is the distance between the building and structures and the fire at which the thermal radiative flux is less than 31.5 kw/m^2, for people, the flux level is 1.4 kW /m^2 [17].The "Screen ASD" is the distance beyond which the thermal radiation fluxes criteria is satisfied, regardless of fire size is 20 m for building, 550 for people.
ASD changes depending on types of fuel , it also change for the same fuel for different pool fire diameters and wind speed and direction as illustrated for gasoline fuelby using model programmed on matlab tofind out ASD for both people and structures.
Ford=(12, 18,30,45,55 m) and wind speed = (2.5) m/s, the ASD is estimated by model for each dike diameter, thenresulted ASD is plotted with dike diameter by MATLAB and the graph (3.8) is obtained.From graph, it can be seen for gasoline pool fire when constant wind speed, the minimum acceptable separation distance increaseslargely for both structures and people when the dike diameter increase.At 30 m diameter, you can find that ASD for people is 150 m whereas for structures is less than 50 m.

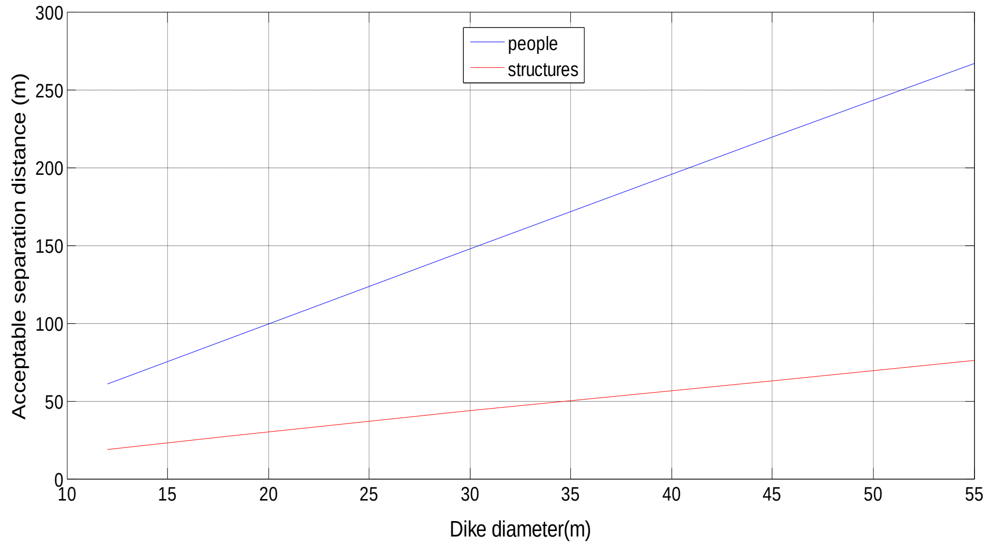

Fig3.8. Acceptable separation distance as function to dike diameter and wind speed.

When Wind speed is variable Ua= (1, 2, 4, 6, and 10)m/s and dike diameter is constant, the estimated ASD by model is plotted versus wind speed and following graph is produced:

