A Quantitative Approach to Determine Fire and Explosion Risk for Storage Tank Having Flammable Liquid

Rahul Porwal,
M.tech (Indu. Safety Engg.)
Dept. of Fire technology and Safety Engg.,
Shiv Kumar Singh Institute of Technology and Science,
Indore, Madhya Pradesh, India
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal

Nisha Kushwaha
Assistant Professor
Dept. of Fire Technology and Safety Engg.
Shiv Kumar Singh Institute of Technology and Science,
Indore, Madhya Pradesh, India
Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal

Abstract:- Fire and explosion both have become most repeatedly occurring disasters in India, which requires more attention, and strict compliance of regulatory authority to mitigate its consequence. The origin of fire hazards in now a day is closely related to the Industrial Rebellion. The frequent happening of fire and explosion hazards has become an area of concern for both the settled and developed nations. Since May 2020, there have been 30 industrial accidents have been reported in India, killing minimum 75 workers. From 2014 to 2017, within three year approximately 8,004 number of such incidents occurred in Indian workplaces killing 6,368 industrial employees in which fire and explosion is one of the major contributor. Fire in storage tanks containing flammable liquid have been increased drastically within three year due to inadequate over flow arrangement, failure to provide safety devices, poor maintenance of control equipment and instrument, loss of primary containment system, and integrity failure of secondary containment system etc. A systematic analytical approach has been determined to identify fire an explosion n risk for one of the biggest storage facility which stored Iso propyl alcohol. A theoretical dispersion modelling study has been performed to identify fire and explosion risk. The dispersion study is used to estimate or to predict the downwind concentration of environment pollutants such as flammable gas or any other gas which is in hazardous nature emitted from the sources such as storage tank or industrial plants or process vessel/ pipeline etc. In the atmosphere, dispersion depends upon the types and numbers of sources, various meteorological factors and topography of the terrain. The main advantages of this dissertation is to provide overall worst case predictable consequence when a chemical release from the storage how far it can be impacted to the surrounding area, plant, machinery, equipment or community. This study will not only gives the resultant perimeter of consequence modelling even although predicts the control measure to bring down the fire an explosion risk in acceptable manner where minimum impacted can be levied as a residual risk.

Keywords:- *Dispersion Model, Flammable Liquid, Fire and Explosion Risk, Industrial Accident.*

I. INTRODUCTION

Storage tanks in petrochemical industry and chemical manufacturing industry contains larger inventory of flammable and hazardous chemicals. A single spark can destroy or may lead to millions of rupees property loss and production loss due to strict government regulation or even industry may shut for a period of time. Incidents which involve fire and explosion risk has become biggest concern in chemical industries. Fire accident pertaining to chemical and petrochemical industry has been increased drastically. Fire incident at Indian oil corporation limited at Jaipur, India again reminds us to not to forget Bhopal gas tragedy and seeking sustainable action to prevent such kind of accident and incident. Chemical industries are trying to get advantages of new innovative technologies but how this innovative technology shall be maintained in order to reduce error or failure of probability is an area of concern. There are many causes of fire incident while handling of flammable substances such as spark due to friction, electrostatic hazard, behavioral at risk, failure to maintain electrical integrity, chemical incompatibility and many more. The consequence of fire may result into flash fire, pool fire, boiling liquid expanding vapour explosion or jet fire etc.

Symbiotec pharma which is situated in special economic zone of Pithampur area of Dhar district in Madhya Pradesh, deals with many hazardous chemicals to produce Active pharmaceutical ingredient- hormone. Symbiotec handles huge quantities of chemicals which may cause accidents depending upon the properties of the chemical (Highly toxicity, highly flammability, corrosive, oxidizer and water reactive substances etc.). chemical incident may take place due to accidental leakage from the storage tanks, leakage from the process vessel or pipelines and damage during transportation of chemicals in the pipeline, manual handling of chemicals or releases from the gas cylinders. Some of these faults may be caused due to rupture or damage of process vessel or pipeline, failure of equipment or instrument, activation of safety devices or human negligence which resulting releases large quantities of chemicals in to the environment. The risk may vary based on hazardous properties of chemical and different process condition. For this dissertation Iso-propyl alcohol storage tank has been selected for the study which is extremely flammable. The IPA releases from the storage tank can affect neighboring plant/public located in nearby area.

The dispersion study is used to estimate or to forecast the downwind concentration of environment pollutants such as flammable gas or any other gas which is in hazardous nature emitted from the sources such as storage tank or industrial plants or process vessel/ pipeline etc. In the atmosphere, dispersion depends upon the types and numbers of sources, various meteorological factors and topography of the terrain.

The main purpose of this dissertation is to contain a model that allows evolution of flammable pollutant (IPA) concentration from storage tank having uneven wind profile and diffusivities with exclusion parameter and to know the impact near by the plant area of Symbiotec plant.

II. METHODOLOGY

Combination of source model and dispersion model methodology will be adopted to estimate the fire & explosion risk of flammable storage tank. The source model predict the type of incident release, rate of release and quantum etc. whereas dispersion models are used to estimate or to predict the downwind concentration of pollutants of flammable gases or vapour whether heavier or lighter than the air. Following below process shall be followed to estimate the fire & explosion risk for storage tank containing flammable liquid.

