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# Safety Analysis of Deluge Sprinkler System for LPG Tank

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**Abstract:** Liquefied petroleum gas (LPG) is mixture of propane and butane it mainly find application in cooking and as a fuel in vehicles. LPG is flammable gas and it usually stored in tanks and vessels by compressing it in to liquid phase. These storage vessels are exposed to hazards like jet fire, BLEVE, vapour cloud explosion. This thesis presents the designing of deluge water fire sprinkler system for protection of the LPG tanks from these hazards and identifying the liquid to be used inside fire sprinkler bulb in way to reduce the time required to reach the operation temperature of sprinkler bulb. The main problem with the current deluge system design is that sprinklers are arranged by considering the floor area which results in improper arrangement of sprinkler around the equipment to be protected. Improper arrangement will lead in to the interaction of the water stream from adjacent sprinklers and this interference will make non uniform water distribution around the equipment and cooling rate will be less in some region, here I am designing by uniformly arranging sprinkler around the LPG tank which will reduce the interference between adjacent sprinklers Model of glass bulb is modeled in solid works and transient thermal analysis is carried out in that model to determine the time required to reach in to the operating temperature of the sprinkler bulb and experimental setup is created and the analysis data is compared with experiment.

## I. INTRODUCTION

### A. General

Liquefied petroleum gas (LPG) is mixture of propane and butane it mainly used in cooking and as a fuel for vehicles. LPG is flammable gas and it usually stored in tanks and vessels by compressing to liquid stage. Auto ignition temperature of LPG is in the range of 410 to 580 deg. Celsius hence it's difficult to ignite by its own temperature. When any leak happens to the storage tank liquid comes out through leak and vaporises to gaseous state, this will form an explosive mixture with the surrounding air. LPG has flammable range varying from 1.8% to 9.5% volume of gas in air. If the explosive mixture formed with air is in flammable range and if it finds any source of ignition this explosive mixture catches fire and this is the mechanism by which LPG catches fire. Other danger associated with LPG is that at atmospheric pressure and temperature it is a gas which is 1.5 to 2 times heavier than air so that it displaces air and level of oxygen is reduced which will produce suffocation to the people in surrounding area.

LPG is now increasingly used as refrigerant to replace chlorofluorocarbons to reduce damage to ozone layer, chlorofluorocarbon can deplete ozone layer. LPG marketed in India shall be governed by Indian Standard Code IS-4576 and the test methods are carried out by IS-1448. Physical properties of LPG are its density is about 525 to 585 kg/m<sup>3</sup> and about 2 times heavier than air, its colourless in both liquid and vapour phase. It has faint smell LPG is slightly toxic but it's not poisonous.

### B. Hazards Of LPG Tank

1) *Boiling Liquid Expanding Vapour Explosion (BLEVE):* Normally BLEVE occurs when fire external to tank heats a tank filled with pressurised liquid. External fire heats the tank wall as well as content inside the tank, this produce more amount of the vapour and as a result pressure inside the tank increases and vaporisation of liquid decreases the level of liquid in the tank. Since level of liquid inside tank decreased major part of heat is absorbed by the container wall this will increase the temperature of the tank wall rapidly. Increase in temperature results in increase in yield stress of the tank wall. Parallel to that pressure inside the tank build up because of the vaporisation of the liquid in to the empty space of tank. The condition of the liquid inside the tank is like it is in liquid phase at a temperature more than that of its normal boiling point temperature. This is because of the fact that boiling point increases with increase in pressure. Inside tank pressure is more than atmospheric hence boiling point also increases so content inside tank will exist as in liquid state. Deterioration in strength and increase in internal pressure beyond its hoop stress will lead in to the sudden disruption of the tank. Then liquid inside the tank comes to the atmospheric condition. The state of liquid is as liquid at a temperature above its normal boiling point at atmospheric pressure, this state is known as metastable state. Liquid in this metastable state will rapidly turn in to gaseous state sudden flash over of liquid will takes place. Sudden flash over will produce large quantity of flammable gas in the atmosphere it mixes with air to

form mixture in flammable range and presence of source of ignition will produce a large fireball. Major risk associated with BLEVE is the flying particle from explosion and over pressure generated due to the explosion. Disrupt segments of tank fill fly like missile which can worsen the situation more.

- 2) *Jet Fire:* Jet fire is produced when pressurised flammable material come out from a leak like stream or jet of flammable liquid. Release of a flammable material at high pressure due to hardware failure (leak) may lead to formation of jet, which may cause jet fire on immediate availability of ignition. The jet flame direction & tilt depend on prevailing wind direction & velocity. Immediate ignition source can only produce jet fire this is because of the available time is more leaked gas forms large vapour cloud which ultimately result in vapour cloud explosion. In jet fire a standoff zone is present it's the distance from the leak where fire starts fire starts only after some distance from the leak it is because in that initial region mixture will be above upper flammable range hence fire is not happening. Length of this zone depends on the velocity of material through leak. The Jet Fire could damage the neighbouring vessels / tanks by direct flame impingement. The thermal radiations may as well affect surrounding population. Jet fire from one tank can cause BLEVE in adjacent tank
- 3) *Vapour Cloud Explosion:* Continuous release of flammable material over a period may lead to formation of vapour cloud due to non-availability of ignition source. If the flammable material leaks from one container it will mix with the air and forms a mixture within flammable range. Delayed availability of the ignition source will lead in to leaking of more flammable material and which in turn will produce a large vapour cloud. If this large vapour cloud in flammable range finds any source of ignition explosion of take place. The main difference between jet fire and vapour cloud explosion is availability of source of ignition immediate ignition can result in to jet fire and delayed ignition can result in to vapour cloud explosion. The explosion may cause overpressure resulting into damage to the surrounding buildings and equipment. Vapour cloud explosion can be of confined and unconfined. Unconfined vapour cloud explosion cause more damage than unconfined vapour cloud explosion. Presence of any obstacle in the enclosure can cause more overpressure in vapour cloud explosion. Presence of obstacles make the cloud more turbulent and rate of burning increases increased rate of burning and turbulence of this cloud produce more number of shock waves. These shock wave merge together and will produce shock wave of higher amplitude, this causes big fireball and more explosion overpressure.

### C. Fire Protection Of Lpg Tank

LPG tank fire protection is achieved by deluge water fire sprinkler system. This system consist of large number of sprinklers arranged in number of rows and completely surrounds structure to be protected. Sudden application of large quantity of water is the main advantage of the deluge water system

The purpose of a deluge system is to deliver sprinkler water coverage to the entire area of a fire in the least amount of time possible. It accomplished by admitting water to sprinklers or spray nozzles that are open at all times. By using automatic fire detection devices a deluge system can apply water to a fire more quickly than a system whose operation depends on the opening of sprinklers as the fire spreads.

Deluge systems are suitable for extra hazard occupancies in which flammable liquids are handled or stored and where a fire may flash ahead of the operation of ordinary automatic sprinklers. Water is not present in the piping lines until the system operates. Because the sprinkler orifices are open, the piping is at ambient air pressure. To prevent the water supply pressure from forcing water into the piping, a deluge valve, which is a mechanically latched valve, is used in the water supply connection. It is a non-resetting valve and stays open once tripped.

Because the sprinklers are of the open type, the deluge valve must be opened as signaled by a specialized fire alarm system. The type of fire detection can be smoke detectors, heat detectors, is selected mainly based on the hazard. The initiation device signals the fire alarm panel, which in turn signals the deluge valve to open. Activation can also be manual, depending on the system goals. Manual activation is usually via an electric or pneumatic fire alarm pull station. Activation of a fire alarm-initiating device or a manual pull station signals the fire alarm panel, which in turn signals the deluge valve to open, allowing water to enter the piping system.

Water flows from all sprinklers simultaneously. Deluge systems are used for fast, total application of water in extra hazardous areas and in water-spray systems.

Deluge valves are essentially check valves with a clapper latched in the closed position. The actuating system unlatches the valve, allowing water to enter the piping system and flow out the heads. The more common design of the deluge valve employs a single differential diaphragm in which the water pressure bears on both sides, while the top side adjoins a closed chamber.

The actuating system opens the closed chamber, allowing the water to push the diaphragm up and off the water seat, releasing water to the system.

The deluge valve can be actuated by pneumatic, hydraulic or manual way. In pneumatic actuation valve is made in to closed position by means of the pressure of the compressed air in pipeline. When the quartzoid bulb breaks pressure in the pipe line reduces when the pressure goes below predetermined value springs which holding gear is compressed that rotates the gear.

Gear is connected to valve similar to that of gate valve when the gear rotate along with that valve raises permitting water to the open sprinklers. From these open nozzles water comes like spray and cools structure to be cooled. Emergency response valve is provided in the system which is manually operated. In case of fire if the automatic opening of valve is delayed manually valve is opened.

## II. LITERATURE SURVEY

### A. Explosion Hazards

- 1) *Explosion hazard of LPG air mixture in vented enclosure with obstacle, Qi Zhang et.al. 2017:* This paper examines the concentration of LPG and the presence of obstacles in enclosure changes explosion characteristics such as explosion over pressure, dynamic pressure and peak temperature. Physical model simulated in this model is an enclosure of 4.6m\*4.6m\*3m with a vent, mathematical model used is finite element computational code. Analysis is carried out by examining different concentrations of 2.5, 4 and 9 LPG and also examines effect on explosion characteristics with the presence of obstacles in enclosure and not. Results shows that explosion over pressure, high temperature range is maximum for stoichiometric concentration and presence of obstacles in the enclosure increases peak over pressure 13 times more than without obstacles.
- 2) *Experimental evaluation of LPG tank explosion hazard, Jan stawczy et.al. 2003:* Liquefied-pressure gases (LPG) are transported and stored in the liquid phase in closed tanks under sufficiently high pressure. In the case of an accident, an abrupt tank unsealing may release enormous quantity of evaporating gas and energy that has a destructive effect on the tank and its surroundings. This paper is an experiment with explosion of small LPG tank and determination of pressure and temperature at which tank containing LPG tank explodes. Experimental set up carried out in cylinder of capacity 5kg and 11kg, sensors are mounted at head measures parameters. Results showed that temperature at which tank disrupts depend upon the level up to which tank filled. Tank filled with 80% of LPG disrupts when propane temperature is 120 degree Celsius. Tank filled with 40% disrupt at temperature of 150 degree Celsius.
- 3) *Esteban J. Bernechea et.al. Optimizing the design of storage facilities through The application of ISD and QRA, 2014*
  - a) *In This Paper Four Strategies Can Be Used To Achieve Safety In Chemical Processes:* inherent, passive, active and procedural are discussed. How-ever, the strategy that offers the best results is the inherent safety approach, especially if it is applied during the initial stages of a project. Inherently Safer Design (ISD) permanently eliminates or reduces hazards, and thus avoids or diminishes the consequences of incidents. . In this paper, we propose a methodology that combines ISD strategies with Quantitative Risk Assessment (QRA) to optimize the design of storage installations. As 17% of major accidents in the chemical industry occur during the storage process and cause significant losses, it is essential to improve safety in such installations.
- 4) *James I. Changa et.al. Journal of loss prevention, 2006:* This paper reviews 242 accidents of storage tanks that occurred in industrial facilities over last 40 years. Fish bone diagram is applied to analyse the causes that lead to the accidents. Corrective action are also provided to help operating engineers handling similar situations in the future. The results shows that 74% of accidents occurred in petroleum refineries, oil terminals or storage. Fire and explosion occur for 85% of the accidents. There were 80 accidents caused by lightning and 72 caused by human errors including poor operation and maintenance. Other causes were equipment failure, sabotage, crack and rupture, leak and line rupture, static electricity, open flame etc. Most of these accidents would have been avoided if good engineering practices would have been adopted.
- 5) *A Review of Very Large Vapour cloud Explosions*
  - a) *Cloud formation and explosion severity, Graham Atkinson et.al. Journal of loss prevention, 2017:* This paper presents a review of Vapour Cloud Explosions (VCEs) to examine the relationship between weather conditions, source term and development of the flammable cloud. The consequences of explosion in clouds with higher reactivity than methane. The review identified that sustained small leaks in low wind conditions are associated with very large clouds and higher likelihood of ignition leading to a severe VCE. The examination of primary data from several LPG and gasoline incident investigations showed that in many cases severe overpressure effects extended to a high proportion of the cloud.

