An Experimental study on Sprinkler Discharge Density Distribution

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Utilization of fire sprinkler system is to make fire extinction easier and to avoid major mishaps or damages. In general sprinkler has two functions. One is detection of fire and the other is to provide adequate distribution of water to control the fire. Each function has to be performed separately. This study is an attempt to find out the water discharge density through different types of sprinklers to locate the Discharge Density Region (D.D.R) under the area covered. The factors like pressure and height shift the density regions.By regulating the factors 'pressure' and 'height' to optimum level , these varying density regions are radially tested by setting up the water collector jars at a specified distance between each other and then operating the sprinkler for water collection in jars for a fixed time limit. In conclusion, optimum pressure & height has been identified with the help of experiments for uniform discharge density distribution and Discharge Density of different types of sprinklers has been compared.

Key words: *Fire Extinction, Fire Sprinklers, Pendant sprinkler, Upright sprinkler, Discharge Density*

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1 INTRODUCTION

Fire is an oxidation reaction between the fuel and the oxygen in the presence of heat, which results in an exothermic reaction in the form of heat and light. To extinguish the fire few fire protection systems are introduced in these modern days. One of those fire protection systems is the sprinkler system which is a fixed firefighting installation done with water as an extinguishing medium. Here water is the most reliable substance that is used to extinguish fire in various states. Water helps in multiple ways in breaking the fire triangle. This water helps to display the smothering (to displace oxygen) and cooling (to displace heat) phenomenon.

The fire sprinkler system is an active fire protection method. It consists of a water supply system that provides adequate pressure and the rate of flow the water distributed by a piping system to which the fire sprinkler is connected. Historically, the fire protection system is employed in factories, large commercial buildings, and homes but now a days they are available at cheaper prices as well.

To make this system much more efficient, we need to redesign the installation by regulating the factors like 'pressure' and 'height' of the sprinklers in such a way that it should meet the existing standards leading to the effective utilization of sprinklers with less investment only. Having more sprinklers will lead to high maintenance problems, time-consuming, and disturbs the aesthetics also. If we go for redesigning installation, we concentrate on discharge density overlapping of consecutive sprinklers, if not, the system cannot extinguish the fire on non-overlapping areas that results in unnecessary wastage of water, fuel to run machinery, and wear tear of equipment as well. If discharge density pattern is improper then inadequate water spray in some regions will result in fire breakouts to bigger one which may result in an increase in death or fatality rates.

To date, many researchers had done in depth experiments and kept their points. One of them expressed their views about the physical characteristics of residential sprinklers by conducting a series of tests, including the tests in the wind tunnel, tests of spray patterns, and tests under controlled fires. Valuable information's and data's were recorded from the analysis [1]. Furtherly, an experimental study on the spray characteristics of residential sprinklers under low-flow and low-pressure conditions [2] was also conducted.

A laser-based shadow imaging system resulted in that spray formation is affected by sprinkler geometry [3]. Some of the studies analyze "regarding the hydraulic calculations on fire sprinkler system from power generation (pump) to end component sprinkler head" [4].

While installing these types of fire protection systems we need to be thorough with the distribution of water through the deflector over the applied physics on commodities [5]. To extinguish the fire at 2nd stage i.e., growth stage extinguishing medium like foam, CO_2, & dry chemical powder is not the only medium but there is also some fire protection system like a sprinkler system, deluge system, mist system.But in the case of the sprinkler system to extinguishing fire, major parameters like 'sprinkler discharge density' & 'working pressure' plays a key role in controlling the fire [6].

But due to some external factors' effectiveness of sprinklers were affected when they are installed in the pipe, duct, etc. Hence to overcome such difficulty fire experimental scenarios are to be designed to test the effectiveness of sprinklers [7].

That's why for adequate spray purpose National Fire Safety Code provides the minimum guidelines on operating pressure, number of sprinklers & flow rate of sprinklers. So that a performance-based fire protection system will be designed [8].

But before sprinkler installation engineers should know about the shape of the area to be covered by sprinkler. Whether its coverage projection is square, rectangular, or circular. Because most of them don't know how the area & discharge density are to be calculated [9]. Also, sprinkler installation should be in such a way that its installation & maintenance should be economically cheaper as most of the organization think of cutting off the maintenance expenses to save the money and to save them from the financial crisis. Hence to avoid too many serious accidents, following the safety norms related to structure are to be made strict. and hence self-life of structure also reduced [10].

