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Design and Development of a Novel Method to Extinguish Fire at High Level Ceiling Clearance

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Abstract

As the model of buildings for instance: Airports, hotel lobbies, convention malls, shopping malls, atria, theatres and many more, with high clearance between ceiling and floor, is increasing very rapidly, there is a unique challenge for fire safety or fire protection engineers to provide proper fire suppression systems to extinguish fire. It is portentous to decide which sprinklers will be used for that situation. In present time, there are not too many alternative fire protection schemes available for buildings with high level ceiling clearance. The paper addresses the theoretical design and analysis of providing fire protection systems at high level ceiling clearance by designing and analysing a seminal solution to suppress fire.

Keywords: Sprinklers • High level ceiling • Telescopic cylinder • Ceiling clearance

Introduction

Nowadays, modern architecture of buildings contains double height areas, for in-stance: Shopping malls, airports etc. In these buildings, the part of the facilities which has high clearance spaces is left without a proper means of automatic fire protection systems which not only a serious problem but also perilous for people. With the use of normal sprinkler system, it is possible to suppress the fire at normal ceiling height but if the ceiling height exceeds to a certain level then there is an issue to how to design a proper fire safety system, as sprinkler heads in this contingence will not be able to extinguish fire in its early stage [1-3]. As per NFPA-13 (installation for sprinkler systems), hospitals, malls, theatres come in light hazard and for light hazard occupancy, quick response sprinkler or standard sprinkler is used. The main purpose behind using quick response sprinkler is that it is installed for life safety purposes. The quick response sprinklers can be used in ordinary hazard occupancy depending upon the situation. There are other sprinklers which can be installed up to 12 to 13 meters or more but for a certain type of occupancies like storage areas.

There was an experiment being done to extinguish fire in its early stage in the year of 2004, by S. Nam in which he used Quick Response Extra Large Orifice Sprinklers for 18.3 metre high ceiling using 2.26 metre high solid pile FM Global Class 2 commodity. The test results were pretty well which showed that quick response extra-large orifice sprinklers can suppress the fire. There were some limitations of that experiment [4].

Limitations of the above experiment

Larger orifice sprinklers are not normally suggested in the following situations. When the design density requirements are less than 0.35 gpm/ft^2 and as the minimum pressure requirement of 7 psi will cause overkill for these hazards. For some specialty hazards that cause flash fires or hidden fast spreading fires that normally require in rack sprinkler protection, be necessary for acceptance by the fire community. Another experiment of fire modelling was being done on computational fluid dynamics in 2013, which showed that in a large concourse area, a sprinkler head 20 m directly above an unshielded fire would require approximately 6 minutes to be acti vated. The fire grows to an unconstrained size by the time the sprinkler becomes operational. It therefore follows that the greater the distance of the sprinkler head is from the fire source, the larger the fire size becomes before the sprinklers are activated. This therefore reduces how effective the system may be in suppressing the fire [5].

CFD analysis has shown that the compartments of great sprinkler height and width can allow the chance of failure for the suppression system to perform its functional objectives. This is the major issue in high level ceiling clearance [4]. The main purpose of the paper is to design and analysis of such system for high level ceiling areas, which is able to extinguish fire in its early stage and in an efficient way.

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Methodology

Brief description

As per the proposed method, there is a compressor, which provides compressed air through pipes directly on to the sprinkler system with the help of joints through which sprinkler is connected. There is the circular thin sheet of the lightest material like gypsum, attached in between the end point of cylinder and sprinkler as shown in the (Figure 1). The sprinkler system piping (branches, cross-mains, and riser) is filled with air or nitrogen. The riser (main pipe) comes from the water storage tank through the pump room [6]. Now, when there is a fire in the room area then due to the heat or smoke, the detector in the room, first detects the smoke and make the compressor to start. Then, the compressor supplies compressed air directly through the air operated valve and then due to the pressure of compressed air, the sprinkler system goes on extension likewise telescopic cylinder up to 3 meters or more. After that, further increase in fire, will burst the sprinkler glass bulb and due to which the air, which is filled in all the pipe system emanates and makes the low pressure zone in the pipe system. The low pressure makes the deluge valve (which is in riser system) to open and supplies the water towards high pressure to low pressure and then the water will be shed down from sprinklers and suppress the fire in an efficient and better way in double height areas [7].

The extension of sprinkler systems will depend upon the application, up to how much meter a designer wants to extend it and depending upon that the pressure will be tested. The air operated valve is used to control the pressure and stops the flow of fluid to the compressor. In this way, the proposed system will be able to suppress the fire with its innovative design and method.