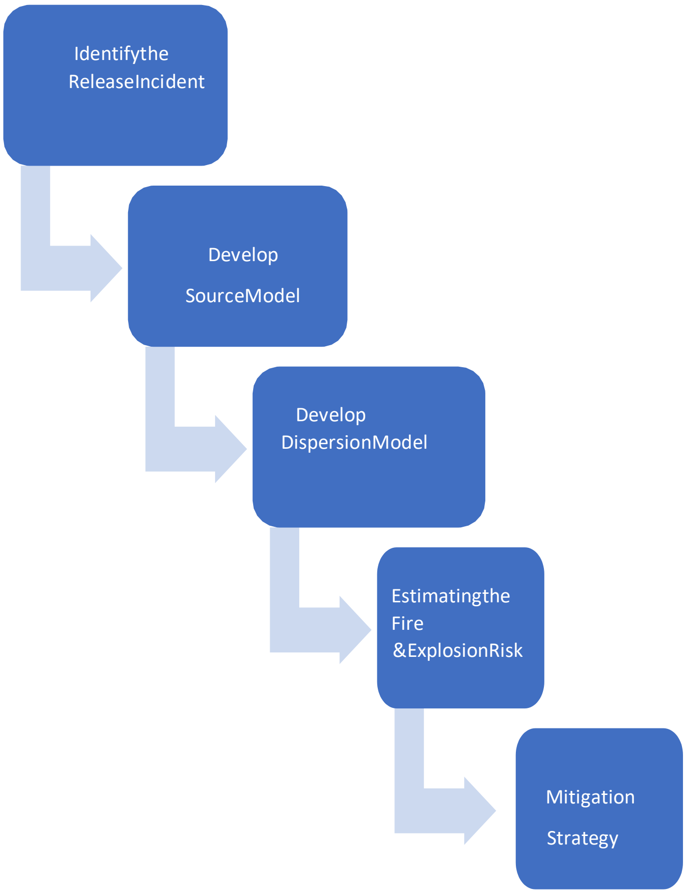


Fig. 1: Methodology for Estimate the Fire &Explosion Risk For Storage Tank Containing Flammable Liquid

- *Step-1- Identify the Release incident*
  Identifying the release incident (what process situations can lead to a release?) or which type of chemical is being released from the source like gas cylinder, process vessel, process equipment or pipeline etc.

- *Step-2- Develop Source Model*
  The source model provides a description of the rate of discharge, the total quantity discharged (or total time of discharge), and the state of the discharge (that is, solid, liquid, vapor, or a combination). Gas and vapor discharges are classified into throttling and free expansion releases. For throttling releases the gas issues through a small crack with large frictional losses; little of the energy inherent to the gas pressure is converted to kinetic energy.

The maximum flow rate is determined by given Equation for source model

$$\left[Q_m = \rho A C_o \sqrt{2\left(\frac{g_c P_g}{\rho} + g h_l\right)}\right] ---- --(Equation no. 1)$$

$Q_m =$ Leak Mass Flow Rate
$A =$ Area of Leakage/Release
$C_o =$ Discharge Coefficent
$P_g =$ Gauze Pressure
$g_c =$ Gravitational Constant
$\rho =$ Density of Liquid
$g =$ Acceleration due Gravity
$h_l =$ Liquid Height Above the Leak

- *Step-3- Develop Dispersion Model*
  Dispersion models describe the airborne transport of toxic materials away from the accident site and into the plant and community. After a release the airborne toxic material is carried away by the wind in a characteristic plume or a puff. The maximum concentration of toxic material occurs at the release point (which may not be at ground level). Concentrations downwind are less, because of turbulent mixing and dispersion of the toxic substance with air. A wide variety of parameters affect atmospheric dispersion of toxic materials:
  - Wind speed,
  - Atmospheric stability,
  - Ground conditions (buildings, water, trees),
  - Height of the release above ground level,
  - Momentum and buoyancy of the initial material released.

A dense gas is defined as any gas whose density is greater than the density of the ambient air through which it is being dispersed. This result can be due to gas with molecular weight greater than that of air or a gas with a low temperature resulting from auto refrigeration during release or other processes.

Following a typical puff release, a cloud having similar vertical and horizontal dimensions (near the source) may form. The dense cloud slumps towards the ground under the influence of gravity, increasing its diameter and reducing its height. Considerable initial dilution occurs because of the gravity-driven intrusion of the cloud into the ambient air. Subsequently the cloud height increases because of further entertainment of air across both the vertical and horizontal interfaces. After sufficient dilution occurs , normal atmospheric turbulence predominates over gravitational forces and typical Gaussian dispersion model characteristics are exhibited.

The Britter and Mcquaid model was developed by performing a dimensional analysis and correlating existing data on dense cloud dispersion. The model is best suited for instantaneous or continuous ground – level releases of dense gases. The release is assumed to occur at ambient temperature and without aerosol or liquid droplet formation. Atmospheric stability from dispersion tests in remote rural areas on mostly flat terrain. Thus the results are not practicable to areas where terrain effects are significant.

The model requires a specification of the initial cloud volume, the initial plum volume flux, the duration of release and the initial gas density. Also required is the wind speed at a height of 10 meter the distance downwind and the ambient gas density.

Following below sub steps to be adopted for dense gas dispersion model.

a) Sub-Step-1- The First step is to determine whether the dense gas model is applicable. The initial cloud buoyancy is defined as

$$\left[g_0 = \frac{g(\rho_0 - \rho_a)}{\rho_a}\right] ------(Equation no. 2)$$

Where

g_0 = is the initial buoyancy factor
g = is the accelearation due to gravity
ρ_0 = is the initial desnity of released material
ρ_a = is the density of ambientair

b) Sub-Step-2- The second step is to determine whether release is continuous or instantaneous

For Continuous

$$\left[\frac{uR_d}{x} \geq 2.5\right] --- (Equation no. 2.1)$$

For instantaneous

$$\left[\frac{uR_d}{x} \leq 0.6\right] --------------- (Equation no. 2.2)$$

u = is the wind speed at 10 m elevation
R_d = is the release duration time
x = is the dwonwind distance in dimensional space

c) Sub-Step-3- The third step is to determine characteristic source dimension for continuous or instantaneous

For Continuous

$$\left[D_c = \left(\frac{q_0}{u}\right)^{\frac{1}{2}}\right] ----(Equation no. 2.3)$$

D_c = is the characteristic source dimension for continuous releases
q = is the initial plume volume flux for dense gas dispersion
u = is the wind speed at 10 m elevation

For instantaneous

$$\left[D_i = (V_0)^{\frac{1}{3}}\right] ----(Equation no. 2.4)$$

D_i = is the characteristic source dimension for instantaneous releases
V_0 = is the initial volume of released dense gas matreial

d) Sub-Step-4- The fourth step is to estimate sufficient dense cloud to require a dense cloud representation for continuous or instantaneous release.