It is understood that fewer attempts were made to study the discharge density of the sprinkler system. Hence this is an attempt that was made through experimental study by considering the parameters like optimization of 'pressure' and 'height' of sprinkler installation in case of different types of hazards named low, medium, and high are elaborated in this paper. Along with this, we have also advised the right installation of sprinklers as per their different density regions in an optimized way. This helps in the reduction of sprinklers in terms of occupancy, efficient firefighting with water in a fruitful manner by the required limit of machinery support, which indirectly saves us from financial investment.

2. Experimental setup

Underwriter laboratory UL approved listing ISO 9001:2000 UL and other international agency like Germany's Vds, FM Global approved pendent sprinkler with standard specifications according to National Fire Protection association (NFPA) 13 having model VK102 with metal casting and Response Time Index (RTI) 50 (meter – second) $^{1/2}$ is used in this experiment. Bulb used in sprinkler having a thickness of 3mm is a quick response type sprinkler (K – Factor = 80) filled with a liquid water – glycerin mixture of red color which operates at the temperature of 68 ^{0}C inside it. The pendent sprinkler which spray water directly downward against deflector, experimental set up is done in well & fully equipped hydraulics laboratory in which standard fire water network pipe is used as a distribution pipe on which sprinkler with orifice diameter of 12.7mm isdirectly feeded with the water and pressure gauge mounted on it to measure the pressure fluctuation.

Initially sprinkler is installed at 3m height with sprinkler coverage area of diameter 3m and 41 water collector jars in 8 lines having 6 jars in each line were placed. Because here the water discharge parabolic nature is radially attained rather than angularly.

2.1.1 Sprinklers

Heat causes the liquid in the bulb to expand, burst the glass and create an opening through which the water is released to extinguish the fire. Fire sprinkler systems are installed in all types of buildings, commercial and residential. They are usually located at ceiling level and are connected to a reliable water source, most commonly city water. In general, automatic sprinkler heads are divided into two categories depending upon the type of heat responsive element, namely fusible link and glass bulb type. Automatic sprinkler heads activate when exposed to temperatures that would be excessive for the particular area being protected. Pendent heads are designed to suspend below support piping. Upright heads are installed above support piping.

All sprinkler heads could be used in either a pendent (hanging) or upright position. After 1953, standard spray sprinklers were designated for specific positions, either upright or pendent, to produce a more predictable distribution pattern to protect the specific hazard.

Pendent and upright sprinklers for the experiment purpose.
Temperature Rating: 155 ° F /68 ° C

- Glass Bulb Colour: Red
- Thread Size: NPT ½ inch or R ½ inch
- Max. Service Pressure: 175psi
- Orifice Size: 12.7mm
- K-factor: 80
- Listing Approvals: ISO 9001:2000 UL

Fig. 1. Pendant sprinkler & Upright sprinkler.

2.1.2 Measuring jar

- Used to measure the volume of liquid
- Diameter 16 cm and height 20 cm

Fig. 2. Measurement Jar

2.1.3 HI Lifter Pump

Model: HL-32MS

- Power KW/HP: 0.75/1.0
- Head Range: 1.5 -2.8(m)
- Discharge: 80-150(LPM)
- Volt Range: 220-240V
- Current: 3.38A

Fig. 3. Hi-Lifter Pump

2.1.4 Water collectors jar setup

Volume holding capacity of each jar is 1000ml. Before actuating sprinkler, temperature of laboratory is noticed i.e. 27 ^{0}**C** and other parameters were taken into consideration like ventilation, adequate atmosphere and also ensured that deflector should parallel to ceiling so that spray pattern should be accurate.

In the setup area of diameter of 3 m , it is divided into 8 equal Parts. one jar is placed on the centre and 60 cm radial distance another 8 jars, similarly at the equi radial distance 120,180,240 and 300 cm radial distance 8 jars each are placed.