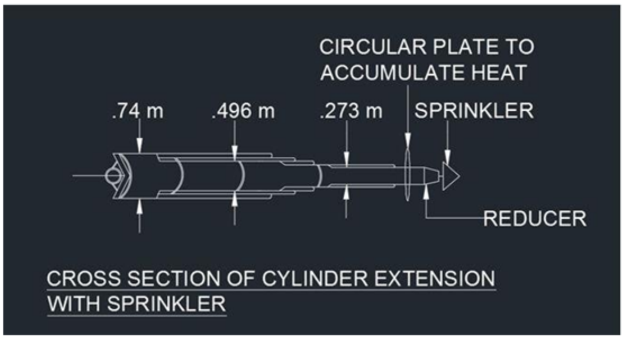

Figure 1. Cross-section of telescopic like cylinder carrying sprinkler.

Working principle

As shown in the above process diagram, when there is the fire, the detector detects the fire and actuates the compressor through control system. The compressor through the air operated valve supplies compressed air to the sprinkler through connecting branches as shown with yellow dot lines in the above Figure 2. These lines are connected with 4-way joints to the sprinkler system. Due to the flow of compressed air directly onto the sprinkler system, the sprinklers which are attached in telescopic cylinder (made up of the lightest material such as carbon composite fiber or magnesium alloy) get extended with the help of air pressure. The air pushes the cylinder up to the desired depth like 3 meters downwards. The cylinder extension can be increased up to 8 to 9 meters or desired distance depending upon the requirements. There is the plate, which is attached in between sprinkler and cylinder end. The main purpose of the thin circular sheet plate is to accumulate heat around the sprinkler so that it starts working fast [8].

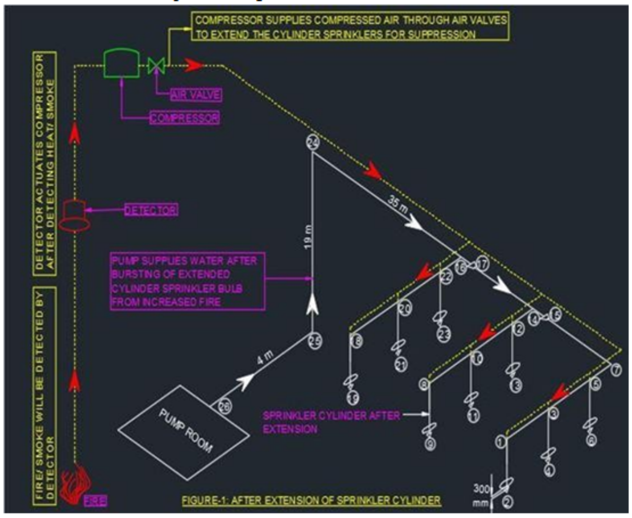

Figure 2. Process diagram.

The area of the sheet will be dependent upon the distance between the sprinklers and the The area of the sheet will be dependent upon the distance between the sprinklers and the distance between the branch lines. To illustrate this, if the distance between the sprinkler is 3.2 meter and the distance between the branches on which sprinklers are attached is 3.5 meter then if the plate diameter is in between 1.2-1.5 meter then it will efficiently accumulate heat and provide proper suppression.

The water system from the pump room to the sprinkler system will be provided by the riser and cross mains as shown in white lines in the figure. The cross-mains and branches of sprinklers is filled with pressurized air of around 0.1 bar and another 0.1-0.2 bar is needed to extend the cylinder as the cylinder is made up of magnesium alloy which is the lightest material. The response time index and temperature of the sprinklers is modified to low and when the desired temperature reaches due to heat, it will further burst the sprinkler bulb, due to which the water starts flowing down from sprinklers [9].

Sample analysis

According to the above isometric (Figure 3), let there are nine sprinklers in the as- sumed maximum area of operation, then the pressure and water needs to suppress the fire, is calculated from Elite Fire Software. The sprinkler is considered to be at the distance of 3 meters from the branch line. Now, according to the calculation,

Hazard type: Light

Design area: 181 sq. met; K- Factor: 115

Design density: 4.1 Lpm/Sq. Met

Sprinkler system: Dry

Maximum area of sprinkler operation: 21 sq. met.

Minimum residual pressure: 50.68 KPa

Hydraulic most demanding residual pressure: 55.65 KPa

Hydraulically most demanding actual flow: 85.75 LPM

Maximum flow velocity: 4.97 m/sec

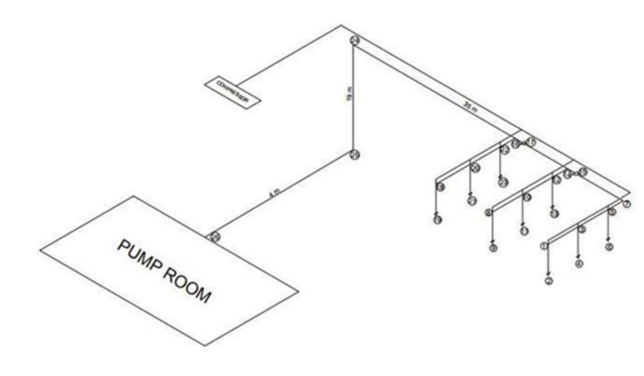

Figure 3. Isometric/node diagram for calculation of sprinkler flow.

