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Basic rules for developing fire sprinkler system in the forest

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Abstract

It is a well-observed phenomenon in developed societies that, in order to return to nature, a part of the society seeks to settle near forests or in the forest creating wildland – urban interface (WUI) areas. It has special features and generates significant risk of fire on the experts try to find responds. In the present study, the authors intend to explore the theoretical foundations of the application of the sprinkler system in forest protecting built environment from fires. Understanding and finding basic rules for the effective sprinkler system application can contribute to reduce the impacts caused by fire. As research methods, the authors based their study mostly on geometric calculation and the physics of evaporation, moreover the basic mathematical formulas as well as logical conclusions were also used. Authors found geometry of circle overlapping generates always problems regarding the effectiveness of sprinkler systems. 50% overlapping in longitudinal axis seems to be acceptable solution. In this case overlapping rate is 78% per circle with 1.6 kg.m-2 water coverage levels and 22% of the circles have 0.8 kg.m-2 water coverage level. As another solution, sequentially used system seems good solution for replacing the evaporated water, where 75% of the coverage level is accepted as lowest threshold of the effective rate.

1. Introduction

It is a well-observed phenomenon in developed societies that, in order to return to nature, the middle class of the society seeks to settle near forests or in the forest (Petrov and Marinov 2020). The extent of the danger and the significance of the risk are shown by the emergence of the concept of WUI (Wildland Urban Interface) in recent decades (Caballero et al. 2007; Johnston 2018), which refers to the mixing of the natural and the built environment. The characteristics of fires in the WUI environment have been examined in a number of studies that suggest that both fire prevention and firefighting face new types of challenges (Radeloff et al. 2018; Koksal et al. 2019). There are a number of answers to the questions generated by the challenges, one of which the authors seek to address in this article. The essence of the question in this article, i.e., the aim of the research, is to examine the possibility that sprinkler systems used in closed areas to extinguish fires could be suitable or not for use in open areas, especially for the forest-related built environment to protect them from the destructive effects of fire. There are many researches focusing on the application of sprinkler system, mostly in closed areas, both residential (Bénichou at al. 1999; Butry at al. 2007; Moinuddin 2019) and industrial environments (Garis et al. 2018; Vishnoi 2017), however the option examination of their effectiveness in open space is missing. Therefore, in the present study, the authors intend to explore the theoretical foundations of the application of the sprinkler system in forest fires, and what principal criteria such a system should meet. Authors believe that this contributes to find basic rules for the effective application.

2. Methods

Authors have examined and analysed the relevant literatures focusing on the sprinkler systems to adapt closed areas experiences to open areas. In addition, they conducted discussions with fire engineers to be expert on this subject. As research methods, the authors based their study mostly on geometric calculation and the physics of evaporation, moreover the basic mathematical formulas as well as logical conclusions were also used. Finding the basic criteria for the effective application of the sprinkler systems this study uses some simplifications and ideal assumptions.

3. Results

Based on Byram's formula (Byram 1959), 2 m flame length takes about 1.2 MWm^{-1} fire intensity, 1 MWm^{-1} assumed in this study. Based on firefighter practice 2 m flame length requires about 5 m wide watered shrub or vegetation strip to stop fire (Bell 1987). Sprinkler heads create circles footprint; in this study, watered circles are 5 m in diameters. 5 m width is effective at cross axis, but left or right side of this axis watered width is less than 5 m, meaning that it is not effective (it is zero at radius distance at the longitudinal axis in case of a simple circle). Therefore, more than 5 m in diameters circles are required or some parts of the circle footprints accepted as limited effectiveness. In this study, authors count with latter option, that is, some parts of the circle footprints have limited effectiveness.

To raise the effective parts of the footprints, authors use overlapping of the circles to ensure the adequate width of the watered strip. In case of 50% overlapping in longitudinal axis the water amount is double in overlapping areas that is 78% (2 x 39%) of the total circle footprint. In case of 5 m in diameter the maximum overlapping is about 4.33 m in cross lane that is 0.67 m less than 5 m.

