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Vulnerability Analysis of a Factory using Highly Flammable Gases

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ABSTRACT

In current civilizations hydrocarbon are a primary source. Oil industries are one way hydrocarbons are processed for use crude oil is processed in several stages to form desired hydrocarbons used as fuel & in other products. Hydrocarbon is useful as well as harmful if it is not treated properly and become the cause of fire & explosion. The main objectives of the paper to give a systematic approach to know behavior of fire & explosion hazard in a factory using flammable gases like LPG. The prevention measures are to avoid any fire or explosion risks by eliminating either the potential ignition sources or both. In this paper Vapor Cloud Explosion modeling is applied for fire and explosion prevention in factories using flammable gas. Vulnerability is the ability of being easily attacked or hurt. In this we find vulnerability to humans and property damages also find out the threat zone. Potential severity of harm by which we identify the level of risk and the prevention take place. This strategy will help us in making emergency preparedness plan, human vulnerabilities and property damages.

Keywords: Vulnerability, Vapor Cloud Explosion Modeling, Flammable gases, Fire, Explosion

I. INTRODUCTION

Fire is a process in which substances combine chemically with oxygen from the air & typically give out bright light, heat & smoke. Explosion is a sudden release of mechanical, chemical, or nuclear energy is a sudden & often violent manner with the generation of high temperature & usually with the release of gases. Factory is the highly risk prone area where the workplace hazard is occurred due to a minor mistake or irregularity and this mistake easily take a form of fire and explosion which cause a dangerous hazard. Fire & Explosion is a hazard if it occurs once then it cannot stop easily as it spread within a short period of time and results in fatal injuries and damages. So by using vapor cloud explosion modeling the human vulnerabilities and threat zone or safe zone can be found.
Some norms & laws which are applicable in industries or factories using flammable gases like:

- The Factories Act, 1948 with The Madhya Pradesh factories Rules, 1962.
- The Gas Cylinders Rules, 2004 chapter II General Provisions.
- The Gas Cylinders Rules, 2004 with the Static and Mobile Pressure Vessels (Unfired) Rules, 1981.
- The Petroleum Act 1934, Rules 1976
- The Explosive Act 1884, Rules 2008
- MSHIC Rules 1989
- OISD Standard
- ISO Standard
- CIMAH Regulations 1996
- OSHA 1970
- The motors transport workers Act 1961
- The Manufacture storage and import of hazardous chemical Rules 2000

Classification of Flammable gases:-

- Extremely flammable gases: Gases ignitable when in mixture of less than or equal to 13% or having a flammable range with air of greater than 12%.
- Flammable gas: Gases other than above, having a flammable range while mixed in air.
- Pyrophoric gas: It is a flammable gas that is liable to ignite spontaneously in air at a temperature of 54 °C or below.

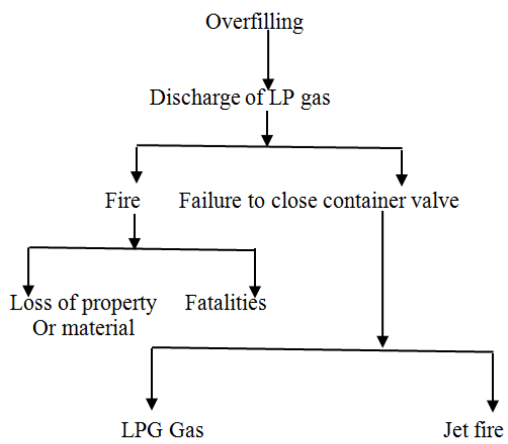
- Chemically unstable gases: It is a flammable gas that is able to react explosively even in the absence of air or oxygen.