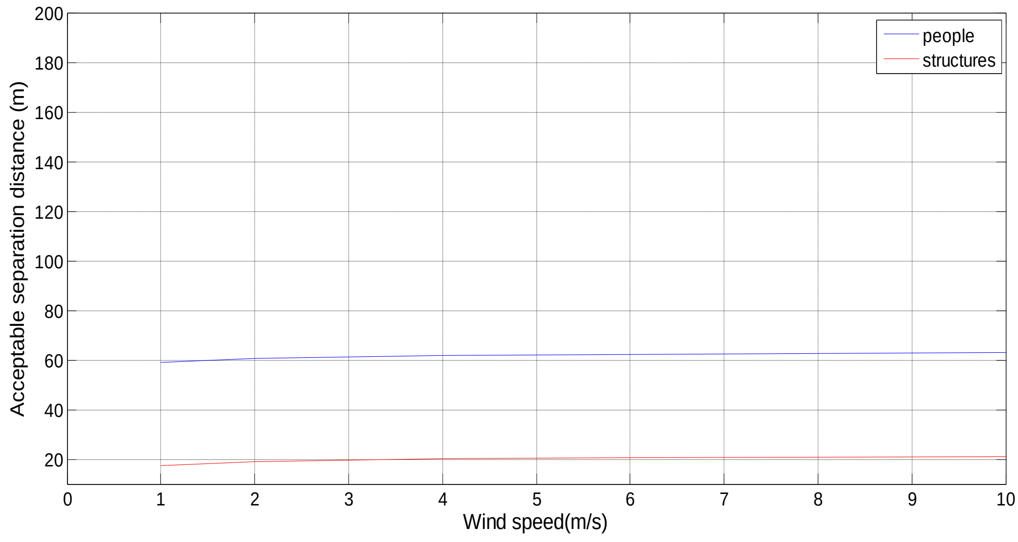

Fig.3.9. Acceptable separation distance as function to wind speed.

From graph,when the dike diameter is constant and wind speed is variable, the minimum acceptable separation distance for both structures and people increase slowly and relatively fixed.

IV. POOL FIRE PROTECTION , PREVENTION AND CONTROL

V.

Storage tanks pose adverse potential risks to life, property and environment. In most cases, the risk factor is high, due to the relatively huge mass of fuels that are stored in one location. For mentioned reason, many safety practices should be done by industries to prevent or minimize the serious effects of pool fire on people and environment. The following aspects are particularly relevant to Pool Fire protection and control:

- Pumping stations should be equipped with drainage systems capable to safe and rapid drain-off of the fuel when a fire starts.
- Periodic maintenance and inspection to detect early any accidental spillage or overfilling which always leads to pool fires.
- Installation of the storage tanks in a way that ensures safe distance between the tanks based on the considerations of dike diameter,wind directions and speeds. This protection also minimizes the probability of the fire in a tank due to exposure to thermal loading.
- Lightening is caused by direct strike , the electrostatic pulses, and earth currents [13].lightening protection devices have been set to minimize lightening hazard but they have proved fall able on many an occasion [3].
- The accumulation of snow can damage the storage tanks and piping Connected to the tank which can result in leaks and give rise to fire hazard,Temporary or permanent covers should be used to protect them from snow and ice [19].
- Heavy rain, or events like a tsunami, which cause flooding may displace stored flammables and damage electrical systems, enhancing risk of fires [21].
- Water Cooling Systems : Cooling of an adjacent atmospheric storage tank wall and roof is an effective means of maintaining temperatures within acceptable limits that will not cause the steel to collapse, the flammable vapors to be discharged to the atmosphere or the hot surfaces to form a source of ignition.
- Foam Systems: Foam methods are the most widely used in firefighting system; they provide an acceptable level of protection. Foam firefighting systems, in which foam is directed on to the fire.

VI. CONCLUSION

This paper has attempted to describe a single point source model for predicting the radiant heat flux from large, full-surface pool fires for various products, various tank diameters and metrological conditions. It is known from studies conducted with different liquid fuels that the burning characteristics and the physical behavior of pool fire changes as the diameter of the fires Increases.Dike diameter, wind speed and direction play lead role in proper layout and installation of storage tanks. It is found out using Single Point Source model thatthe radiant heat flux received at specific point from Heptane pool fire was greatest whereas from methanol burning was lowest as well asthe radiant heat flux and flame tilt increase when the wind speed and tank size increase so, wind conditions and dike diameter should be taken into consideration in prediction the radiant heat flux and safe separation distance between tanks. Radiant heat flux is important for (i) estimating if or when an adjacent tank may ignite due to exposure to radiant heat, (ii) estimation of the safe separation distances between storage tanks,(iii) An estimation of the type and level of protection required, in order to prevent escalation. Most of the pool fire accidents can be avoided by proper layout of tanks based on thermal distribution, periodic maintenance for tanks and pipes to prevent accidental leakage as well as fire protection devices should be provided.

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