### B. Designing Of Deluge Water Sprinkler

- 1) *Characterisation of industrial deluge system designed for the protection of large horizontal cylindrical LPG vessel, G. F Davis et.al. 2004:* The deluge systems on two industrial LPG tanks (of 50 and 60 tonnes capacity) plus that on a “full scale” experimental facility (nominal 13 tonne tank) have been evaluated in terms of the water distribution produced on the tank surface. The water distributions have been characterised in terms of water film depths and surface water flow rates at a number of locations across the tank surface using techniques described. In this paper experimental set up was created and water distribution produced on the 13 tonne, 50 tonne, 60 tonne LPG tank analysed. Water distribution measured in terms of water film depth and surface flow rate. Experimental setup consist of 24 sprinklers distributed around the tank in 4 rows and tank divided to different zones, water film depth and surface flow rate measured in these location. Results shows there is considerable variation in water distribution throughout the tank this is due to overlapping and interaction of adjacent sprinklers.
- 2) *Electrically controlled dynamic sprinkler activation, computational assessment of potential efficiency, Leonid Tanklevskiy et.al. 2017:* It is approach to reduce the sprinkler response time. Main drawback of deluge system is cover are is much greater than potential fire size.in conventional deluge system after breaking of the bulb all the sprinkler activates and water flows through every sprinkler in that area. Group enforced activation is new approach in which one leader sprinkler actuates first and within 10 seconds surrounding group of sprinklers are actuated. In this paper conventional system is compared with group enforced activation in which activation done by electrical. Increased fire water rate is observed from group enforced activation which reduces time of suppression.
- 3) *Viking Deluge System Manual:* Deluge System is a fixed fire protection system in which the pipe system is empty until the deluge valve operates to distribute pressurized water from open nozzles or sprinklers. Deluge systems are more complex than wet pipe and dry systems because they contain more components and equipment. The deluge valve is activated by operation of a fire detection system installed in the same area as the sprinklers. Deluge system can be activated by a hydraulic, pneumatic, electric, or manual release system or any combination of these release systems. But, in all cases, the deluge valve itself is activated hydraulically. When the detection device is activated, the deluge valve is tripped and water flows into the piping system, discharging through all spray nozzles or sprinklers simultaneously. Deluge systems are used where conditions of occupancy or special hazards require quick application of large quantities of water. These systems are used to create a buffer zone in high-hazard areas or in areas where fire may spread rapidly, and they can also be used to cool surfaces to prevent deformation or structural collapse or to protect tanks, process lines, or transformers against explosion. Through the inlet water comes and this is blocked by one deluge valve by the pressure inside the priming chamber. Priming chamber usually filled with air or water air allows quicker actuation of the deluge valve.
- 4) *NFPA 13 Standard for Installation of Sprinkler System:* Discuss about different type of sprinkler and their installation requirements. Different sprinklers are anti-freeze sprinkler system which contains anti freezing solution and are connected to water pipelines. Deluge sprinkler system, sprinkler system employing open sprinklers that are attached to a piping system that is connected to a water supply through a valve that is opened by the operation of a detection system installed in the same areas as the sprinklers. Dry pipe system pipelines connected with air after actuation water is allowed to flow through the pipelines. Wet pipe system and pre action system. NFPA 13 provides minimum discharge requirements in different locations like ordinary hazard, extra ordinary hazard location. Fire main pipe diameter shall not go below 6 inch. Minimum distance between two sprinklers is 6 feet and maximum distance between them is 15 feet. Maximum coverage area of one sprinkler is limited to 130 square feet
- 5) *Oil Industry Safety Directorate standard 144. Liquefied Petroleum Gas Installations:* It is impractical and prohibitively costly to design fire protection facilities to control catastrophic fires. Usual requirement of an effective fire protection system is to prevent emergencies from developing into major threat to the installations and surroundings. Medium velocity sprinkler system with automatic heat detection having remote/ local operated Deluge valve with spray density of Minimum 10.2 LPM/ SqM shall be provided on all above ground storage vessels. For water flow calculations aggregate surface area of all vessels within distance of 30 Mts. from the periphery of the affected LPG vessel shall also be considered as single risk. The Fire Water pressure system shall be designed for a minimum residual pressure of 7.0 kg/ cm<sup>2</sup> g at the remotest place of application in the plant. Water for the hydrant service shall be stored in any easily accessible surface or underground lined reservoir or above ground tanks of steel, concrete or masonry. The effective capacity of the reservoir above the level of suction point shall be minimum 4 hours aggregate working capacity of pumps

### C. Measuring Of Sprinkler Bulb Thermal Response

- 1) *Determination of activation temperature of glass bulb sprinkler using a thermal liquid bath, Mohammed M khan et.al. 2006:* A thermal liquid bath was used to determine the activation temperature of a wide range of temperature rated (57–1828C) glass bulb (3 and 5mm diameters) sprinklers using water and glycerine. An optical switch and a thermocouple were installed adjacent to each sprinkler (within 10mm) to record the activation of each glass bulb in the liquid bath having a uniform temperature distribution, experimental setup consist of thermal liquid bath used to determine the activation temperature of wide range of glass bulbs liquids used as bath are water and glycerine and experiment conducted on two glass bulb size of 3mm and 5mm. Activation temperature and maximum allowable rate of liquid temperature determined.
- 2) *Thermally responsive frangible bulb. Jerome S. Pepi et.al:* Thermally responsive frangible bulb contains one liquid which when heats expand burst the bulb. Bulb is situated in between support and sprinkler outlet cap so that when bulb bursts sprinkler outlet opens. Use of liquid enables wide range of operating temperature and quick response to the sprinkler bulb. Bulb is initially filled with a liquid, the remaining space being largely a bubble. The liquid used has been chosen because of its low freezing point, large co-efficient of thermal expansion, low specific heat. Various types of liquids have been used for filling the bulbs, such as: mercury, carbon tetrachloride, alcohol, tetra chloro ethane, acetone, tri ethylene glycol, ethylene glycol and glycerol.
- 3) *Measuring modified glass bulb sprinkler thermal response in plunge and compartment fire experiments. , Kevin frank et.al. 2017:* The response of commercial fire sprinkler glass bulbs has been extensively characterised in convection-dominated dry gas flows but in real fires there may be more factors that influence the heat transfer to the bulbs such as radiation from the fire or cooling from adjacent sprinkler sprays. . Modified glass bulb is made with thermo couple inside it. In this paper thermal response analysed using hot air. Hot air of 120 degree is used to determine the thermal response of the fire sprinkler bulb. Hot dry air allowed to pass through the bulb and determined the operating temperature of the bulb and as well as the time required to reach in to the operating temperature.

### D. Numerical Analysis Of Explosion

Numerical investigation of surface conduit parallel gas pipeline explosion based on TNT equivalent method, Yanbao Guo et.al. 2016

With the rapid development of petroleum industry, the transport pipelines of oil and gas are increasingly constructed to minimize land use conflicts. Therefore, the parallel pipelines are unavoidable in order to save land resource, reduce the pipeline construction and maintenance costs.

The economy and security of pipeline laying and running is the primary problem considered in pipeline construction, which the parallel spacing plays a decisive role to. The leakage of natural gas is very serious and dangerous due to its flammable and combustible.

Numerical solution of natural gas leak was carried out based on TNT equivalent method and analysing safe distance between surface conduit parallel gas pipelines. From gas leakage model velocity of leakage determined by assuming leak as orifice, Gaussian plume diffusion model used to describe continues leakage of gas. Safe distance between parallel pipeline is determined as minimum of 4m.