Results and Discussion

Theoretical analysis of compressor size

Suppose, the radius of each telescopic cylinder is 0.05, 0.03, 0.02 meters and each cylinder extends up to 1 meter. Hence the total volume of cylinder or air needed to extend the cylinder is $pi^* h^*$ $(r_1^2+r_2^2+r_3^2)$, which is 0.011932 cubic meter and let it extends in 10 seconds then it will be 0.0011932 cubic meter per second or 2.52 CFM. For 25 sprinkler cylinder 63.20 CFM air is needed along with the air available in the pipe [10]. The need of compressor is only for a single time at fire incident. The actual size will depend on practical analysis (Tables 1 and 2).

Project data			
Description of hazard	Light hazard	Sprinkler system type	Dry
Design area of water application	181 m^2	Maximum area per sprinkler	21 m^2
Default sprinkler K-factor	115 km	Default pipe material	Sched 40 steel dry
Inside hose stream allowance	0 Lpm	Outside hose stream allowance	0 Lpm
In rack sprinkler allowance	0 Lpm	Temperature rating	57.23°C
Water supply test data			
Hydrant elevation	0 m	Static pressure	0 kPa
Test flow rate	0 Lpm	Test residual pressure	0 kPa
Calculated system flow rate	921 Lpm	Calculated inflow residual pressure	647.29 kPa
Calculated project data			
Calculation	Demand	Calculation	Demand
HMD minimum residual pressure	50.68 kPa	Minimum desired flow density	4.10 Lpm/m^2
Number of active nodes	26	-	-
Number of active pipes	25	Number of inactive pipes	0
Number of active sprinklers	9	Number of inactive sprinklers	0

Table 1. Calculated data.

Values of flow velocity	
HMD sprinkler node number	2
HMD actual residual pressure	55.65 kPa
HMD actual GPM	85.75 Lpm
Sprinkler summary	
Sprikler system type	Dry
Specified area of application	181 m^2
Adjusted area of application	235.3 ft^2
Minimum desired density	4.1 Lpm/m^2
Application average density	5.088 Lpm/m^2
Application adjusted density	3.914 gpm/ft^2
Application average area per sprinkler	20.11 m^2
Adjusted area per sprinkler	281.42 ft^2
Sprinkler flow	921 Lpm
Average sprinkler flow	102.33 Lpm
Flow velocity and imbalance summary	
Maximum flow velocity	4.97 m/sec
Maximum velocity pressure	12.33 kPa

Table 2. Summary and flow velocity.

Values of flow and pressure	
Number of unique pipe sections	25
Number of flowing sprinklers	9
Pipe system water volume	337.08 L
Sprinkler flow	921 Lpm
Non-sprinkler flow	0 Lpm
Minimum required residual pressure at system inflow node	647.29 kPa
Demand flow at system inflow node	921 Lpm

Table 3. Flow and pressure requirement.

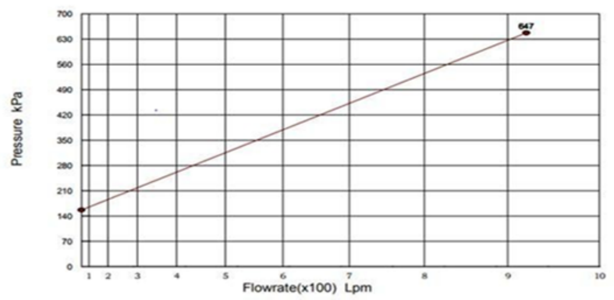

Figure 4. Graph between flow rate and pressure. Note: Calculated residual pressure: 647.29 kPa, Calculated flow rate: 921 Lpm, Pressure required for first sprinkler downstream from inflow node to flow: 156.72 kPa.

The results are quite good as it shows an appropriate pressure, fluid demand and flow velocity during an operation time [11] (Table 3). The flow velocity is 4.97 meters/second and as per design criteria it should not be more than 6 meters/second. Another foreground point is that the hydraulic most residual pressure is an approximate equal to the minimum operating pressure for a sprinkler to operate (Figure 4). The calculated system flow rate is 921 LPM. Hence the design is safe.

Conclusion

The proposed method is suitable to suppress fire at high level ceiling clearance in an effective way as it will not make fire to take a massive form. It will extinguish fire in its starting phase. It will be useful for those areas where the design density requirements are less than 0.35 gpm/ft^2. as well as more than that. It will be able to cater the problems associated with large orifice sprinklers as it is not good enough to just design large orifice sprinklers. Sometimes, it can be possible to take alternate options to protect areas with small orifice sprinklers. Where the ceiling level is high, and the sprinkler heads are at remote distance from the fire source so this raises a serious doubt as to the successful fulfillment of the functional objectives of sprinkler system, so in this case the proposed method will be suitable to use for extinguishment of fire.

Limitations

The installation cost of the system will be high but maintenance will be low. Proper ceiling clearance should be provided for the proper installation of the system. Number of use of compressors will be depended upon the number of sprinklers. If sprinklers are more, than two or more small capacity compressors can be used.

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