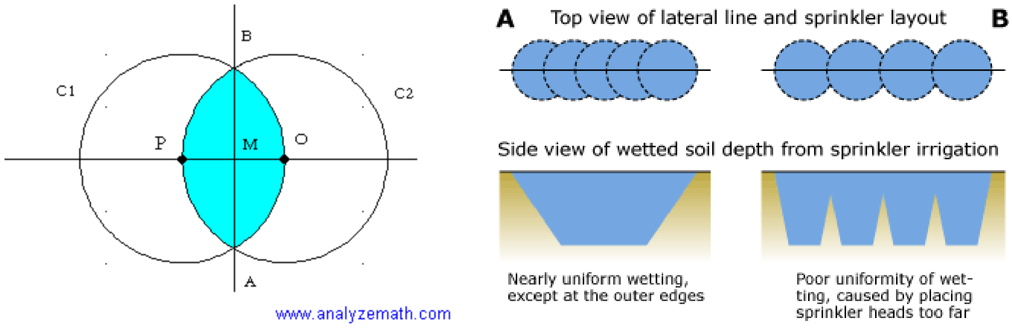

Figure 1. Circle overlapping (left) (Wolfram MathWorld) and footprints of sprinkler systems (right) (Salinity Management Guide 2007)

The 50% overlapping requires more sprinkler head that is 1 head per 2.5 m. Higher position of sprinkler would mean bigger diameter of watered surface however more than 5 m means waste in water use. About 50% overlapping means the optimal water use. It is economical question how many water wasted can balance the higher price of using more sprinkler head. In short time water use is not very important but as a stable, long time existing system can be.

The 1 MWm^{-1} fire intensity, like a shrub or bush fires, requires about 1.2 – 1.8 kgm^{-2} water for stopping fire spread (Murgatroyd 2002; Solarz and Jordan 2010, Delforge 2011). As a thumb rule authors take 1.6 $kg.m^{-2}$ water as effective amount in this study. Each vegetation surface has limited capability of keeping water on its surface. More water than the maximum means that it will flow down the ground and it has no cooling effect. Because of the geometry there is no ideal solution for the effectiveness however it should be optimized or use thumb rules. In this example, 78% (2 x 39%) of overlapping of each circle footprint with 1.6 kgm^{-2} amount of water should be accepted as effective cover rate.

Because of the overlapping of sprinklers' footprint each sprinkler head should produce 0.8 kgm^{-2} water. Top view area of the 5 m in diameter circle is about 20 m^2; it means 1 sprinkler head should produce 16 kg of water (0.8 kgm^{-2} x 20 m^2 = 16 kg). After producing the required amount of water in theoretic and economic view sprinkler heads should stop the water not to waste it.

High temperature as well as low humidity assumed in case of intensive shrub fire; authors count with above 30 ^{0}C degrees. At this temperature thin water layer (or small droplets) on leaves can evaporate quickly. It depends mainly on the temperature, humidity, wind and the surface area of leaves (or the rate of water and surface). Because of the surface tension of the water some additives (e.g., foam agent) is required (ca. 0.1 – 0.5%) to cover the vegetation surface (leaves) with water steadily (or "drops on leaves" is accepted). In case of shrub the leaf area index (LAI) is about 2 that mean a 5 m in diameter circle has 20 m^2 top view area but 40 m^2 of 3D leaf surfaces. This means that the evaporation surfaces of a 5 m in diameter circle shrub land is about 40 m^2. In ideal case on 31 m^2 leaf surface (78% of 40 m^2) has 0.8 kgm^{-2} water amount, on 9 m^2 (22% of 40 m^2) has 0.4 kgm^{-2} water amount, however it means 1.6 kgm^{-2} and 0.8 kgm^{-2} water amount in top view case.

Rate of water evaporation depends on many factors (Ward and Fang 1999; Marek and Straub 2001), however in this case – sunshine, above 30 ^{0}C degrees, less than 15% humidity, slight wind – as a thumb rule, we can calculate with about 1.5 mmh^{-1}, meaning that overlapping area became totally dry again in 32 minutes, not overlapped area in 16 minutes. After producing the required water – 16 kg per 20 m^2 top view footprint of sprinkler head – because of the evaporation theoretically there are two options:

A) Continuously used sprinklers to compensate the evaporation.

B) Sequentially used sprinklers to replace the evaporated amount of water.