### E. Problem Identification

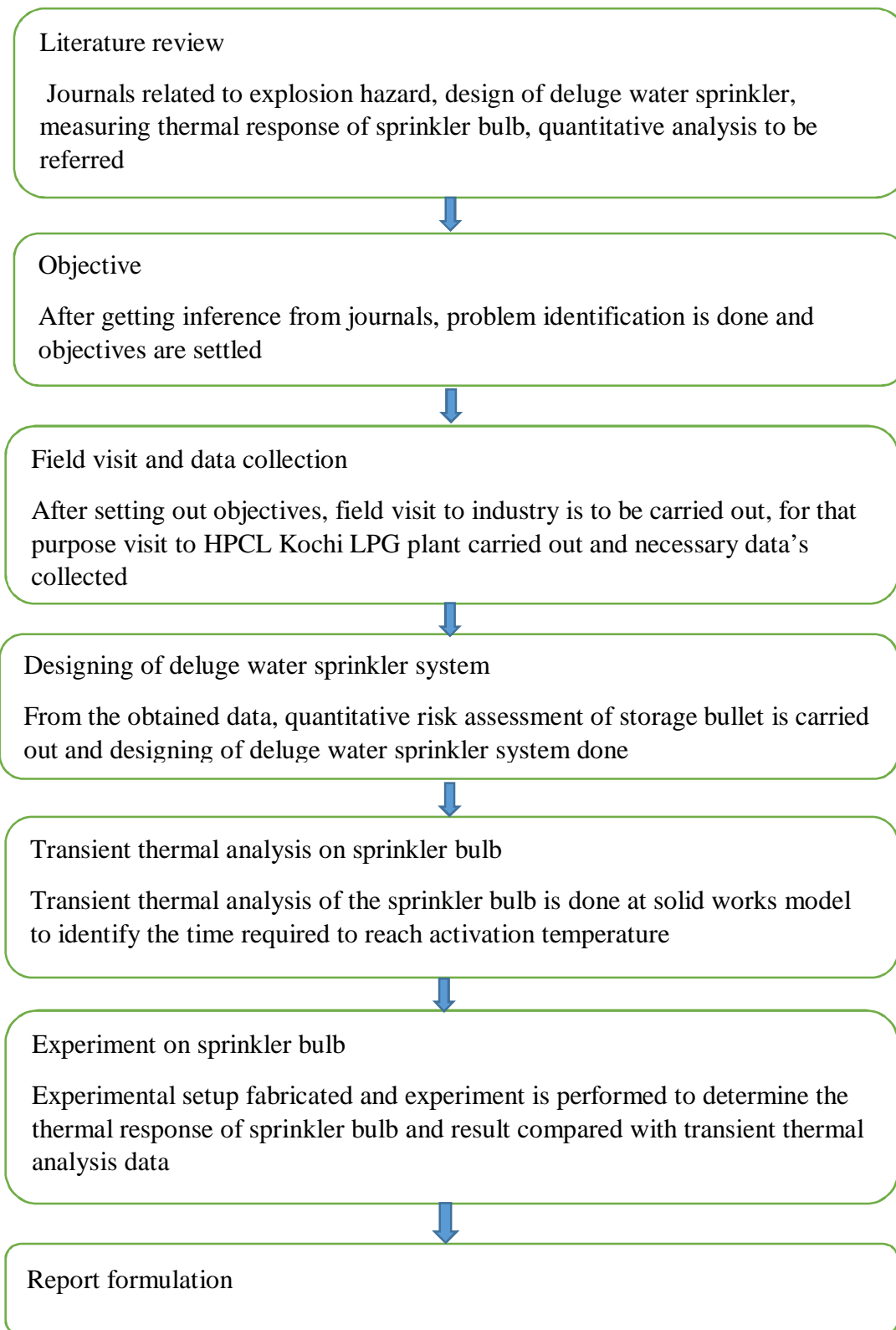
In almost every LPG plant deluge system is designed by considering total storage, drawback of this system is that if fire happens water will come from all the sprinkler placed in that area irrespective of the potential size of fire here which will results wastage of large quantity of fire water.

Here I am designing for each LPG bullet which will minimise the amount of water lost and provides fast rate of cooling to structure to be protected improper arrangement of sprinkler will result in overlapping and interaction of water from adjacent sprinklers and water distribution will not be uniform in the structure to be protected.

### F. Objective

To conduct quantitative risk assessment to determine the level of risk and determine the safe distance. To design deluge water fire sprinkler system for LPG storage bullet to get protection for storage bullet in case of fire

### III. METHODOLOGY



A. *LPG Plant in Kochi*



Figure 1

B. *Deluge Sprinkler System*



Figure 2



#### IV. CALCULATION AND ANALYSIS OF SPRINKLER

##### A. Datas Collected

HPCL plant is divided in to totally 9 zones. For the calculation of total fire water demand highest risk area is required in this plant highest risk zone is zone 4 which is the filling section. Operation carried out in filling section is that LPG from pipelines are filled in to the cylinders in 14.2 kg and 19 kg.

##### 1) Data for fire Water Calculation

Table 4.1 Dimension of filling section

length	50 m
breadth	50 m
Area	2500 Sqm
Water density requirement	10.2 LPM/Sqm

Table 4.2 fire pump specification

Capacity	410 KL/ Hr
Rpm	2100
Rating	188 Kw

##### 2) Data for Quantitative Risk Assessment: In Kochi HPCL plant 3 LPG bullet are stored as mounted bullet, mounted bullet means they are stored underground and they are securely bordered by concrete walls

Table 4.3 specification of mounted bullet

Capacity	300MT
Diameter	6m
Height to which LPG filled	4.3
Pressure	14.5 kg/cm <sup>2</sup>

##### 3) Data For Designing Of Deluge Sprinkler System: Deluge sprinkler system is designed for LPG bullet stored in storage gantry, in storage gantry 4 LPG bullet is stored having capacity of 17 tonne each.

Table 4.4 Dimension of LPG bullet at storage gantry

Capacity	17 Tonne
Pressure	75 psi
Diameter	2.4m
Length	6.8m

**B. Calculation And Results**

1) **Quantitative Risk Assessment of 300 MT LPG Bullet:** Diameter of the LPG bullet is = 6m and its filled to length of 4.3m remaining space is left for to compensate for the volume of vapour . Considering this bullet has one circular hole of 20mm diameter at a height of 1m from the bottom. Shape of the bullet is cylindrical with 2 hemispherical end. Assuming duration of leakage for period of 2 minutes. Pressure inside the storage bullet is 14.5 kgf/cm<sup>2</sup> Considering liquid discharge model ie; only liquid phase is released. Using Bernoulis equation we can calculate the velocity of leakage

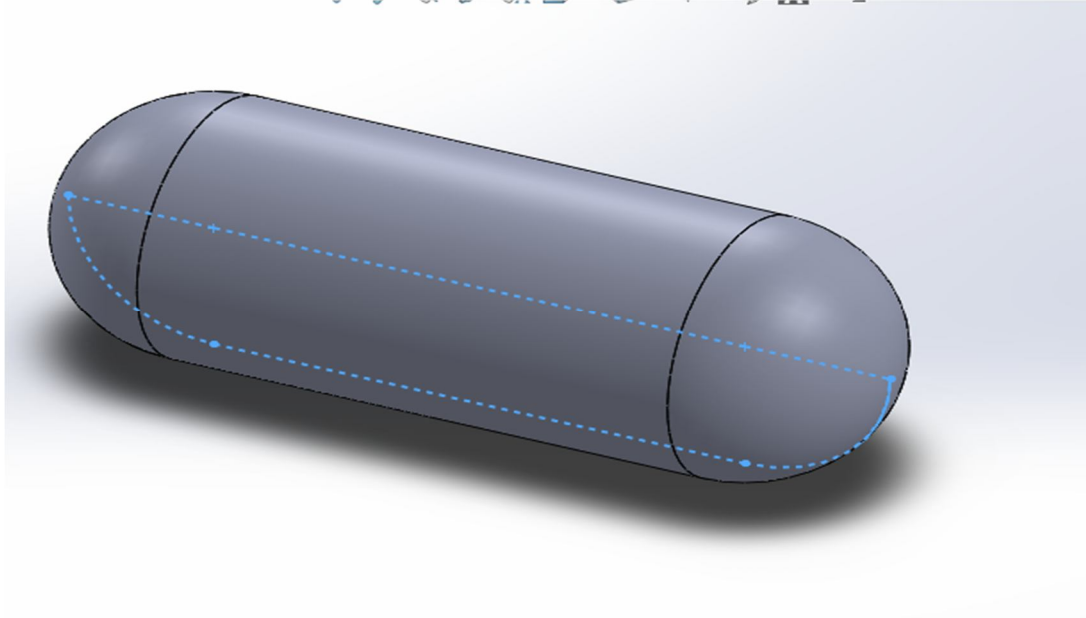


Fig 4.2 300 MT LPG bullet

$$P_1/gd + V_1^2/2g + Z_1 = P_2/gd + V_2^2/2g + Z_2$$

$P_1$  = pressure inside storage tank

$V_1$  = velocity of liquid at tank surface

$d$  = density of liquid

$g$  = acceleration due to gravity

$P_2$  = atmospheric pressure

$V_2$  = Velocity of leak

$Z$  = datum head

$P_1 = 14.5 \text{ kgf/cm}^2$  (gauge), converting to bar

$$14.5 \text{ kgf/cm}^2 = 14.5 * 0.980665 = 14.2196 \text{ bar}$$

$d$  = density of the liquid = 560 kg/m<sup>3</sup>

$$V_2 = (2(P_1 - P_2)/d + 2g (Z_1 - Z_2))^{1/2}$$

$$Z_1 - Z_2 = 4.3 - 1 = 3.3\text{m}$$

$$P_1 - P_2 = 14.2196 \text{ bar}$$

$$V_2 = (2 \times 14.2196 \times 10^5 / 560 + 2 \times 3.3 \times 9.81)^{1/2} = 71.7 \text{ m/s}$$

Velocity of liquid LPG leak through hole = 71.7 m/s

$$\text{Area of hole} = \pi/4 \times D^2$$

$D$  = diameter of hole = 20 mm

$$\text{Area} = \pi/4 \times .02^2 = 3.1416 \times 10^{-4} \text{ m}^2$$

$$\text{Mass flow rate} = \text{d} \times \text{a} \times \text{v} = 560 \times 3.1416 \times 10^{-4} \times 71.7 = 12.16 \text{ kg/s}$$

Assuming duration of leak is 2 minutes

Total amount of LPG leaked in 2 minutes = 120 × 12.61 = 1513. 69 kg. It is obtained that circular hole of 20 mm leak can liberate 1513.69 kg of liquid LPG for a period of 2 minutes. Assume that this finds an ignition source and explosion taken place.

2) *TNT Equivalency of this Explosion:* TNT Equivalency is the mass of the TNT which can produce the same explosion effect. TNT equivalent is a convention for expressing energy, typically used to describe the energy released in an explosion. The "ton of TNT" is a unit of energy defined by that convention to be 4.184 gigajoules, which is the approximate energy released in the detonation of a metric ton (1,000 kilograms or one mega gram) of TNT. In other words, for each gram of TNT exploded, 4184 joules of energy are released.

$$W_{TNT} = \mu \times M \times E_C / E_{TNT}$$

$\mu$  = explosion coefficient

M = mass of LPG leaked

$E_C$  = heat of combustion of LPG

$E_{TNT}$  = heat of combustion of TNT

$\mu = .05$ ,  $M = 1513.69\text{kg}$ ,  $E_C = 42.6 \text{ MJ/Kg}$ ,  $E_{TNT} = 4.184 \text{ MJ/Kg}$

$$W_{TNT} = .05 \times 1513.69 \times 42.6 / 4.184 = 770.6 \text{ Kg}$$

Mass of TNT required to produce same energy effect of these explosion is 770.6 Kg.

To determine the radius of affected zone

Scaled range distance for different overpressure

Table 4.5 scaled range corresponding to over pressure

Over pressure (bar)	Scaled range ( feet )
.01	16
.03	23
.16	65
3	170

Scaled radius is given by the equation

$$RG = ZG \times W_{TNT}^{1/3}$$

RG = radial distance from the discharge

ZG = scaled ground distance

$W_{TNT}$  = TNT equivalent

Assuming blast over pressure as .03 bar then corresponding scaled distance,  $ZG = 23$  feet

$$RG = 23 \times 770.6^{1/3} = 210.86 \text{ feet} = 64.31 \text{ m}$$

Radius of affected zone due to this explosion = 64.31 m

3) *Fire Water Calculation:* Total fire water requirement of the plant is determined

Total water requirement is calculated by considering the highest risk zone. HPCL plant is totally divided in to 9 zones in which highest risk zone is zone 4 which is the filling section. Even though there is 300 MT LPG storage bullet it's not considered as highest risk zone, this is because these bullet are mounted bullet chance of failure in such bullet is very low. Risk is considered as combination of probability and severity, in filling section occupancy is more and probability of failure is also high so that filling section is considered as highest risk zone. Operation carried out in filling section is LPG from the pipelines is transferred in to the domestic cylinders of size 14.2 and 19 kg this is known as pipeline transfer. There are 24 scores present in one carousel which means that at a time 24 cylinders are filled.