For Continuous

$$\left[\left(\frac{g_0 q_0}{u^3 D_c}\right)^{\frac{1}{3}} \geq 0.15\right] --(Equation no. 2.5)$$

For instantaneous

$$\left[\frac{\sqrt{g_0 V_0}}{uD_i} \geq 0.20\right] --- (Equation no. 2.6)$$

e) Sub-Step-5- In this step adjust the concentration and identify the effective concentration.

$$\left[Effective\ Concentration\ C = \frac{C^*}{C^* + (1 - C^*)\left(\frac{T_a}{T_0}\right)}\right] --- (Equation no. 2.7)$$

C = is the efective concentration
C^* = is the require concentration
T_a = is the ambient temperature
T_s = is the source temperature

- *Step-4- Estimating the Fire & Explosion Risk*
After getting the results from above step and step-5, get the equation of α, β & in line with effective concentration C^* or $\frac{C_m}{C_0}$

from the below table and figure to get the downward distance.

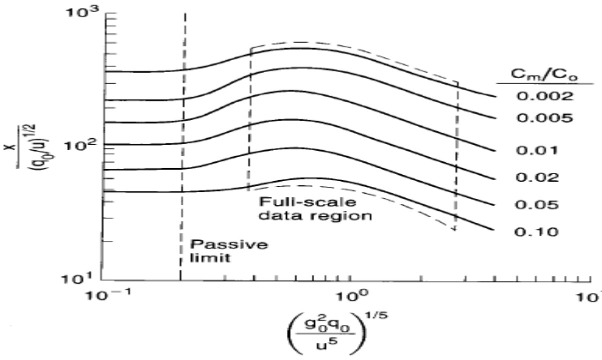


Fig. 2: Britter-Mc Quaid Dimensional Correlation for Dispersion of Dense Gas Plumes

ISSN No:-2456-2165

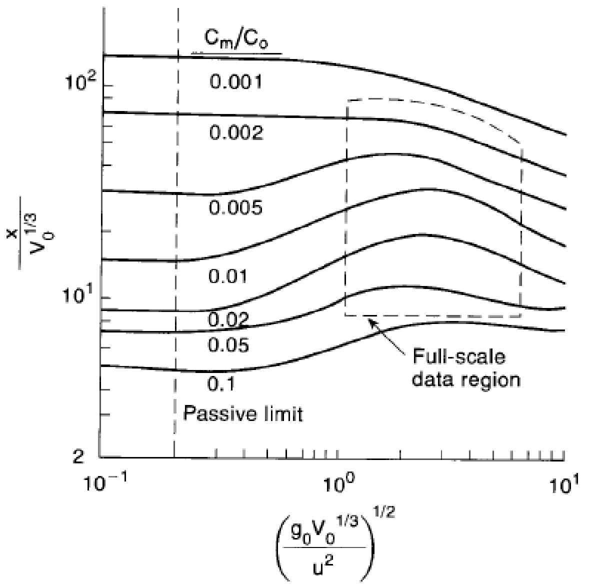


Fig. 3: Britter-Mc Quaid Dimensional Correlation for Dispersion of Dense Gas Puffs.

Concentration ratio (C_m/C_o)	Valid range for $\alpha = \log\left(\frac{g_o^2 q_o}{u^5}\right)^{1/5}$	$\beta = \log\left[\frac{x}{(q_o/u)^{1/2}}\right]$
0.01	$\alpha \le -0.70$	2.25
	$-0.70 < \alpha \le -0.29$	$0.49\alpha + 2.59$
	$-0.29 < \alpha \le -0.20$	2.45
	$-0.20 < \alpha \le 1$	$-0.52\alpha + 2.35$
0.005	$\alpha \le -0.67$	2.40
	$-0.67 < \alpha \le -0.28$	$0.59\alpha + 2.80$
	$-0.28 < \alpha \le -0.15$	2.63
	$-0.15 < \alpha \le 1$	$-0.49\alpha + 2.56$
0.002	$\alpha \le -0.69$	2.6
0.002	$-0.69 < \alpha \le -0.25$	$0.39\alpha + 2.87$
0.002	$-0.25 < \alpha \le -0.13$	2.77
0.002	$-0.13 < \alpha \le 1$	$-0.50\alpha + 2.71$

Table 1: Equation Used to Approximate the Curves in Britter-McQuaid Dimensional Correlation provided in figure 2: for Plumes

Concentration ratio (C_m/C_o)	Valid range for $\alpha = \log\left(\frac{g_o V_o^{1/3}}{u^2}\right)^{1/2}$	$\beta = \log\left(\frac{x}{V_o^{1/3}}\right)$
0.1	$\alpha \le -0.44$	0.70
	$-0.44 < \alpha \le 0.43$	$0.26\alpha + 0.81$
	$0.43 < \alpha \le 1$	0.93
0.05	$\alpha \le -0.56$	0.85
	$-0.56 < \alpha \le 0.31$	$0.26\alpha + 1.0$
	$0.31 < \alpha \le 1.0$	$-0.12\alpha + 1.12$
0.02	$\alpha \le -0.66$	0.95
	$-0.66 < \alpha \le 0.32$	$0.36\alpha + 1.19$
	$0.32 < \alpha \le 1$	$-0.26\alpha + 1.38$
0.01	$\alpha \le -0.71$	1.15
	$-0.71 < \alpha \le 0.37$	$0.34\alpha + 1.39$
	$0.37 < \alpha \le 1$	$-0.38\alpha + 1.66$
0.005	$\alpha \le -0.52$	1.48
	$-0.52 < \alpha \le 0.24$	$0.26\alpha + 1.62$
	$0.24 < \alpha \le 1$	$0.30\alpha + 1.75$
0.002	$\alpha \le 0.27$	1.83
	$0.27 < \alpha \le 1$	$-0.32\alpha + 1.92$
0.001	$\alpha \le -0.10$	2.075
	$-0.10 < \alpha \le 1$	$-0.27\alpha + 2.05$