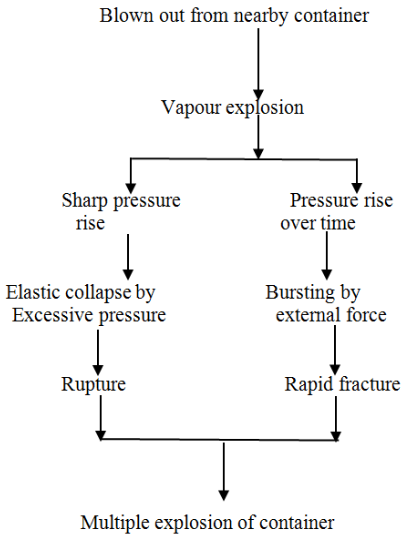
II. METHODS AND MATERIAL

Empirical models are based on correlations obtained from analysis of experimental data. The models described below constitute a selection of methods commonly used in industry for risk assessment, vulnerabilities, threat zones and safe zone. Accidental vapor cloud explosions do not occur under controlled conditions. Various experimental programs have been carried out simulating real accidents. Quantities of fuel were spilled, dispersed by natural mechanisms, and ignited. It had been common practice for many years to compare the air blast effects of a VCE with the blast from a TNT charge. The available combustion energy in the vapor cloud is converted into an equivalent charge weight of TNT. This approach was attractive since the blast effects of TNT as a function of distance from the explosion source are well known. So here we have applied TNT equivalent model. The TNT equivalent method is based on the assumption that gas explosions in some way resemble those of high charge explosives, such as TNT. However, there are substantial differences between gas explosions and TNT. It is now well understood that blast effects from vapor cloud explosions are determined not only by the amount of fuel burned, but more importantly by the combustion mode of the cloud. In energy scaled coordinates, the TNT blast represents a single curve, whereas the blast waves generated by vapor cloud explosions are represented by a family of curves corresponding to various cloud combustion modes. Furthermore, there are dramatic differences between explosions involving vapor clouds and high explosives at close distances for the same amount of energy, the high explosive blast overpressure is much higher and the blast impulse is much lower than that from a VCE. However, the TNT equivalent method is reasonable for far-field predictions of VCE over pressure.

In factory there is mainly LPG is used as a flammable gas. LPG is the naturally occurring fuel and it is also produced through the cracking or refining process for other hydrocarbons. LPG is the name given to the mixtures of commercial butane and propane. The LPG is normally composed of propane and butane mixed in different proportions. The LPG gas or vapour will diffuse into the atmosphere very slowly unless the wind velocity is high; Open flames will ignite air-gas mixtures which are within the flammable limits; Gas-air mixtures may be brought below the flammable limit by mixing with large volumes of nitrogen, carbon dioxide, steam or air; Fine water sprays reduce the possibility of igniting gas-air mixtures; The vapour pressure of this fuel is greater than gasoline. It is safely stored only in closed pressure vessels designed, constructed and maintained according to appropriate regulations and equipped with safety devices as required. Liquid in open vessels will evaporate to form combustible mixtures with air even if the ambient temperature is many degrees below the boiling point. The rapid removal of vapour from the tank will lower the liquid temperature and reduce the tank pressure. The liquids will expand in the storage tank when atmospheric temperature rises; Storage tanks must never be filled completely with liquid; Liquid drawn from the storage tank will cause freeze burns on contact. This is due to the rapid absorption of heat by the liquid upon vaporization in the open. Condensation will occur in gas distribution lines when surrounding temperatures are below the boiling point of the liquid. Liquefied petroleum gases are excellent solvents of petroleum products and rubber products. Special pipe joint compound and rubber substitutes are available for use in distribution. LPG cylinders will be placed on a firm foundation and secured in an upright position. All LPG cylinders will be equipped with valve-protection devices. LPG cylinders will not be stored closer than 10 feet to the kettle. LPG cylinders will be placed away from vehicular traffic. LPG cylinders will not be stored inside buildings. Acetylene bottles will bered in the upright position and secured.

Block diagram of LPG overfilling





Sample Calculation

Sample of calculation for LPG bullet

The calculation of explosion storage LPG tank capacity of 56 gallon which is liquefied under the pressure and has above ground storage at ambient temperature has the following details.

Following models are used VCE modeling:

1. TNT equivalent model
2. TNO multi energy model
3. Modified baker model

From above methods, TNT equivalent model is used for VCE modeling of LPG:

TNT equivalent model for VCE:

The TNT equivalent W is given by

$$W = \frac{MH_c}{E_{TNT}}$$

W, Equivalent mass of TNT(kg)

Ƞ,Empirical explosion efficiency = 0.05 (psychometric chart)

M, Mass of hydrocarbon(kg)= 8975 kg

H_c, Heat of combustion of flammable substance(j/kg)

[LPG] =45940 kj/kg

E_{TNT}, Heat of combustion of TNT(j/kg) $=14.5\times10^3$ kj/kg

$$W = \frac{45940\times8975\times0.05}{14.5\times10^3}$$

$= 1421.76$ kg

Total capacity = 56 gallon
Design Temperature = -42 to 55°C,
Design Pressure = 20 kg/cm2 or 1.96 mpa
Density of LPG = 0.52
Normal Working Pressure = 15 Kg/cm²,
Tank = Bullets,
Maximum Filling ratio = 80%,
Maximum Ambient Temperature = 45°C.
Heat of combustion of LPG (H_c) = 46000kj/kg

Capacity of tank= 56 gallon
Convert gallon into kg;
1 us gallon =3.78 L
56×3.78= 211.682 L
Density of LPG = 0.52
211.68×0.52=110.073=110kg (Approx)

Calculation for intensity of radiation:

1. $t_d = 0.9m^{1/4}$
   t_d = Duration of combination
   $= 0.9(110)^{1/4} = 2.84$ sec

2. $D_{max} = 5.8m^{1/3}$
   D_{max} = Diameter of fireball
   $= 5.8(110)^{1/3}$
   $= 2.735$ m

3. $H_{FB,}$ Height of fire wall $= 0.75\times D_{max}$
   $= 0.75\times27.35$
   $= 20.51$ m

4. Thermal radiation from fire ball or
   Maximum emitted thermal flux =
   $E_{max} = 0.133\times f\times H_c \times MF_B^{1/2}$

Where: - f, Radiant heat fraction $= 0.27\ P_B^{0.32}$

As normal bursting pressure is 15kg/cm^2 and maximum bursting pressure are 20 kg/cm^2 so we are taking maximum bursting pressure for calculation, so that we can identify the maximum limit of bullet.