Dimension of filling section

Length = 50 m

Breadth = 50 m

Total area of filling section = 2500 m<sup>2</sup>

Water density requirement = 10.2 lpm/m<sup>2</sup>

Total water requirement through sprinkler = 2500 × 10.2 = 25500lpm

$$= 25500 \times 60 = 1530000 \text{ litre/hour}$$

$$= 1530 \text{ Kl/hr}$$

As per the norms oisd in addition to sprinklers 2 fire monitor should be provided

Discharge through one monitor = 288 KL/hr

Total discharge from monitor =  $288 \times 2 = 576$  KL/hr

Total fire water required = fire water requirement through sprinkler + fire water requirement through monitor

$$= 1530 + 576 = 2106 \text{ KL/hr}$$

Total storage requirement is calculated by taking water requirement for 4 hours. 4 hours is taken by the assumption that it will take 4 hours for fire engine to reach in to the plant.

Total requirement =  $2106 \times 4 = 8424$  KL.

Total fire water storage requirement of the entire plant = 8424 KL.

Number of fire pump required

Discharge from one fire pump available at HPCL Kochi plant = 410 KL/hr

Total fire water requirement of the plant = 2106 KL/hr

Number of fire pump required =  $2106/4 = 5.136$ , taking as 6

Fire water required to operate 6 pumps =  $6 \times 410 = 2460$  KL/hr

Total fire water required to operate it for 4 hours =  $2460 \times 4 = 9840$  KL

Total storage capacity required for the plant = 9840 KL

4) *Designing Deluge Water System for LPG Bullet:* To design deluge water sprinkler system first total fire water requirement for one storage bullet is calculated. This is done by calculating total surface area of the storage bullet and multiplying it by water density. Additional 20 percentage is considered to compensate for wind loss. Then number of sprinkler required to cover total surface area of the bullet is calculated. This is done by the assumption that spray cone from deflector is 60 degree and sprinklers are spaced 1.8 m from the tank surface. As per NFPA 13 minimum distance of 6 feet should be maintained between two adjacent sprinklers and maximum should not exceed beyond 15 feet. Maximum area covered by one sprinkler is limited to 130 square feet, and at the point of application of fire water minimum pressure of 7 kg/cm<sup>2</sup> should be maintained

Fire water requirement of one LPG bullet stored in storage gantry

Dimension of LPG bullet

Diameter = 2.4 m

Length = 6.8 m

Pressure = 75 psi

Capacity 17 Tonne

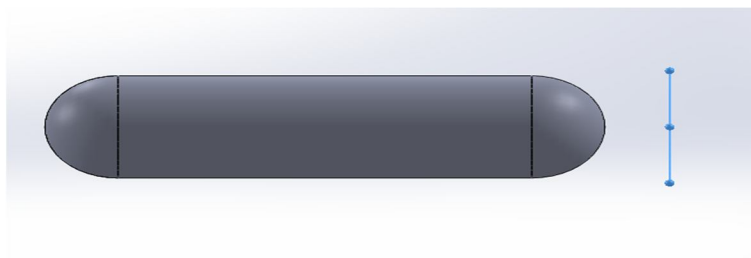


Fig 4.3 17 Tonne LPG bullet

Surface area of the bullet = surface area of cylinder + 2 × surface area of hemisphere

Surface area of cylinder =  $\pi DL$

$$= \pi \times 2.4 \times 6.8 = 51.19 \text{ m}^2$$

Surface area of 2 hemisphere =  $2 \times 2\pi R^2$

$$= 4 \times \pi \times 1.2^2 = 18.095 \text{ m}^2$$

Total surface area =  $18.095 + 51.19 = 69.285 \text{ m}^2$

Total surface area of bullet in which fire water to be applied =  $69.285 \text{ m}^2$

Fire water application rate = 10.2 Lpm/m<sup>2</sup>

Fire water requirement of LPG bullet =  $10.2 \times 69.285 = 706.71 \text{ Lpm}$

$$= 706.71/1000 \times 60 = 42.40 \text{ m}^3/\text{hr}$$

Considering 20 % loss due to wind, water required to compensate this wind loss

$$= 20/100 \times 42.4 = 8.48 \text{ m}^3/\text{hr}$$

Total fire water required for 17 Tonne LPG bullet =  $8.48 + 42.20 = 50.88 \text{ m}^3/\text{hr}$

Number of fire sprinklers require

Arranging sprinklers at a distance of 1.8m from tank surface

Spray angle of nozzle = 60 degree

Sprinkler are arranged at a distance of 1.8m from the tank surface and spray cone of sprinkler is assumed as 60 degree which means after hitting the deflector stream of water is deflected to angle of 60 degree

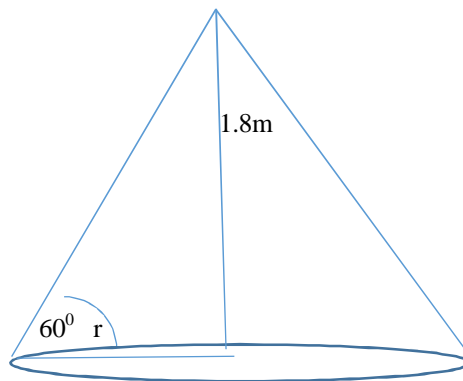


Fig 4.4 spray cone of nozzle

Radius of spray cone = r

$$\tan 60 = 1/r, r = 1.8/\tan 60 = 1.034\text{m}$$

Area of spray cone =  $\pi r^2$

$$= \pi \times 1.034^2 = 3.36\text{m}^2$$

Minimum number of sprinkler require to cover LPG bullet =  $69.28/3.36 = 20.61$

21sprinkler

Length covered by one sprinkler =  $1.034 \times 2 = 2.068\text{m}$

Length of the tank = 6.8m

Number of sprinkler in horizontal direction =  $9.2/2.068 = 5$  sprinkler

In vertical direction =  $2.4/2.068 = 2$  sprinkler

### 5) Fire Sprinkler Design

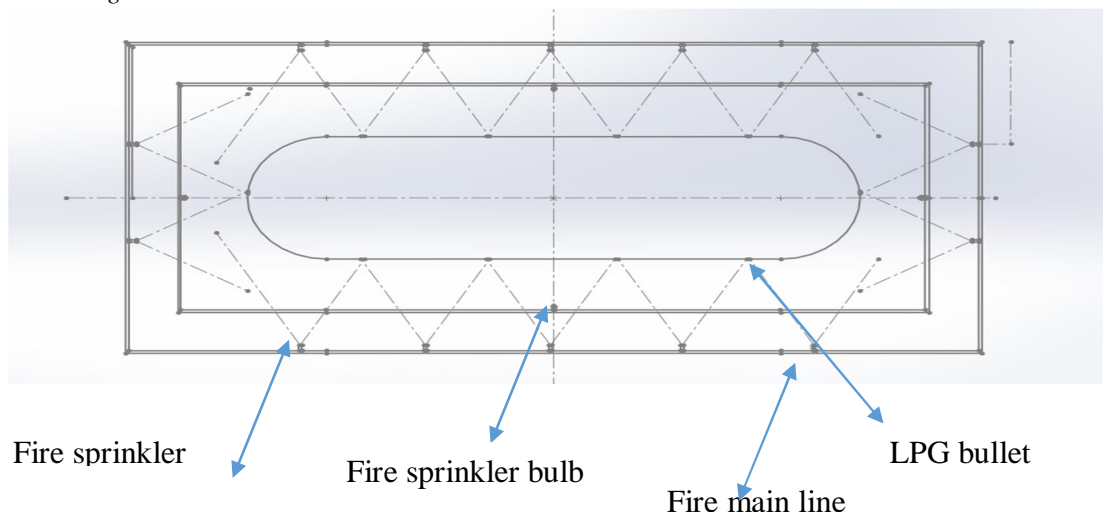


Fig 4.5 deluge water sprinkler design

6) *Fire Sprinkler Bulb*: Fire sprinkler bulb is the detection part of automatic sprinkler system. It is exposed to fire when fire comes its temperature get increases and it breaks then it actuates the valve by releasing the holding pressure through it. Depending upon the application various classification of sprinkler bulb are there. In LPG plant they are using bulb with activation temperature of 79 degree. This bulb is filled with one expanding liquid it expands when temperature increases. And apply pressure on the walls of glass bulb.

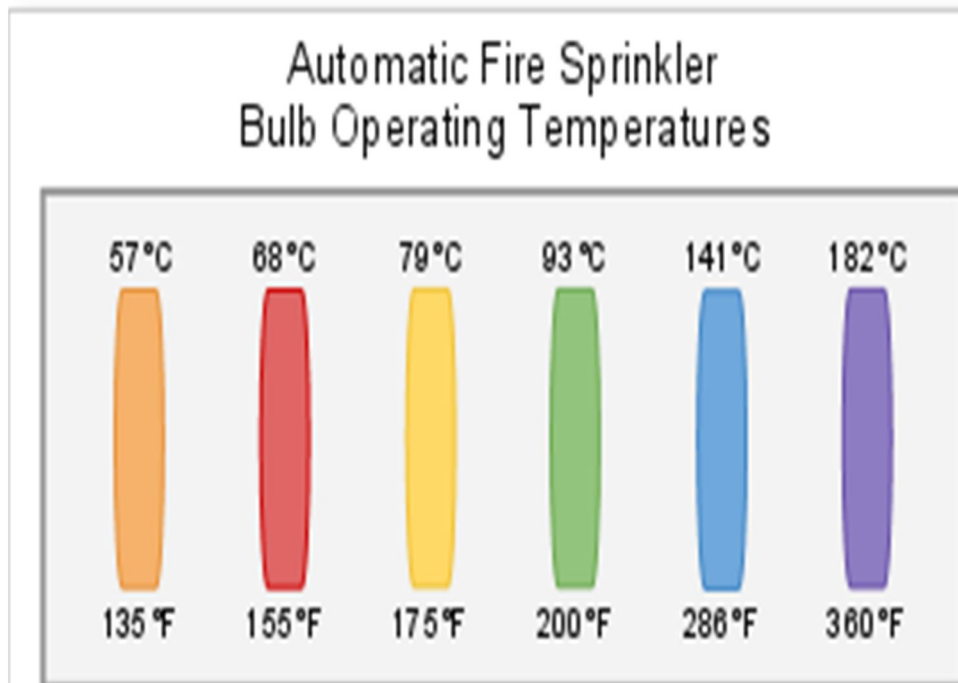


Fig 4.6 Fire sprinkler bulb classification

7) *Transient Thermal Analysis Of Sprinkler Glass Bulb*: Transient thermal analysis of fire sprinkler bulb is carried out using solidworks 2017 software. Thermal analysis is carried out on 2 different glass bulb model each is filled with different liquid and in each case time required to reach average temperature of glass bulb to 79 degree is noted. This is done to select the liquid used to fill inside the bulb. Liquid with minimum time to reach average glass temperature to 79 degree is to be selected for early activation of sprinkler. To carry out transient thermal analysis first step is modelling of geometry. Model of glass bulb is drawn in solid works 2017. For that first select one plane and draw one centre line. Draw the two dimension model first then revolving this model we will get the three dimensional drawing. Dimension of the glass bulb modelled is bulb of 5 millimetre diameter and of length 5 centimetre.