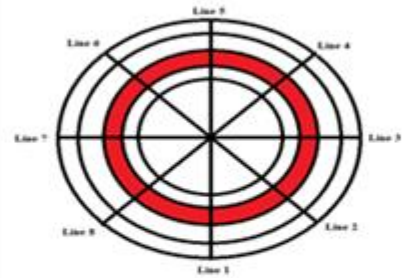

Fig. 4. Measurement jars set up

3. RESULTS AND DISCUSSIONS

3.1. Pendant sprinkler installed at height 3m

Initally pendant sprinkler installed at the height of 3m and measurement jars placed on the setup as per Fig 4 Pump has been run for 3 minutes and the water has been collected at measurement jars for both 2 bar and 2.5 bar pressure. Volume of the each jar measured and results were tabulated in Table 1.

TABLE 1
PENDANT SPRINKLERS INSTALLED AT 3 M

Volume of water collected at jar (ml)	Pressure	Distance from the center of water collectors (cm)					
		0	60	120	180	240	300
Line 1	2 bar	300	310	630	370	260	245
	2.5 bar	260	300	550	320	230	220
Line 2	2 bar	--	260	350	410	350	270
	2.5 bar	--	270	310	380	330	260
Line 3	2 bar	--	250	390	500	320	240
	2.5 bar	--	240	340	360	300	230
Line 4	2 bar	--	260	330	400	370	250
	2.5 bar	--	230	280	378	310	225
Line 5	2 bar	--	280	600	340	230	220
	2.5 bar	--	300	610	330	250	210
Line 6	2 bar	--	270	330	420	370	210
	2.5 bar	--	260	295	370	340	240
Line 7	2 bar	--	247	360	380	300	210
	2.5 bar	--	265	350	390	330	210
Line 8	2 bar	--	275	350	510	280	215
	2.5 bar	--	280	320	400	350	250

3.2. Pendant sprinkler installed at height of 3.5m

Pendant sprinkler now installed at the height of 3.5 m, ex periments were conducted like earlier and results were tabulated Table 2

TABLE 2
PENDANT SPRINKLERS INSTALLED AT 3.5 M

Volume ofwater collected at jar (ml)	Pressure	Distance from the center of water collectors (cm)					
		0	60	120	180	240	300
Line 1	2 bar	380	320	410	550	300	220
	2.5 bar	350	300	390	540	310	230
Line 2	2 bar	--	310	350	430	380	280
	2.5 bar	--	330	360	410	330	260
Line 3	2 bar	--	270	400	400	410	250
	2.5 bar	--	280	410	450	380	240
Line 4	2 bar	--	280	360	560	320	230
	2.5 bar	--	315	400	405	330	220
Line 5	2 bar	--	300	390	500	270	210
	2.5 bar	--	245	370	550	340	215
Line 6	2 bar	--	320	340	420	400	250
	2.5 bar	--	290	370	430	300	250
Line 7	2 bar	--	260	380	410	430	230
	2.5 bar	--	310	430	450	350	230
Line 8	2 bar	--	330	450	600	280	240
	2.5 bar	--	292	390	430	320	240

3.3. Upright sprinkler installed at height of 3 m

Now Upright sprinklers are installed at the height of 3 m similar type of experiments conducted like earlier and results were tabulated Table 3.

TABLE 3
UPRIGHT SPRINKLERS INSTALLED AT 3 M

Volume of water collected at jar (ml)	Pressure	Distance from the center of water collectors (cm)					
		0	60	120	180	240	300
Line 1	2 bar	210	210	535	270	160	140
	2.5 bar	166	200	450	225	130	122
Line 2	2 bar	--	160	270	300	255	170
	2.5 bar	--	170	210	282	233	160
Line 3	2 bar	--	150	290	390	210	145
	2.5 bar	--	144	240	270	205	135
Line 4	2 bar	--	160	233	310	270	155
	2.5 bar	--	132	180	278	210	128
Line 5	2 bar	--	200	510	240	133	120
	2.5 bar	--	200	510	238	152	110
Line 6	2 bar	--	170	230	323	275	110
	2.5 bar	--	162	195	270	240	150
Line 7	2 bar	--	147	250	260	200	113
	2.5 bar	--	168	250	295	231	110
Line 8	2 bar	--	180	240	400	170	117
	2.5 bar	--	180	220	300	250	155

3.4. Upright sprinkler installed at height of 3.5 m

Now Upright sprinklers are installed at the height of 3.5 m similar type of experiments conducted like earlier and results were tabulated Table 4.