Table 2: Equation Used to Approximate the Curves in Britter-Mc Quaid Dimensional Correlation provided in figure 3: for Puffs

- *Step-5- Mitigation Strategy*

The purpose of this dispersion modeling study is to estimate fire & explosion risk for storage tank containing flammable liquid. Based on this study mitigation strategy should be adopted to bring down the risk in acceptable manner or monitoring of risk. Release mitigation is defined as "lessening the risk of a release incident by acting on the source (at the point of release) either (1) in a preventive way by reducing the likelihood of an event that could generate a hazardous vapour cloud or (2) in a protective way by reducing the magnitude of the release and / or the exposure of local persons or property. Mitigation plan shall be included in view of layer of protection if one layer fails another layer can. This mitigation strategy includes risk reduction strategy like elimination, substitution, engineering control, administrative control and necessary personal protective equipment.

III. PLANT DESCRIPTION

Symbiotec pharma which is situated in special economic zone of Pithampur area of Dhar district in Madhya Pradesh, deals with many hazardous chemicals to produce Active pharmaceutical ingredient- hormone. Symbiotec handles huge quantities of chemicals which may cause accidents depending upon the properties of the chemical (Highly toxicity, highly flammability, corrosive, oxidizer and water reactive substances etc.). chemical incident may take place due to accidental leakage from the storage tanks, leakage from the process vessel or pipelines and damage during transportation of chemicals in the pipeline, manual handling of chemicals or releases from the gas cylinders. Some of these faults may be caused due to rupture or damage of process vessel or pipeline, failure of equipment or instrument, activation of safety devices or human negligence which resulting releases large quantities of chemicals in to the environment. The risk may vary based on hazardous properties of chemical and different process condition. For this dissertation Iso-propyl alcohol storage tank has been selected for the study which is extremely flammable. The IPA releases from the storage tank can affect neighboring plant/public located in nearby area.

API manufacturing plant generally designed as per GMP guideline where quality and safety are kept on first priority. Good Manufacturing Practice (GMP) is a system for ensuring that products are consistently produced and controlled according to quality standards. It provides a high level assurance that medicines are manufactured in a way that ensures their safety, efficacy and quality. GMP applies to both Active Pharmaceutical Ingredients (APIs) and Finished Pharmaceutical Products (FPPs). Some of GMP elements are Purchase and storage of Raw Material and finished goods, Process Control, Quality Control, Personnel Training, Personnel Hygiene, Building and Maintenance, Process Instrumentation, Records, Housekeeping, Sanitation, Contamination, Packaging and labeling etc. To maintain the GMP environment pharmaceutical infrastructure has more or less same for most of the industry. Following below are the parts of the Manufacturing Plant were from raw material to finish goods in form of APIs are manufactured.

- Raw Material Warehouse
- Process Technical Area
- Process Clean Area
- Process ML Area
- Quality Control Laboratory
- Solvent Recovery Plant
- Utility Area
- ETP Hazardous Waste Storage Area

Fig. 4: Plant Description

IV. FIRE AND EXPLOSION ASSESSMENT

Based on the above methodology fire and explosion risk for storage tank containing flammable liquid has been determined for one of the biggest manufacturing unit of Symbiotec pharma lab Pvt. Ltd. Here Iso Propyl Alcohol storage tank has been taken into the account for assessment. IPA is highly flammable liquid having low flash point. Dispersion modelling study shall be followed after analyzing the release quantity and then fire an explosion risk can be assessed.

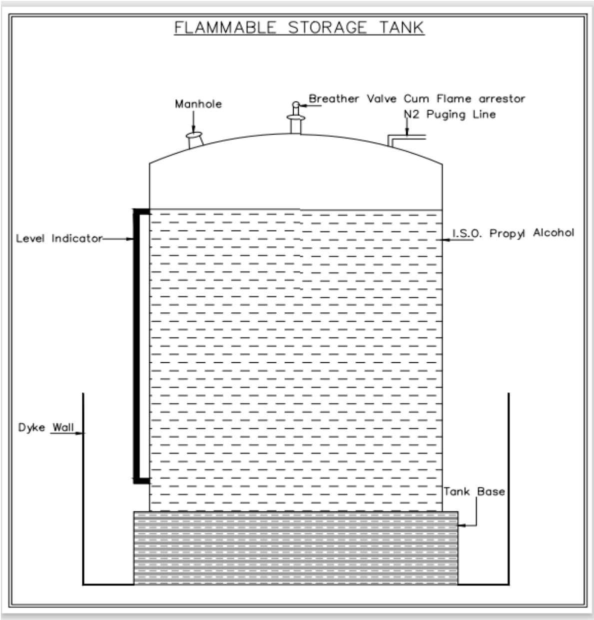


Fig. 5: IPA storage facility

- Step-1- Identify the Release incident

First step is to identify the release incident it has been assumed that the storage tank having flammable liquid iso propyl alcohol. The storage tank is located in tank farm area at Symbiotec facility. The storage tanks as per figure 5.1 has inerting facility with nitrogen gas , the storage tanks is equipped with the breather valve cum flame arrestor. This storage tanks having adequate dyke area as secondary containment system to avoid further overflow of material. A leak scenario around 1 inch on the side wall of the storage tanks has been considered and spilled material accumulated in the dyke wall of storage tanks which further dispersed into the environment may have fire and explosion risk when it comes in contact with ignition source. The tanks is filled with 85% capacity of storage tanks (20 KL) and leak height is around 3.48 meter.