Case A): Because the evaporation is 16 kg per 20 m^2 (40 m^2 leaf surface) per 16 min, the rate is 1 $kg.min^{-1}$ per sprinkler head footprint area (20 m^2); it means requirement for compensate evaporation loss is 1 $kgmin^{-1}$ per sprinkler head. It can be very difficult to find applicable sprinkler head. Moreover, in case of continuously used sprinklers water mist will change the circumstances drastically – cool down the sprayed area and humidity up to 100% – meaning that the evaporation will be reduced even more, as an end point of the function at 100% air humidity actually there is no evaporation.

In case B) the question is that, what is the effective frequency of switching on and off the sprinkler heads. This frequency should depend on the acceptable coverage level of water comparing to the required 16 kg per sprinkler head footprint (20 m^2). Authors think 75% of the coverage level – that is 12 kg per sprinkler head footprint (20 m^2) – is acceptable. It means 22% will be covered by 0.6 kgm^2 (in 3D with LAI: 0.3 kgm^{-2}) while 78% of the head footprint will be covered by 1.4kgm^{-2} (in 3D with LAI: 0.7 kgm^{-2}). Taking into account the evaporation rate that is 1.5 $mm.h^{-1}$ the required switch on frequency is 4 min (0.1 kgm^{-2} evaporated water per 1.5 mmh^{-1} = 1.5 $kgm^{-2}h^{-1}$ evaporation rate). Counting with 4 min sequentially used sprinkler heads the coverage level of non-overlapping area swings between 75-100%, that is 0.6-0.8 $kg.m^{-2}$ on top view footprint, however in case of overlapping area it swings between 87.5-100% that is 1.4-1.6 kgm^{-2}.

Theoretically, on the overlapping area the coverage level should jump up to 1.8 kgm^{-2} that is 112.5% however leaves have limited capability to keep water on its surface[5]. In case of shrubs, it is about 1.2 – 1.8 kgm^{-2}, in this example 1.6 kgm^{-2}. More water than enough means lost as well as the amount above the upper limit of effectiveness. This means that 12.5% as an extra is not effective because it goes down to the ground. Logically each sprinkler head footprint has one overlapping part that is 39% of the total area. In case of 5 m in diameter circle it takes 7.8 m^2 of 20 m^2. The lost water is 0.2 kgm^{-2} x 7.8 m^2 = 1.56 kg. This amount takes 23.4 kg wasted water of the total of 60 kg used water per hour.

The 300 m long wetting zone requires 120 sprinkler heads (2.5 m per head). Total water amount – to reach the protection capability (120 heads x 20 m^2 x 0.8 kgm^{-2}) – takes 1,920 kg water. Water consumption of the system – in case of 4 min sequential use of heads replacing the evaporated water (60 kgh^{-1} per head x 120 heads) – takes about 7,200 kg water per hour. Wasted part of the used water during service is 39% that means 2,808 kg water per hour.

4. Conclusions

There are many studies dealing with the application of sprinkler systems to suppress fires or to stop fire spread in residential settlements or in industrial environments but there is no study focusing on the usage of sprinkler system stopping fire propagation in open spaces or rural area. Du to serious fires happened in the near past all around the world this study try to find some fundamentals to help future studies focusing on similar topics.

Results say that the geometry of circle overlapping generates always problems regarding the effectiveness of sprinkler systems. 50% overlapping in longitudinal axis seems to be acceptable solution (2.5 m per head). In this case overlapping rate is 78% per circle with 1.6 $kg.m^{-2}$ water coverage levels and 22% of the circles have

[5] In case of aged forest crown it is about 5 kgm^{-2}.

0.8 kgm^{-2} water coverage level. Sequentially used system seems good solution for replacing the evaporated water, where 75% of the coverage level is accepted as lowest threshold of the effective rate. As an example, 300 m long protection zone requires 120 sprinkler heads. Building up this zone it requires 1,920 kg water for wetting up, then keeping it in service it requires 7,200 kgh^{-1} water. In this case 39% of the service water is lost because it is above the upper limit of effectiveness.

As a final conclusion, sprinkler system can be an effective solution against fire creating a barrier or for stopping it in a professional point of view however both the issue of economic and the technical optimization require further study.

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