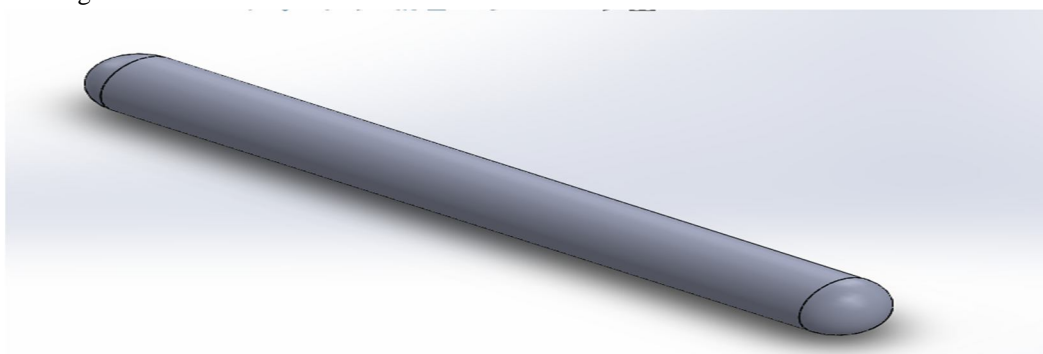


Fig 4.7 Model of fire sprinkler bulb created in solid works

Figure shows model of fire sprinkler bulb designed in solid works software. Usually this sprinkler bulb is filled with one expanding liquid it may be fully or partially filled. After modelling the geometry next procedure is adding material into the model, for that make sectional view of the model and add material to the bulb and liquid inside it.

Bulb is made of glass and liquid used for analysis are ethylene glycol, acetone, tetra chloro ethylene, glycerine and ethanol. With this five liquid transient thermal analysis of the glass bulb is to be done. After assigning material property then next step is selecting flow simulation in solid works and analysis is carried out in wizard window of solid works. In wizard window name of the project and units are assigned. Type of analysis is time dependent heat conduction in solids, total time of the analysis is 100 seconds. Selection of fluid is done from fluid domain and if fluid is not present in domain add the required fluid to the fluid domain with their property. Initial temperature of solid given as 25 degree Celsius. Boundary conditions assigned to the analysis are glass bulb wall was exposed to flame having temperature of 150 degree and heat transfer coefficient of 25 w/m<sup>2</sup>. Before running project meshing of geometry is to be done and in results we need to get average temperature of solid and liquid for that these two are selected from the global goal option. After that run the project and after completion of all iterations we will obtain result in the form of time vs temperature graph of solid and liquid as well as temperature distribution is exported to excel sheet to obtain the time to reach average glass temperature to 68 degree.

Transient thermal analysis on fire sprinkler bulb filled with tetra chloro ethylene.

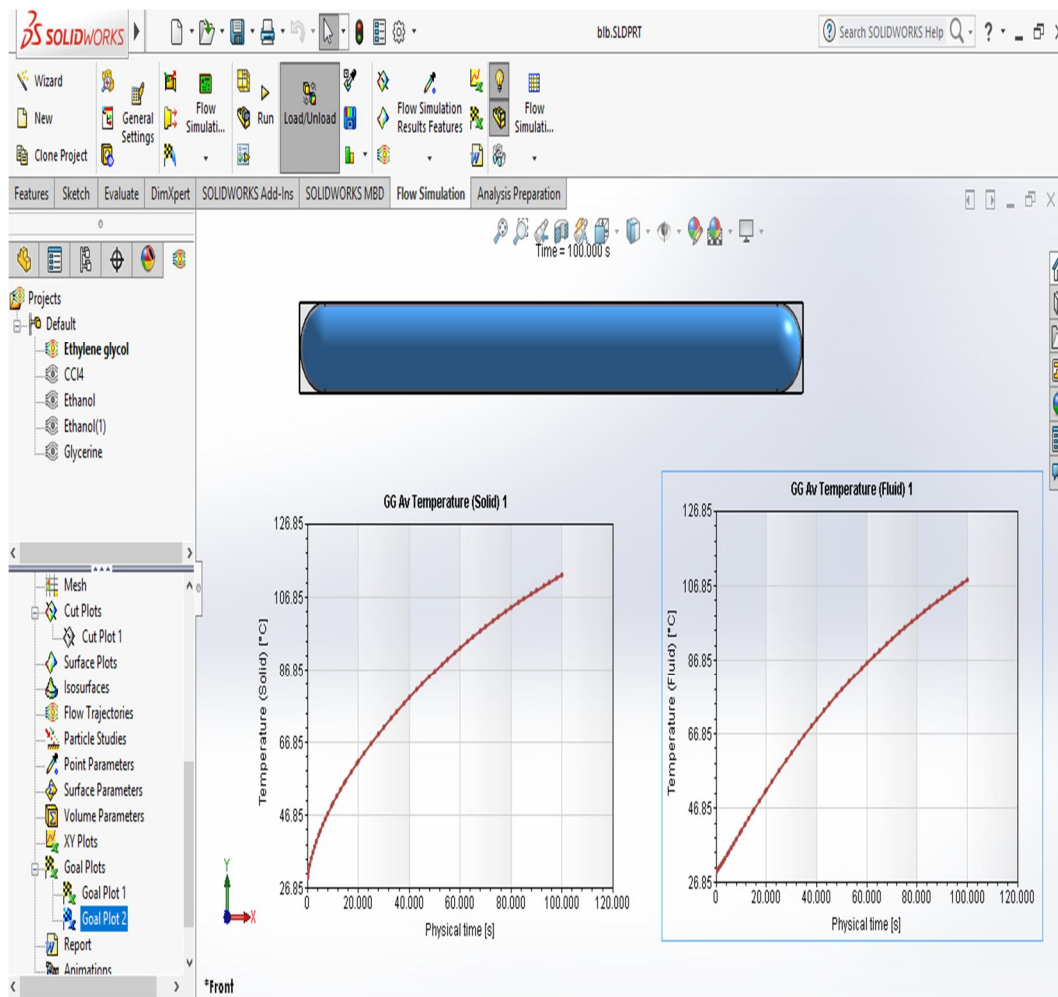


Fig 4.8 Transient thermal analysis on bulb filled with tetra chloro ethylene

Image shows transient thermal analysis of fire sprinkler glass bulb with tetra chloro ethylene as the expanding liquid filled inside. Glass bulb is assumed as filled with tetra chloro ethylene and transient thermal analysis is carried out. Total analysis time is 100 seconds which means graph show the variation of average temperature of glass bulb and the liquid inside the bulb in 100 seconds. Also same temperature distribution is exported in to excel sheet.

Temperature distribution of sprinkler bulb when it filled with tetra chloro ethylene

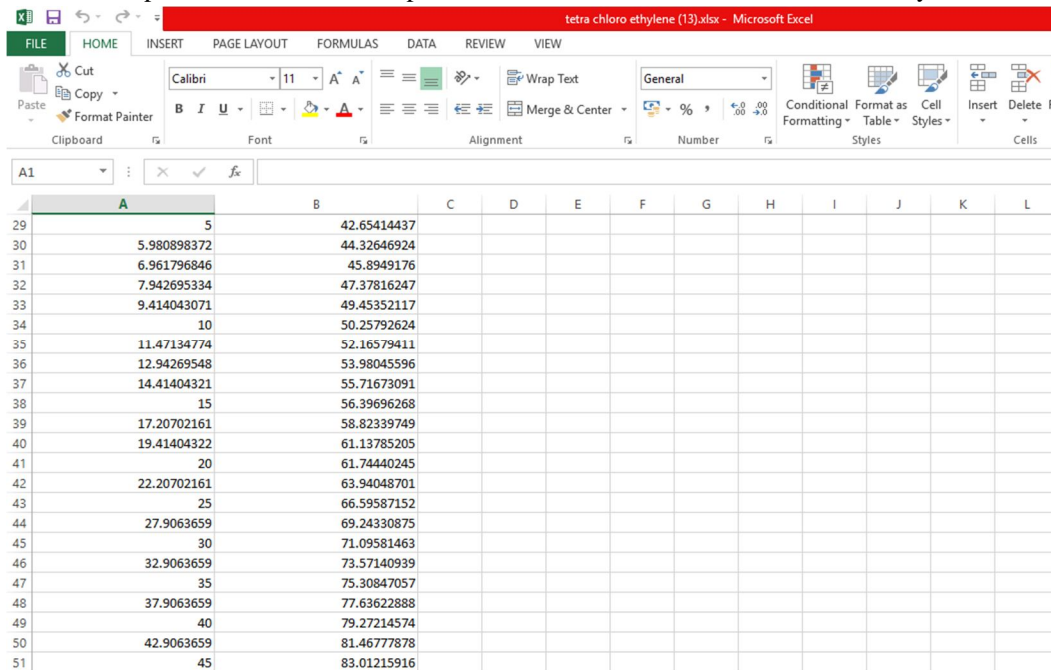


Fig 4.9 Temperature distribution of bulb with tetra chloro ethylene

Image shows the temperature distribution of glass bulb filled with tetra chloro ethylene as expanding liquid inside it and it exposed to flame having temperature of 150 degree Celsius, temperature distribution for a period of 100 seconds is obtained from solid works transient thermal analysis. From this data time taken to reach average temperature of glass bulb to 68 degree is obtained as 27 seconds.