- Step-2- Develop Source Model

The source model for IPA is being leaked out from the storage tank can obtained by below given formula.

The maximum flow rate is determined by given Equation for source model

$$\left[Q_m = \rho A C_o \sqrt{2\left(\frac{g_c P_g}{\rho} + g h_l\right)} \right] - (Equation no. 1)$$

ISSN No:-2456-2165

Q_m = Leak Mass Flow Rate
A = Area of Leakage/Release
C_o = Discharge Coefficent
P_g = Gauze Pressure
g_c = Gravitational Constant
ρ = Density of Liquid
g = Acceleration due Gravity
h_l = Liquid Height Above the Leak

Given:
Dia of leakage = 1 inch = 0.0254 meter
Area of Release = $A = \pi r^2$
Area of Release = $A = 3.14 \times \left(\frac{0.0254}{2}\right)^2$
Area of Release = $A = 3.14 \times \left(\frac{0.0254}{2}\right)^2$
Area of Release = 0.000506 square meter
The discharge coefficient C, is assumed to be 0.61
Resultant Pressure = Nitrogen Pressure in the tank + Atmospheric Pressure
Resultant Pressure =0.26 kg/cm^2 + 1 kg/cm^2
Resultant Pressure = 1.26 kg/cm^2

Q_m = Leak Mass Flow Rate
A = Area of Leakage/Release = 0.000506 square meter
C_o = Discharge Coefficent = 0.61
P_g = Gauze Pressure = 1.26 kg/cm^2
g_c = Gravitational Constant = 0.61
ρ = Density of Liquid = 786 kg/m^3
g = Acceleration due Gravity = 9.8 m/s^2
h_l = Liquid Height Above the Leak = 3.48 m
Form Equation 1

$$\left[Q_m = \rho A C_o \sqrt{2\left(\frac{g_c P_g}{\rho} + g h_l\right)}\right] - Equationno.1)$$

$$Q_m = \left[786 * 0.000506 * 0.61 * \sqrt{2\left(\frac{1 * 1.26 * 10^5}{786} + 9.8 * 3.48\right)}\right]$$

$$[Q_m = 0.2426\sqrt{320.61 + 68.208}]$$
$$[Q_m = 0.2426 * \sqrt{388}]$$
$$[Q_m = 02426 * 19.718]$$

Total Leak Rate

$$[Q_m = 4.7837\ kg/s]$$

The volumetric discharge rate is given by total leak rate divided by vapour density of IPA which is 2.1

$$\left[q_0 = \frac{4.78\ {kg}/{s}}{2.1\ {kg}/{m^3}}\right]$$

$$\left[q_\circ = 2.276\ {m^3}/{s}\right]$$

- Step-3- Develop Dispersion Model

Based on the above methodology the dispersion model shall be calculate by below given formula as the vapour density of Iso propyl alcohol is 2.1 which heavier than the air hence Following below sub steps to be adopted for dense gas dispersion model.

a) Sub-Step-1- The First step is to determine whether the dense gas model is applicable. The initial cloud buoyancy is defined as

$$\left[g_0 = \frac{g(\rho_0 - \rho_a)}{\rho_a}\right] ------(Equationno.3)$$

Where
g_0 = is the initial buoyancy factor
g = is the accelearation due to gravity
ρ_0 = is th einitial desnity of released material
ρ_a = is the density of ambientair

The ambient air density is computed from the Ideal gas law and gives a result of 1.22 kg/m3 thus the equation is

$$\left[g_\circ = g\left(\frac{\rho_\circ - \rho_a}{\rho_a}\right)\right]$$
$$\left[g_\circ = 9.8\left[\frac{1.76 - 1.22}{1.22}\right]\right]$$

$$\left[g_\circ = 4.34\ {m}/{s^2}\right]$$

b) **Sub-Step-2-** The second step is to determine whether release is continuous or instantaneous

For Continuous

$$\left[\frac{uR_d}{x} \geq 2.5\right] --- (Equationno.3.1)$$

For instantaneous

$$\left[\frac{uR_d}{x} \leq 0.6\right] ----- (Equationno.3.2)$$

u = is the wind speed at 10 m elevation
R_d = is the release duration time
x = is the dwonwind distance in dimensional space

$$\left[\frac{uR_d}{x}\right]$$

u=Wind speed=6.3m/s

R_d=Spill Duration=600
$\frac{uR_d}{x} = \frac{6.3*600}{x} \geq 2.5$
$\frac{3780}{x} \geq 2.5$
x≥1512m
Hence Release is continuous.

c) Sub-Step-3- The third step is to determine characteristic source dimension for continuous or instantaneous

For Continuous

$$\left[D_c = \left(\frac{q_0}{u}\right)^{\frac{1}{2}}\right] - - - - - - - - (Equation no. 3.3)$$

D_c = is the characteristic source dimension for continuous releases
q_0 = is the initial plume volume flux for dense gas dispersion
u = is the wind speed at 10 m elevation

For instantaneous

$$\left[D_i = (V_0)^{\frac{1}{3}}\right] - - - - - - (Equation no. 3.4)$$

D_i = is the characteristic source dimension for instantaneous releases
V_0 = is the initial volume of released dense gas matreial

Dense cloud model applies

$$\left[D_{c=} \left(\frac{q_\circ}{u}\right)^{1/2}\right]$$

$$\left[D_{c=} \left(\frac{2.27}{6.3}\right)^{1/2}\right]$$

$$D_{c=} 0.60m$$

d) **Sub-Step-4-** The fourth step is to estimate sufficient dense cloud to require a dense cloud representation for continuous or instantaneous release.