TABLE 4
UPRIGHT SPRINKLERS INSTALLED AT 3.5 M

Volume of water collected at jar (ml)	Pressure	Distance from the center of water collectors (cm)					
		0	60	120	180	240	300
Line 1	2 bar	285	220	315	450	200	110
	2.5 bar	251	205	285	340	210	130
Line 2	2 bar	--	205	248	332	282	182
	2.5 bar	--	231	260	310	231	155
Line 3	2 bar	--	175	310	300	305	155
	2.5 bar	--	180	305	350	281	140
Line 4	2 bar	--	180	265	458	225	131
	2.5 bar	--	215	301	305	228	120
Line 5	2 bar	--	210	290	400	170	112
	2.5 bar	--	140	270	440	242	115
Line 6	2 bar	--	220	241	322	298	150
	2.5 bar	--	192	272	328	200	149
Line 7	2 bar	--	165	285	305	325	140
	2.5 bar	--	200	331	350	255	230
Line 8	2 bar	--	220	352	500	185	145
	2.5 bar	--	192	294	331	220	142

3.5 ANALYSIS

Based on the data collected, Discharge density is to be collected based on the below mentioned formula

$$\text{Discharge Density} = \frac{\text{Volume of water collected}}{\text{time x cross section arae}} \quad \text{...... (1)}$$

Discharge density in lpm/m^2
Volume of water collcted in lit
Time – 3 minutes
Cross section area of measuring jar – 0.02 m^2

Average volume of 8 jars collected at different equi radial distance 60 cm is calculated and by using the equation (1), Discrage density is calculated and the values are tabulated in Table 5.

TABLE 5
DISCHARGE DENSITY –PENDANT SPRINKLERS - 3 M

Distance from the center(cm)	Average volume of water collected (ml)		Discharge Density (lpm/m²)	
	2 bar	2.5 bar	2 bar	2.5 bar
0	300	260	5	4.33
60	269	268	4.48	4.47
120	412	382	6.96	6.36
180	416	366	6.94	6.1
240	310	305	5.17	5.08
300	233	231	3.88	3.84

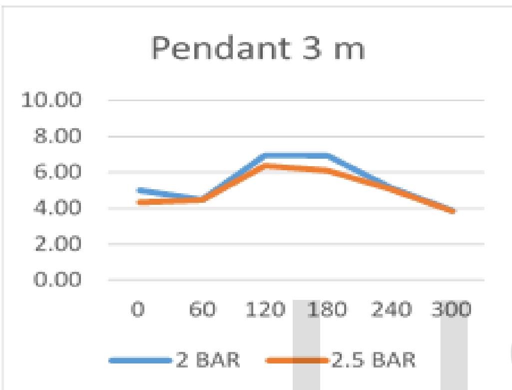

Fig. 5. Pendant sprinkler Discharge Density variation when installed at 3 m with 2 bar and 2.5 bar pressure

From the Fig No.5 It is found that, discharge density is initially decreasing from the centre value till 60 cm radial diatnace and then increasing till 120 cm radial distance and then remains constant till 180 cm and then decreasing from 180 cm radial distance to 300 cm for both 2 bar and 2.5 bar pressure.

Similarly, for Pendant sprinker installed at the height of 3.5 m, values are calculated and tabulated in Table 6

TABLE 6
DISCHARGE DENSITY –PENDANT SPRINKLERS – 3.5 M

Distance from the center(cm	Average volume of water collected (ml)		Discharge Density (lpm/m²)	
	2 bar	2.5 bar	2 bar	2.5 bar
0	380	260	6.33	4.33
60	299	295	4.98	4.92
120	385	390	6.42	6.5
180	484	458	8.06	7.64
240	349	333	5.81	5.54
300	239	236	3.98	3.93

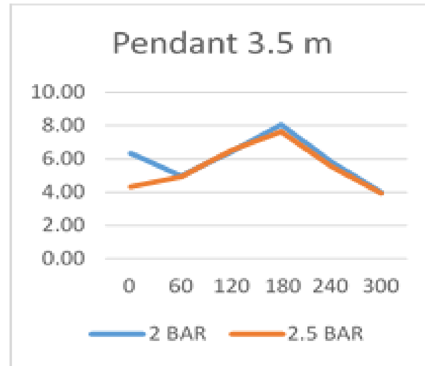

Fig. 6. Pendant sprinkler Discharge Density variation when installed at 3.5 m with 2 bar and 2.5 bar pressure

From the Fig No.6 ,It is found that, discharge density is initially decreasing from the centre value till 60 cm radial diatnace and then increasing till 180 cm radial distance and then decreasing from 180 cm radial distance to 300 cm for 2 bar pressure.