Hence P_B =20 kg/cm^2 or 1.96 Mp_a (Assume)
$f= 0.27(1.96)^{0.32}$
$f= 0.27 \times 1.240$
f=0.33(Radiant heat fraction)
$E_{max} = 0.0133\times0.33\times46000\times (110)^{1/2}$
$=298.6$kw/m^2

5. Radiation received by a target at a distance of 10 m (assumed):

I, Intensity of radiation is expressed as

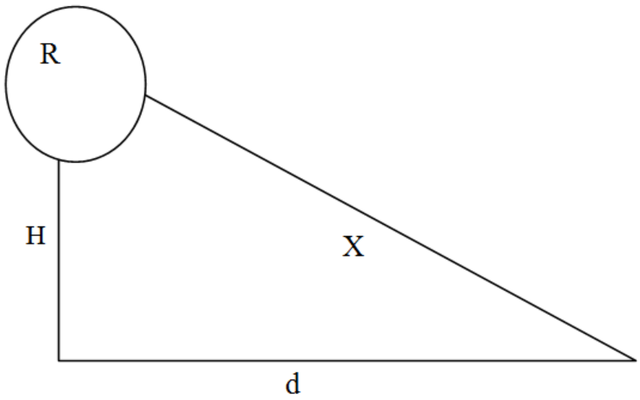
$$= \tau \times f \times Ep$$

$P_{w:}$ Partial pressure of water vapors

$$\tau = 2.02(P_w \times X)^{-0.09}$$

$$= 2.02(4035.79.147)^{-0.09}$$

=0.783 atmospheric transmissivity (Dimensional less)



$X = \sqrt{H^2 + d^{2}} - R$

$= \sqrt{(20.51)^2 + (10)^2}\ -13.67$

= 9.147 m

F, View factor= $D^2/4(r + x)^2$

$= (27.35)^2 / 4(13.67+9.147)^2$

=748.022/2082.461

= 0.35(View factor)

Ep, Emissive power= $\eta \times M \times H_c / \pi \times D^2 \times t$

$= 0.25 \times 110 \times 46000/\pi(27.35)^2 \times 2.84$

= 189.63kw/m^2

I= $\tau \times f \times Ep$

$= 0.783 \times 0.35 \times 189.63$

= 51.97kw/m^2 to target at 10m distance.

The intensity of explosion in which result is 51.97 kW/m^2 to target at 10m distance.

Thermal dose: The thermal expression is give by (Explosion)

Dose= $I^{4/3}$ t

Where, I= Incident thermal flux (kw/$m^{2)}$

t = Duration of exposure (s)

Dose = $(51.97)^{4/3} \times 10$ (Assume t= 10 sec)

= 1914 (kW/$m^{2)}$ $^{4/3}$ s

This result concludes that thermal dose 1914 (kW/$m^{2)}$ $^{4/3}$ s effect is 50% lethality, members of the public.

Thermal dose Fatality criteria (use for fireballs)

Thermal Dose units (kW/m^2) $^{4/3}$ s	Effect
1000	1% lethality
1800	50% lethality, members of the public
2000	50% lethality, offshore workers
3200	100% lethality

These two tables showed the rank and level of hazards:

Description	Level
Extremely harmful	4
Harmful	3
Slight harmful	2
Very slight harmful	1

Description	Rank
Very likely	4
Likely	3
Unlikely	2
Very unlikely	1

III. RESULTS AND DISCUSSION

Modelling refers to the calculation or estimation of numerical values(or graphical representations of these) that describe the credible physical outcomes of loss of containment scenarios involving flammable, explosive and toxic materials with respect to their potential impact on people, assets, or safety functions. Here we have applied the TNT equivalent method for the determination of the human vulnerabilities in the terms of thermal dose which has been found 1914 (kW/$m^{2)}$ $^{4/3}$ s for the 10 seconds which results in the 50% fatalities from the thermal intensity of the explosion because explosion also results in thermal (heat) and pressure wave which has been determined 51.97 kW/m^2 from the target at a distance of 10 m.

IV. CONCLUSION

The fire safety preventing methodologies helps in control various kind of hazards & accidents & reduce the rate of loss in many kinds of industries. This approach is to give a systematic way to minimize the fire & explosion hazard in a high risk area. This paper gives an overview of the modeling required to create a safe atmosphere under the guidance of various laws related to health & safety. The tool is used in the form of VCE model is the TNT equivalent model which helps in the determination of behavior of fire and explosion and the vulnerabilities of human with the thermal dose.

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