Transient thermal analysis of sprinkler bulb filled with ethanol

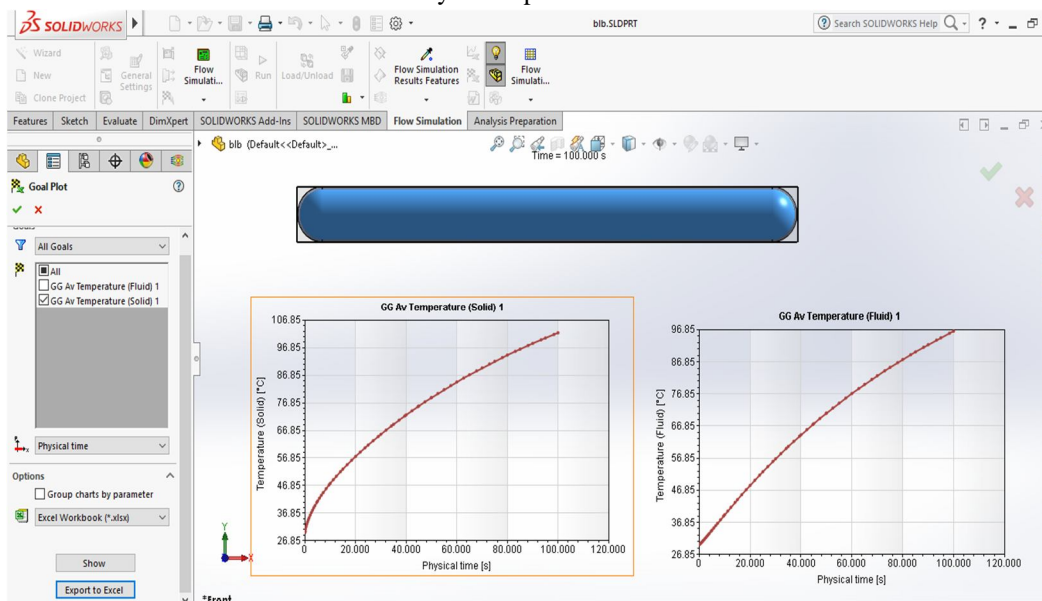


Fig 4.10 transient thermal analysis of bulb with ethanol

Image shows transient thermal analysis of fire sprinkler glass bulb with ethanol as the expanding liquid filled inside. Glass bulb is assumed as filled with ethanol ethylene and transient thermal analysis is carried out. Total analysis time is 100 seconds which means graph show the variation of average temperature of glass bulb and the liquid inside the bulb in 100 seconds. Also same temperature distribution is exported in to excel sheet.



Temperature distribution of the sprinkler bulb

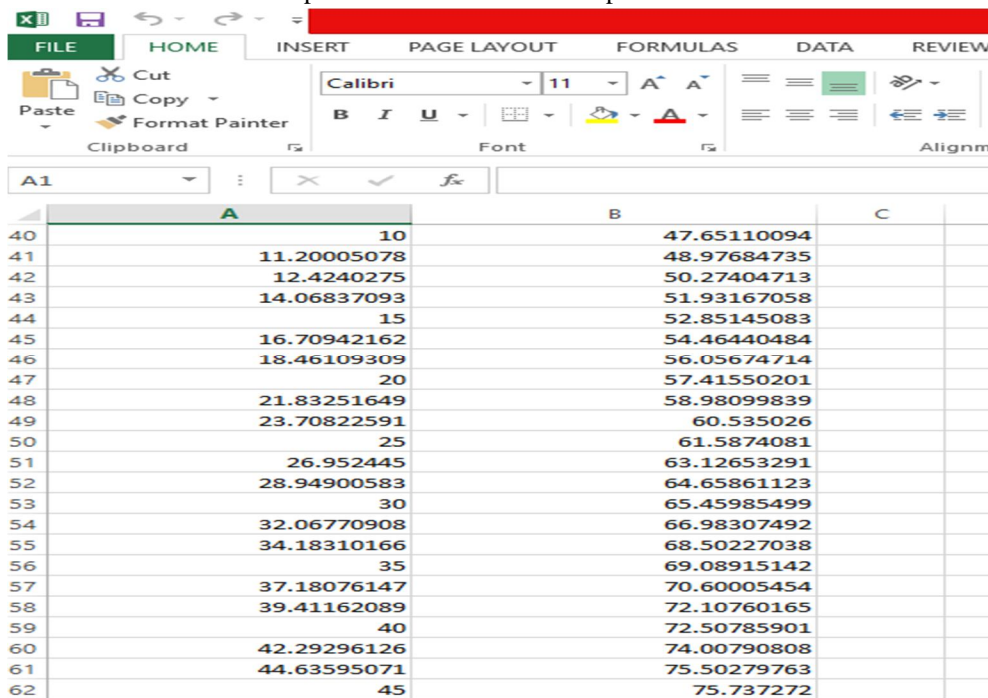


Fig 4.11 temperature distribution of bulb with ethanol

Image shows the temperature distribution of glass bulb filled with ethanol as expanding liquid inside it and it exposed to flame having temperature of 150 degree Celsius, temperature distribution for a period of 100 seconds is obtained from solid works transient thermal analysis. From this data time taken to reach average temperature of glass bulb to 68 degree is obtained as 34 seconds.

Transient thermal analysis on glass bulb filled with acetone

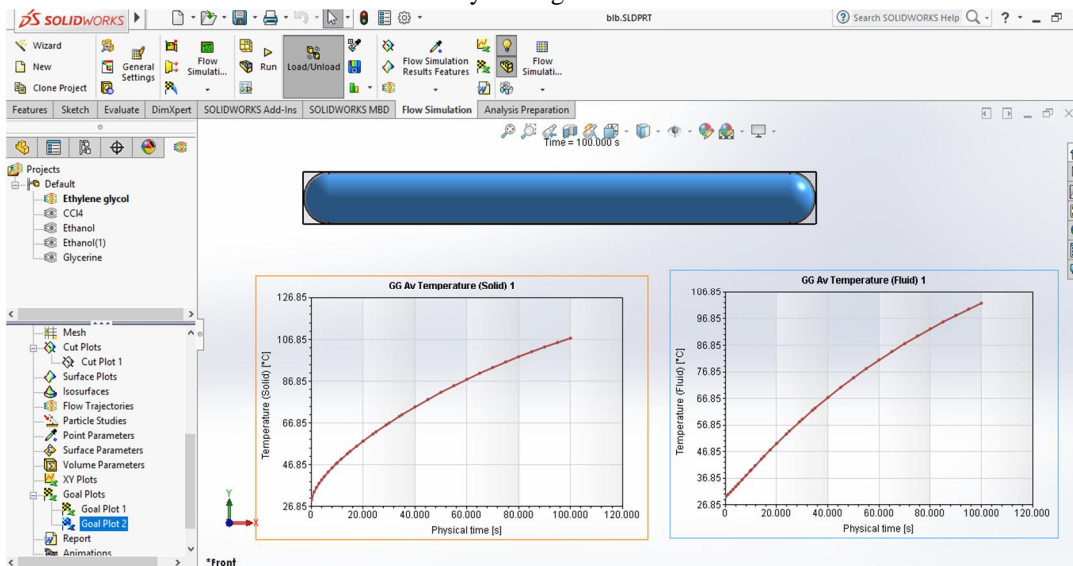
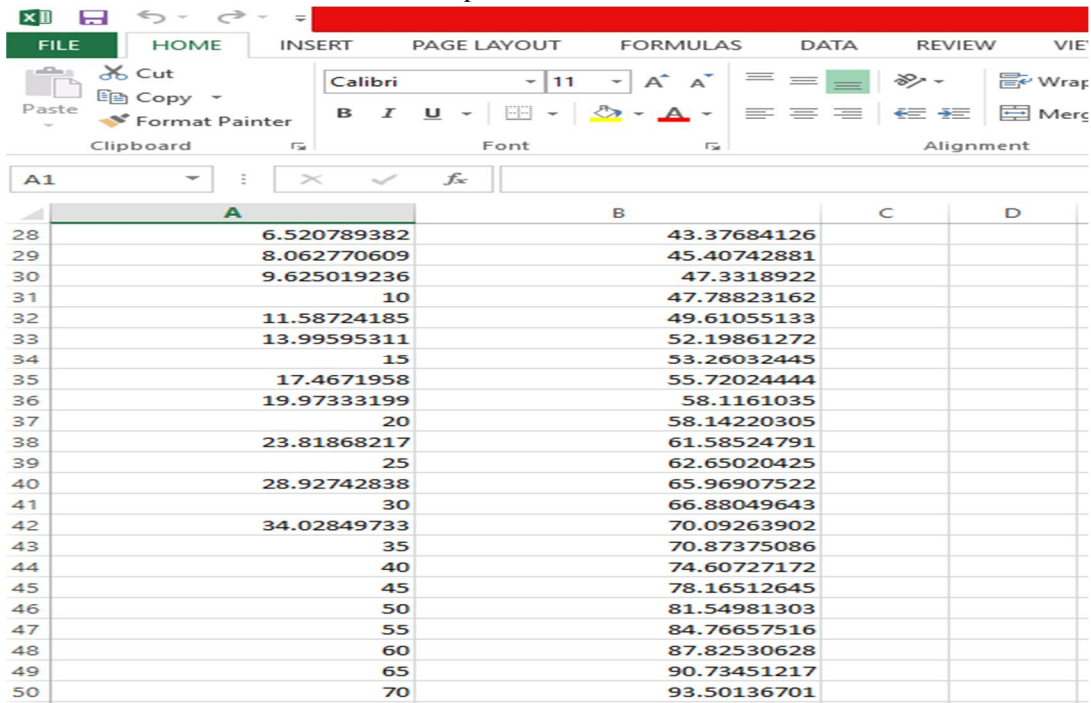


Fig 4.12 transient thermal analysis of bulb with acetone

Image shows transient thermal analysis of fire sprinkler glass bulb with acetone as the expanding liquid filled inside. Glass bulb is assumed as filled with acetone and transient thermal analysis is carried out. Total analysis time is 100 seconds which means graph show the variation of average temperature of glass bulb and the liquid inside the bulb in 100 seconds. Also same temperature distribution is exported in to excel sheet.

Temperature distribution



	A	B	C	D
28	6.520789382	43.37684126		
29	8.062770609	45.40742881		
30	9.625019236	47.3318922		
31	10	47.78823162		
32	11.58724185	49.61055133		
33	13.99595311	52.19861272		
34	15	53.26032445		
35	17.4671958	55.72024444		
36	19.97333199	58.1161035		
37	20	58.14220305		
38	23.81868217	61.58524791		
39	25	62.65020425		
40	28.92742838	65.96907522		
41	30	66.88049643		
42	34.02849733	70.09263902		
43	35	70.87375086		
44	40	74.60727172		
45	45	78.16512645		
46	50	81.54981303		
47	55	84.76657516		
48	60	87.82530628		
49	65	90.73451217		
50	70	93.50136701		

Fig 4.13 temperature distribution of bulb with acetone

Image shows the temperature distribution of glass bulb filled with acetone as expanding liquid inside it and it exposed to flame having temperature of 150 degree Celsius, temperature distribution for a period of 100 seconds is obtained from solid works transient thermal analysis. From this data time taken to reach average temperature of glass bulb to 68 degree is obtained as 32 seconds.