For the 2.5 bar pressure, Discharge density increases from centre to 180 cm and then decreaing till 300 cm.

Now the Upright sprinklers are installed at the height of 3 m and values are calculated and tabulated in Table 7

TABLE 7
DISCHARGE DENSITY –UPRIGHT SPRINKLERS – 3 M

Distance from the center(cm)	Average volume of water collected (ml)		Discharge Density (lpm/m²)	
	2 bar	2.5 bar	2 bar	2.5 bar
0	210	260	3.5	4.33
60	172	170	2.87	2.83
120	320	282	5.33	4.7
180	312	270	5.19	4.5
240	209	206	3.49	3.44
300	134	134	2.23	2.23

From the Fig No.7 ,It is found that, discharge density is initially decreasing from the centre, till 60 cm radial diatnace and then increasing till 120 cm and then remains constant till 180 cm and then decreasing from 180 cm radial distance to 300 cm for both 2 bar and 2.5 bar pressure.

Upright sprinklers are now installed at the height of 3.5 m and values are calculated and tabulated in Table 8

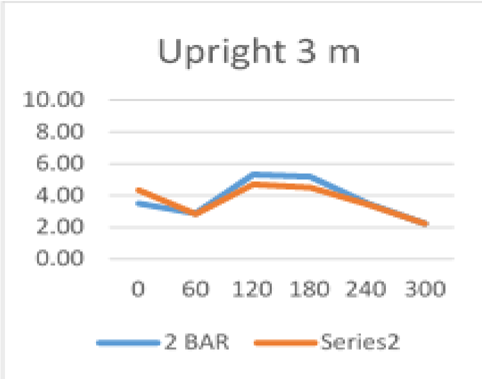

Fig. 7. Upright sprinkler Discharge Density variation when installed at 3 m with 2 bar and 2.5 bar pressure

TABLE 8
DISCHARGE DENSITY –UPRIGHT SPRINKLERS– 3.5 M

Distance from the center(cm)	Average volume of water collected (ml)		Discharge Density (lpm/m^2)	
	2 bar	2.5 bar	2 bar	2.5 bar
0	285	260	4.75	4.33
60	199	198	3.32	3.29
120	288	285	4.80	4.74
180	383	370	6.39	6.19
240	249	250	4.15	4.17
300	141	143	2.34	2.39

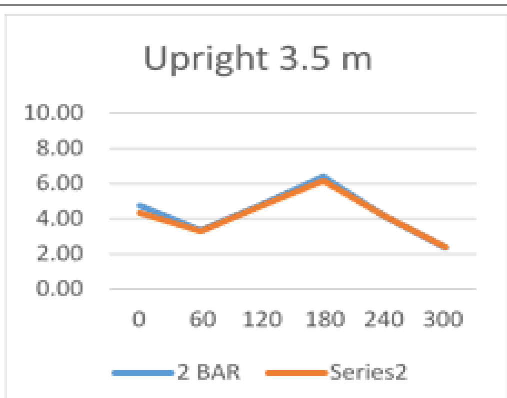

Fig. 8. Upright sprinkler Discharge Density variation when installed at 3.5 m with 2 bar and 2.5 bar pressure

From the Fig No.8, It is found that, discharge density is initially decreasing from the centre, till 60 cm radial diatnace and then increasing till 180 cm and then decreasing from 180 cm radial distance to 300 cm for both 2 bar and 2.5 bar pressure.

4. Conclusion

It is expected that fire sprinklers need to uniform discharge density is radial .dirrection.Based on the above experiments, in Pendant & Upright type sprinklers installed at the height of 3 m, constant discharge density is observed in the region 120-240 cm for both 2 bar & 2.5 bar pressure.
In Pendant & Upright type sprinklers installed at the height of 3.5 m, no constant discharge density is observed in any region for both 2 bar & 2.5 bar pressure.

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