For Continuous

$$\left[\left(\frac{g_0 q_0}{u^3 D_c}\right)^{\frac{1}{3}} \geq 0.15\right] - - - - - (Equation no. 3.5)$$

For instantaneous

$$\left[\frac{\sqrt{g_0 V_0}}{u D_i} \geq 0.20\right] - - - - - (Equation no. 3.6)$$

$$\left[\left(\frac{g_\circ q_\circ}{u^3 D_c}\right)^{1/3} = \left\{\frac{[(4.34) * (2.27)]}{[(6.3) * (0.60)]}\right\}^{1/3}\right]$$

$$\left(\frac{4.34 * 2.27}{6.3 * 0.60}\right)^{1/3}$$

$$\left(\frac{9.85}{150.02}\right)^{1/3}$$

$$(0.065)^{1/3}$$

$$0.40 \geq 0.15$$

e) **Sub-Step-5-** In this step adjust the concentration and identify the effective concentration.

$$\left[Effective\ Concentration\ C = \frac{C^*}{C^* + (1 - C^*)\left(\frac{T_a}{T_0}\right)}\right] - - - (Equation no. 3.7)$$

C = is the efective concentration
C^* = is the require concentration
T_a = is the ambient temperature
T_s = is the source temperature

If the Original concentration C^* Then the effective concentration is given by

$$C = \frac{C^*}{C^* + (1 - C^*)\left(T_a/T_\circ\right)}$$

Where
T_a Is ambient temp.
$T_\circ$ Is source temp.

Both is absolute temp For our required concentration of 10%

$$\left[\frac{0.1}{0.1 + (1 - 0.1)0.83}\right]$$

$$\frac{0.1}{0.847}$$

$$0.11$$

$$C^* or \frac{C_m}{C_0} = 0.11$$

- *Step-4- Estimating the Fire & Explosion Risk*
  After getting the results from above step and step-5, get the equation of
  α, β & in line with effective concentration C^* or $\frac{C_m}{C_0}$

from the below table and figure to get the downward distance..

The value of C^* or $\frac{C_m}{C_0}$ = 0.11 comes under the figure 1.1 Britter-McQuaid Dimensional Correlation for Dispersion of Dense Gas Plumes than we need to figure out the value of $\left(\frac{g_\circ q_\circ}{u^5}\right)^{1/5}$ & $\frac{x}{\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}}}$

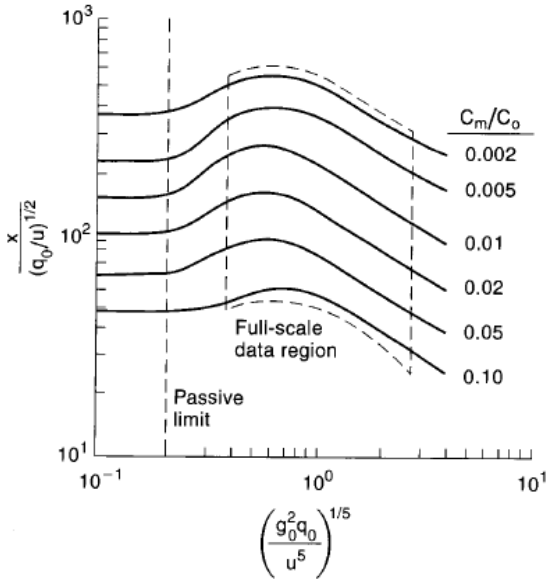


Fig. 6: Britter-Mc Quaid Dimensional Correlation for Dispersion of Dense Gas Plumes

ISSN No:-2456-2165

Concentration ratio (C_m/C_o)	Valid range for $\alpha = \log\left(\frac{g_o^2 q_o}{u^5}\right)^{1/5}$	$\beta = \log\left[\frac{x}{(q_o/u)^{1/2}}\right]$
0.01	$\alpha \le -0.70$	2.25
	$-0.70 < \alpha \le -0.29$	$0.49\alpha + 2.59$
	$-0.29 < \alpha \le -0.20$	2.45
	$-0.20 < \alpha \le 1$	$-0.52\alpha + 2.35$
0.005	$\alpha \le -0.67$	2.40
	$-0.67 < \alpha \le -0.28$	$0.59\alpha + 2.80$
	$-0.28 < \alpha \le -0.15$	2.63
	$-0.15 < \alpha \le 1$	$-0.49\alpha + 2.56$
0.002	$\alpha \le -0.69$	2.6
0.002	$-0.69 < \alpha \le -0.25$	$0.39\alpha + 2.87$
0.002	$-0.25 < \alpha \le -0.13$	2.77
0.002	$-0.13 < \alpha \le 1$	$-0.50\alpha + 2.71$

Table 3: Equation Used to Approximate the Curves in Britter-Mc Quaid Dimensional Correlation provided in figure 6: for Plumes

Compute the Dimensionless Group

$$\left[\left(\frac{g_\circ q_\circ}{u^5}\right)^{1/5} = \frac{[(4.34\,m\,/\,s\hat{\ }2\,)\hat{\ }2\,(2.27\,m\hat{\ }3\,/\,s)\,]}{(6.3\,{}^{m}/_{s})^5}\right]$$

$$\left[=\left(\frac{4.34^2\ \times 2.27}{6.3^5}\right)^{\frac{1}{5}}\right]$$

$$\left[=\left(\frac{42.67}{9924.36}\right)\right]$$

$$\left[=(0.0042)^{\frac{1}{5}}\right]$$

$$\left[\left(\frac{g_\circ q_\circ}{u^5}\right)^{1/5} = 0.336\right]$$

$$\left[\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}} = \frac{\left(\frac{2.27\frac{m^3}{s}}{6.3\frac{m}{s}}\right)^{\frac{1}{2}}}{x}\right]$$

$$\left[\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}} = 0.06m^2\right]$$

$$\left[\frac{x}{\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}}}\right]$$