Transient thermal analysis of sprinkler bulb filled with ethylene glycol

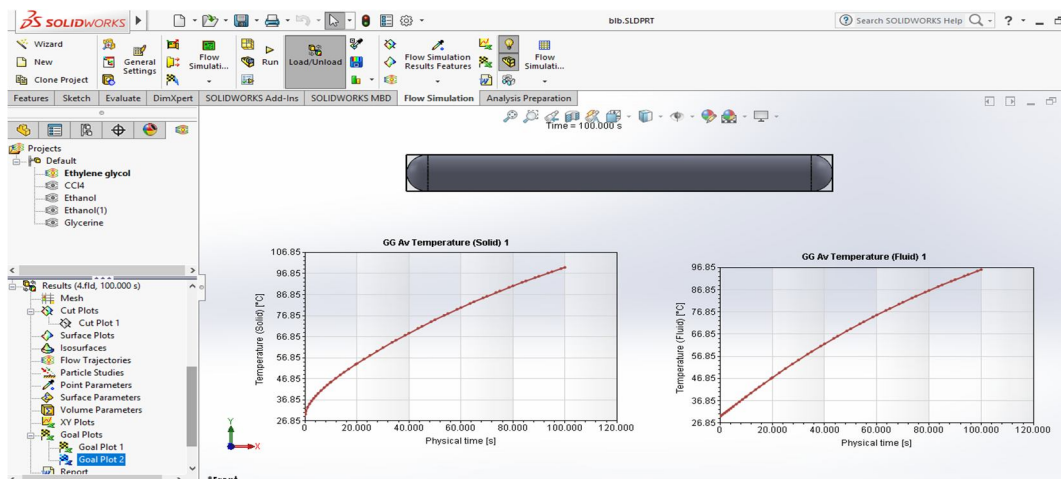
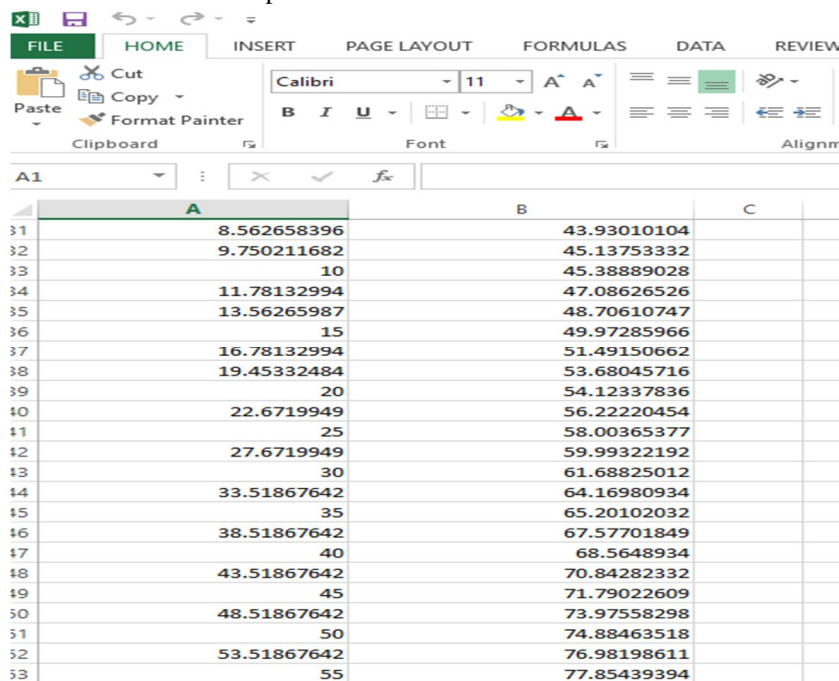


Fig 4.14 transient thermal analysis of sprinkler bulb with ethylene glycol

Image shows transient thermal analysis of fire sprinkler glass bulb with ethylene glycol as the expanding liquid filled inside. Glass bulb is assumed as filled with ethylene glycol and transient thermal analysis is carried out. Total analysis time is 100 seconds which means graph show the variation of average temperature of glass bulb and the liquid inside the bulb in 100 seconds. Also same temperature distribution is exported in to excel sheet.

Temperature distribution of bulb with e



	A	B	C
31	8.562658396	43.93010104	
32	9.750211682	45.13753332	
33	10	45.38889028	
34	11.78132994	47.08626526	
35	13.56265987	48.70610747	
36	15	49.97285966	
37	16.78132994	51.49150662	
38	19.45332484	53.68045716	
39	20	54.12337836	
40	22.6719949	56.22220454	
41	25	58.00365377	
42	27.6719949	59.99322192	
43	30	61.68825012	
44	33.51867642	64.16980934	
45	35	65.20102032	
46	38.51867642	67.57701849	
47	40	68.5648934	
48	43.51867642	70.84282332	
49	45	71.79022609	
50	48.51867642	73.97558298	
51	50	74.88463518	
52	53.51867642	76.98198611	
53	55	77.85439394	

Fig 4.15 temperature distribution ethylene glycol

Image shows the temperature distribution of glass bulb filled with ethylene glycol as expanding liquid inside it and it exposed to flame having temperature of 150 degree Celsius, temperature distribution for a period of 100 seconds is obtained from solid works transient thermal analysis. From this data time taken to reach average temperature of glass bulb to 68 degree is obtained as 40 seconds.

Transient thermal analysis sprinkler bulb filled with glycerine

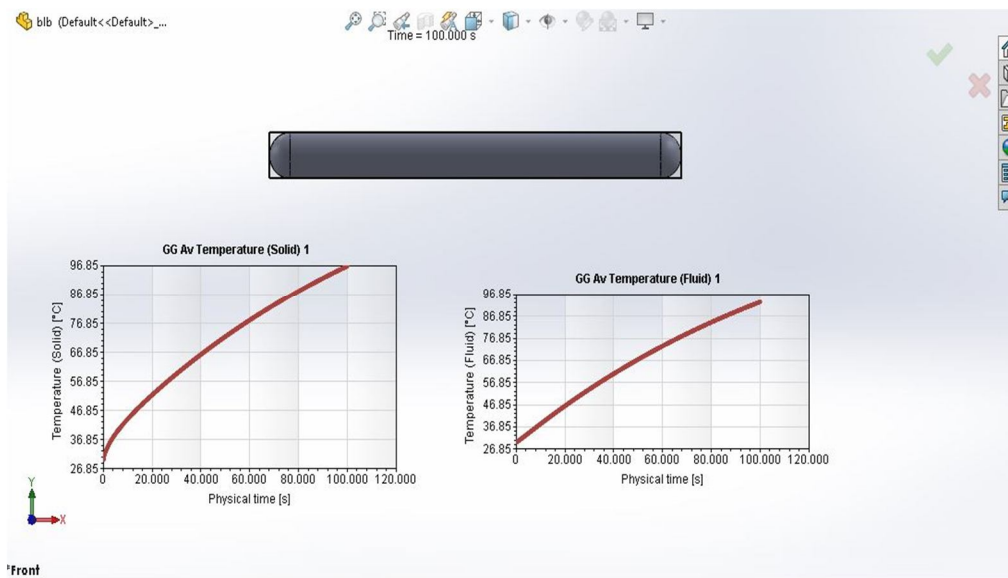


Fig 4.16 transient thermal analysis of glass bulb with glycerine

Image shows transient thermal analysis of fire sprinkler glass bulb with glycerine as the expanding liquid filled inside. Glass bulb is assumed as filled with glycerine and transient thermal analysis is carried out. Total analysis time is 100 seconds which means graph show the variation of average temperature of glass bulb and the liquid inside the bulb in 100 seconds. Also same temperature distribution is exported in to excel sheet.

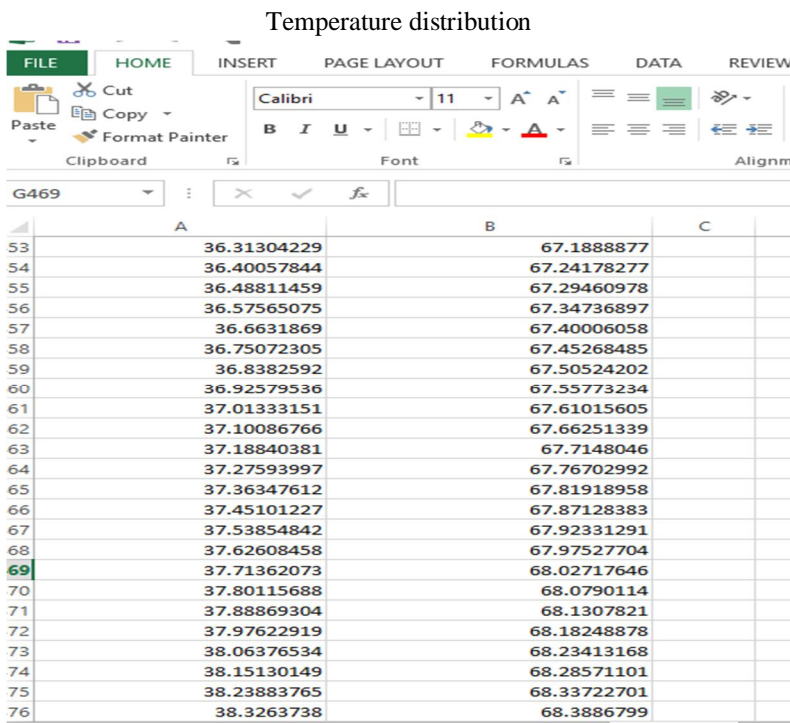


Fig 4.17 temperature distribution of bulb with glycerine

Image shows the temperature distribution of glass bulb filled with glycerine as expanding liquid inside it and it exposed to flame having temperature of 150 degree Celsius, temperature distribution for a period of 100 seconds is obtained from solid works transient thermal analysis. From this data time taken to reach average temperature of glass bulb to 68 degree is obtained as 37 seconds.

- 8) *Experimental Setup:* Experimental setup is created to determine the time to reach activation temperature of the sprinkler bulb. Experimental setup consist of lighted candle and with use of k type thermo couple temperature of the flame and temperature above the flame are noted and determined the height at which 150 degree occurs, temperature was varying from 130 to 180 degree in that height experiment was conducted by taking the assumption as average temperature of that region is 150 degree. Fire sprinkler bulb is placed in that region and determined the time required to reach activation temperature of the fire sprinkler bulb. Bulb used is omex fire sprinkler bulb, it is filled with glycerine based liquid. Purpose of this liquid is which expands on heating and apply pressure on the bulb walls. Colour of the bulb is red which indicates that operating temperature of that glass bulb is 68 degree

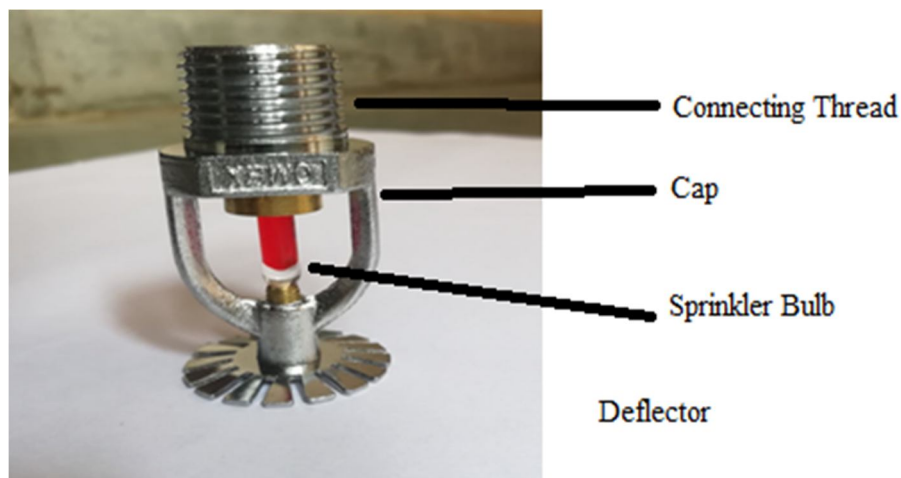


Fig 4.18 fire sprinkler bulb

Table 4.6 Omex fire sprinkler bulb specification

Diameter	5 mm
Operating temperature	68 degree
Liquid used	Glycerine

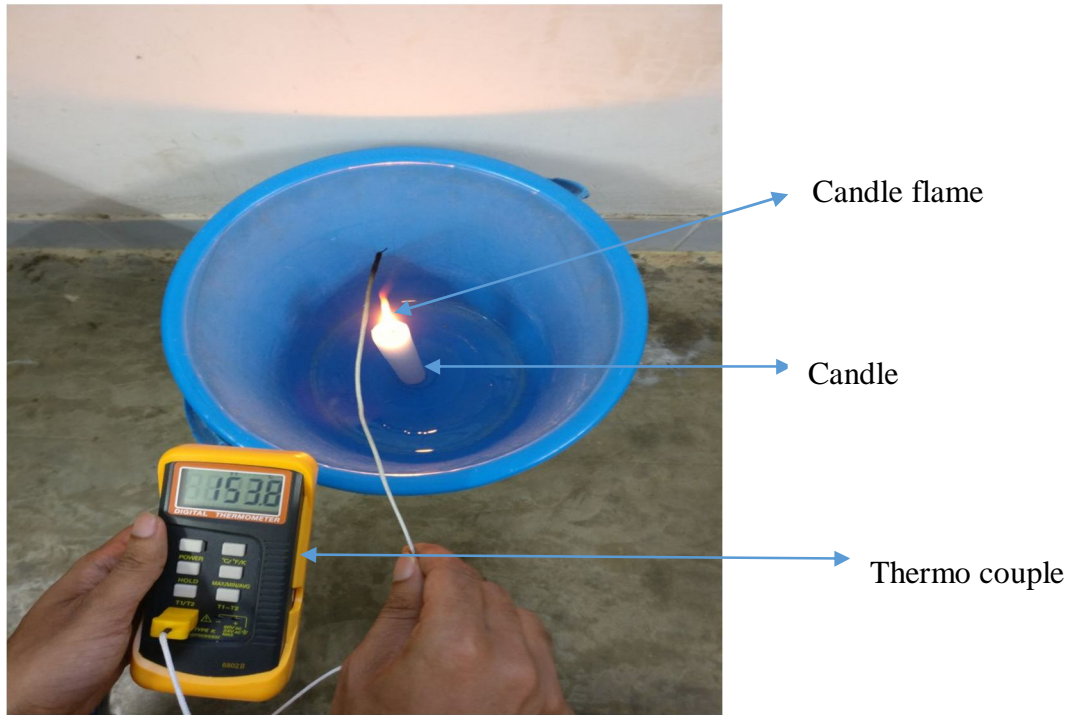


Fig 4.19 Thermo couple using to measure temperature

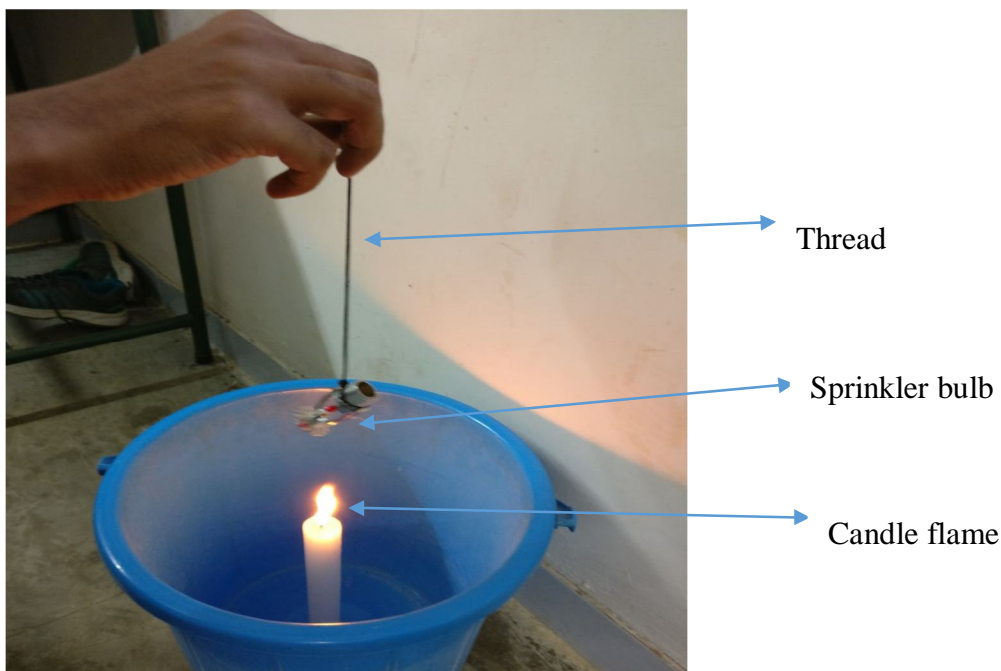


Fig 4.20 Experimental setup

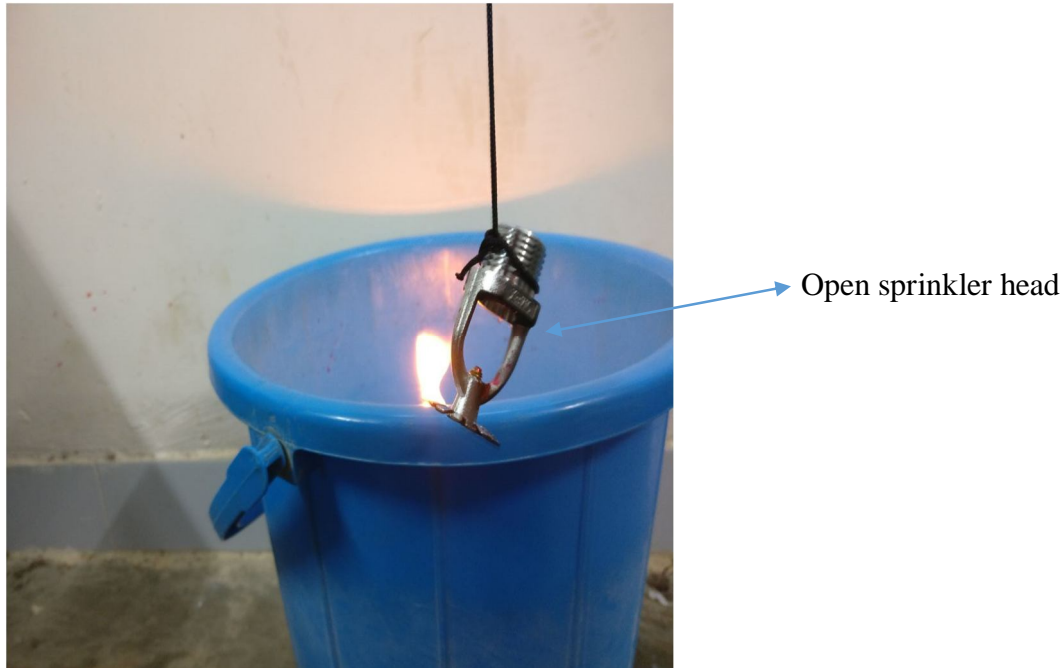


Fig 4.21 Broken bulb after experiment

Experiment is carried out with 5 sprinkler bulbs and average time is taken as average time required to reach activation temperature.

Table 4.7 average time to reach activation temperature

Sl no	Average time to reach activation temperature
1	39
2	44
3	47
4	40
5	36

Average time is obtained as 41 seconds.

## V. CONCLUSION AND FUTURE SCOPE

### A. Conclusion

Quantitative risk assessment of the LPG storage tank is carried out by considering a leak of 20 mm diameter in 300 MT LPG bullet at a height of 1 meter from the bottom and it is found out that impact of explosion affects in radius of 64 meter. So special care should be taken for the construction within this periphery, material used should have strength to withstand the overpressure generated. Total fire water storage requirement of the HPCL Kochi plant is found out as 9840 KL and HPCL has current storage capacity of 10000 KL it satisfies the storage requirement. It is obtained that total 21 sprinklers are required to completely cover 17 tonne LPG storage bullet, to uniformly arrange these sprinkler around the bullet these are arranged in two rows and each row contains 5 sprinklers horizontally, uniform arrangement of sprinkler around will reduce the interaction of adjacent sprinklers and provides better rate of water distribution around the LPG storage bullet. Transient thermal analysis on sprinkler bulb is done in solid works 2017 software and obtained result is compared with experimental result and it is obtained that by using tetra chloro ethylene as liquid inside sprinkler bulb time required to reach operating temperature is minimum and suggesting that tetra chloro ethylene can be used inside sprinkler bulb to provide better thermal response. Every early indication of the fire is important in case of emergency response, since tetra chloro ethylene has better thermal response than glycerine early detection of fire can be achieved.

### B. Future Scope

Future scope can be to validate the different results obtained from different fluids analysed in software experimentally. Finding best suitable fluid for the sprinkler bulb experimentally is beyond scope of this project and can be future scope.

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I consider myself exceptionally fortunate that we had indulgent guides, learned philosophers and caring friends to successfully steer us through one of the most interesting periods of our academic career. Today when our endeavour has reached its friction, I look back in mute gratitude to one and all without whose help we are sure this reality would have been a dream.

This work has been possible through the direct and indirect co-operation of various people of Erode Sengunthar Engineering College (ESEC) towards whom I wish to express my gratitude. I am extremely thankful to ESEC faculties who provided me challenging opportunity to work on this project.

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It's not only my duty but a matter of joy and pleasure to once again convey my thanks to all.

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