For Determine downwind distance the initial Concentration of Gas $C_\circ$ is essential

$$\left[\alpha\left[\frac{(g_\circ q_\circ)}{u_5}\right]^{\frac{1}{5}} = A = 0.336\right]$$

$$\left[\beta\left[\frac{(q_\circ)}{u}\right]^{\frac{1}{2}} = \beta = 0.6010\right]$$

$$\left[Cm_{/c_\circ} = 0.023\right]$$

$$[0.45\alpha + 2.39]$$

$$[0.45 * (-0.47) + 2.39]$$

$$[-0.211 + 2.39]$$

$$2.179$$

$$\left[10^{2.179} \ = \frac{x}{\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}}}\right]$$

$$\left[15\% = \frac{x}{0.6010}\right]$$

$$[x = 90.75]$$

$$[x = 91\ mtr]$$

$$\left\{\beta = \log\left[\frac{x}{\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}}}\right]\right\}$$

$$\left\{2.17 = log\left[\frac{x}{\left(\frac{q_\circ}{u}\right)^{\frac{1}{2}}}\right]\right\}$$

$$\left[10^{2.17} \ > \frac{x}{0.6010}\right]$$

$$[x > 147 * .60]$$

$$[x > 88]$$

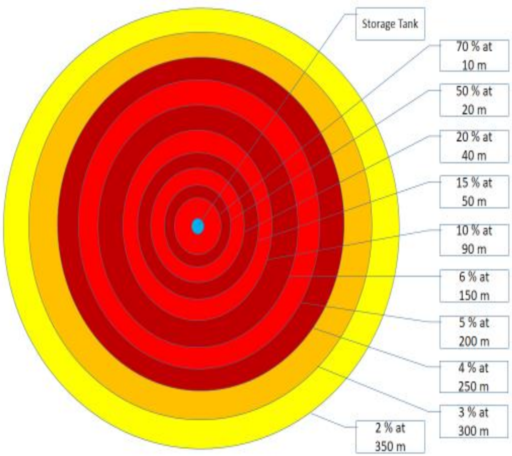
Based on the above calculation it has been determined that the Spill material of IPA vapour will be dispersed into the atmosphere at least 91 meter distance from the storage tank to reach the 10% of its concentration. Whereas the LEL of IPA is 2 % only which has higher risk of fire and explosion .

Fire and explosion risk has been determined for storage facility located at Symbiotec Pharma lab Pvt. Ltd. at

Pithampur, Dhar district of Madhya Pradesh. The storage tank having flammable liquid is located in tank farm area which is totally separated from the manufacturing facility. The storage tank is equipped with over flow protection system called high fill alarm system, breather valve cum flame arrestor, nitrogen blanketing system and adequate sizing of secondary containment system with capacity of 1105 of storage capacity. The fire and explosion risk for storage tanks has been performed based on the leakage scenario in which premature failure of primary containment system of storage tank having rupture of 1-inch diameter and material Iso propyl alcohol was spilled and contained into the dyke area and spilled material further dispersed into the environment and may have frequent probability to fire and explosion risk due to leakage. The dispersion concentration of release material from storage tanks has been shown in below table which is significant higher than the safe limit. In all the assessed dimensions the concentration was observed more than the 2% where the lower explosion limit for IPA is 2% having greater risk of fire and explosion risk. From storage tank to till 350 meter if any ignition source present than there is greater chances to occurring fire and explosion.

Sr. No.	Distance in meter	% of Concentration
1	10	70
2	20	50
3	40	20
4	50	15
5	90	10
6	150	6
7	200	5
8	250	4
9	300	3
10	350	2

Table 4: Dispersion Concentration of Release Material From Storage Tank



Name of Chemical	Lower Explosive Limit	Upper Explosive Limit
Iso Propyl Alcohol	**2%**	**12%**

Fig. 7: Dispersion Modeling of IPA Leakage

- *Step-4- Release Mitigation Measures*

In Symbiotec Pharma Lab Pvt. Ltd. following below types of hierarchy of controls needs to be ensured to bring down the risk into the acceptable range.

a) Inherent safety- Inventory reduction: Less consumption of IPA should be explored so that the storage quantity can be reduced from 20 KL to 5 KL. Once the quantity is reduce the consequence can also be minimized.

b) Engineering design Plant physical integrity: Since IPA is highly flammable and dense vapour and easily can catch fire when naked flames are available.
   - All the fitting up to 350 meter must be flameproof type to avoid any ignition source from electrical fixtures.
   - Mechanical integrity (Thickness testing) of storage tank needs to be taken out on periodical interval.
   - Mechanical integrity (Hydro test) of storage tank needs to be taken out on once in five year or on before product change.
   - Preventive maintenance to be carried out for breather valve cum flame arrestor, level transmitter, temperature indicator , flow transmitter, pressure gauze etc.
   - Dyke wall integrity needs to be inspected on regular basis by walk through observations.

c) Strict compliance of Work permit system especially hot work permit- Do not allow to issue hot work involving hot work such as welding, cutting , drilling , grinding work which produce naked flame or sparks. Take special precautions and hot work permit due to some unavoidable situation.

d) Management Operating policies and procedures- SOP Safe Operating Procedure to be displayed at prominent places.

e) Training – Training has been imparted to all plant personnel for handling and emergency during fire and explosion.

f) Provision of lightening arrester in case of lightning strikes occurs.

g) Provision of double earthing system to dissipate electro static charge while tanker deployment, loading and unloading of tanker, connecting hose pipe, flanges and joints , delivery pump and other accessories to avoid electrostatic charge.

h) Provision of Gas detector and alarm system in case of leakage occurs, immediately response can be taken.

i) Provision of Fire protection system like fire extinguisher portable type, sprinkler system, fire hydrant system, foam arrangement to fire fight the situation.

j) Emergency response- Ensure potential emergency such as fire due to leakage from storage tank has been incorporated in on site emergency plan.

k) Personal protective equipment- Compatible PPE like SCBA self-contained breathing apparatus pressure suit, gumboot, full sleeves rubber hand gloves are available at the site to mitigate the leakage risk.

l) Ensure availability of training fire fighter and emergency response team to tackle the emergency.

ISSN No:-2456-2165

V. CONCLUSION

This dissertation has been performed for Symbiotec Pharma Lab Pvt. Ltd., Pithampur Dhar District in Madhya Pradesh where Fire and Explosion risk for storage tank has been determined. It has been assumed that there is leakage on tank wall at least 1 inch diameter and the material stored in the storage tank Iso propyl alcohol was leaked from the storage tank and contained into the dyke wall of storage tank which was further dispersed into the atmosphere. The spilled material was dispersed into the environment may catch fire and explosion when it comes in contact with any naked flame or sparks. The dispersion distance where concentration of flammable liquid has been determined and control measures were suggested to mitigate the fire and explosion risk.

The concentration near the storage tank at least up to 10 meter was observed 70 % however the Lower explosive limit of Iso propyl alcohol is 2 % and Upper explosive limit is stand at 12 % in which between this band width fire or explosion can occurs, beyond this band width there is no chance of fire and still there is risk exists when leakage stops or slows release then concentration can meet the band width requirement between 2 % to 12 %. At 10 meter distance there may be health risk for emergency repose team member due to health hazard of material.

The maximum distance at 350 meter the concentration was observed at least 2% which is at LEL of IPA and having greater chances to occurring fire and explosion.

This dissertation includes the risk mitigation approaches start from the elimination, substitution, engineering controls, administrative control, personal protective equipment and medical aid services.

REFRENCES

[1.] James I. Chang (2005).”A STUDY OF STORAGE TANK ACCIDENTS ”a Department of safety, Health and Environmental Engineering, National Kaohsiung First University of Science and Technology, Kaohsiung, Taiwan, ROC

[2.] Tamil Selvan. R (2015) “FIRE, EXPLOSION AND DISPERSION MODELLING OF AUTOMATIC LPG DISTRIBUTION SYSTEM OF HIGH RISE BUILDING APARTMENTGIS” University Of Petroleum and Energy Studies Dehradun, India. Dehradun, India.

[3.] Tim Jones (2015) “DISPERSION MODELLING FOR EXPLOSION RISK ANALYSIS” Principal Consultant, MMI Engineering, The Brew House, Wilderspool Park, Greenall’s Avenue, Warrington.

[4.] Simon Coldrick (2017).”EVALUATION OF THE DRIFT GAS” Health and Safety Executive Harpur Hill Buxton Derbyshire SK17 9JN.

[5.] Helene Hisken (2016)”MODELLING IN FLACS-HYDROGEN” Proceedings Eleventh International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions, Dalian, 24-29 July 2016: 1069-1086. ISBN 978-7-89437-165-2.

[6.] Tejeswi Ramprasad (2015).” “GAUSSIAN DISPERSION MODEL TO ESTIMATE THE DISPERSION OF PARTICULATE MATTERS (PM2.5) AND SULFUR DIOXIDE (SO2) CONCENTRATIONS ON TRIBAL LAND, OKLAHOMA” Department of Kaw Nation Environmental, Kaw City, OK 74641, USA.

[7.] Rajesh Paul (2017) “DISPERSION MODELING OF ACCIDENTAL RELEASE OF CHLORINE GAS” Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

[8.] Li Jianfeng (2011)”A TYPICAL SMALL-SCALE CHLORINE LEAK AND DISPERSION SIMULATION IN INDUSTRIAL FACILITIES” Beijing Municipal Institute of Labor Protection, Beijing, China.

[9.] Azizan Ramli(2018)”CONSEQUENCE MODELLING FOR ESTIMATING THE TOXIC MATERIAL DISPERSION USING ALOHA: CASE STUDIES AT TWO DIFFERENT CHEMICAL PLANTS” Norfaridah Abdul Ghani, Norhaniza Abdul Hamid and Mohd Shaiful Zaidi Mat Desa.

[10.] Irene G. Chow Pineda(2007)”GAUSSIAN MODELLING OF THE DISPERSION OF HYDROGEN SULPHIDE FROM HELLISHEIDI POWER PLANT, ICELAND” Universidad Centroamericana Facultad de Ciencia, Tecnología y Ambiente Avenida Universitaria, Managua NICARAGUA.

[11.] AHF Emergency Response Guidelines(2018)” EMERGENCY PREPAREDNESS AND RESPONSE GUIDELINES FOR ANHYDROUS HYDROGEN FLUORIDE (AHF) AND HYDROFLUORICACID (HF)” Hydrogen Fluoride Panel American Chemistry Council 700 Second Street, NE, 20002 Washington, DC.

[12.] M.J. Ivings (2016)- “EVALUATING VAPOR DISPERSION MODELS FOR SAFETY ANALYSIS OF LNG FACILITIES” Health & Safety Laboratory Buxton, Derbyshire, UK

[13.] Nishant Pandya (2006).” TOXIC RELEASE DISPERSION MODELLING WITH PHAST: PARAMETRIC SENSITIVITY ANALYSISAN” Toulouse 31029, Cedex 4, France.

[14.] XU Bo (2008)“GIS-BASED TOXIC-GAS-VESSEL LEAKAGE, DISPERSION AND SIMULATIONS” International Institute for Earth System Science, Nanjing University, Nanjing, Jiangsu, China, 210093.

[15.] Jorge Bardina (2019). “WEB-BASED TOXIC GAS DISPERSION MODEL FOR SHUTTLE LAUNCH OPERAT IONS”NASA Ames Research Center, Mail Stop 269-2, Moffett Field, California, USA.

[16.] Mr. M. Iyyappan (2017).”COMPARATIVE STUDY ON MULTIPLE POINT INDUSTRIAL SOURCE COMPLEX (MPC) – SHORT - TERM PERIOD AND SEASONAL AVERAGE PERIOD REGULATORY MODELS”Assistant Professor, Govt Polytechnic College, Sankarapuram