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Electrically controlled dynamic sprinkler activation: Computational assessment of potential efficiency

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ABSTRACT

Electrically controlled dynamic sprinkler activation is the novel technology of managing large automatic fire suppression systems that offers considerable potential advantages over conventional (thermal) sprinkler activation. It is designed to reduce the sprinkler response time, to ensure sprinkler activation in case of high ceiling clearance, and it can also be used for dynamic group activation enabling flexible response to the actual fire pattern and preventing the fire spread beyond the area protected by the group. Since the practical experience of using the new sprinkler activation algorithms is yet to be elaborated, this work attempts computational evaluation of the group enforced activation efficiency. Fire suppression dynamics is compared for a growing fire source impacted by the automatic sprinkler systems of two types: with conventional (thermal) and new (group enforced) activation algorithms. The effects of ceiling clearance, water flow rates, spray refinement, and of the horizontal airflow are examined.

1. Introduction

Due to its simplicity, reasonably low cost, availability, environmental and toxic harmlessness of water, fire sprinklers are currently most widely used in automatic fire suppression systems [1]. Practically every large industrial, storage or public sites are equipped with sprinklers. According to British Automatic Fire Sprinkler Association [2], annual sprinkler production is about 40 million. The most important limitation of fire sprinklers is their activation delay, which depends on the sprinkler inertia, fire size and location, ceiling clearance and the longitudinal airflow. This may potentially produce a scenario when the increase of wetted area is slower than the expansion of fire size. As a result, fire suppression system can no longer control the fire. Furthermore, if the ceiling clearance is too high, sprinkler may not activate at all.

A more efficient alternative to take a rapidly spreading fire under control is a deluge system [1], in which a number of sprinklers are simultaneously activated by a low-inertial fire detector thereby protecting a large area including fire source. Since activation delay is lower than that in conventional sprinkler systems, and the protected floor area is greater than the fire size, the probability of faster fire suppression is accordingly higher. Size of the area protected by the deluge system is a matter of optimization. However, if protected sections are too small, then the problem of identifying proper section to be activated has to be addressed. This problem cannot be resolved by conventional smoke detectors. Also, reduction of section size leads to a higher cost of the entire system. As such, practically used deluge systems cover floor area, which is much greater than a potential fire size. This results in high water requirement, which may not be possible to obey, and in unjustified losses due to damage caused by water spilled in fire suppression.

In spite of the basic principles of sprinkler fire suppression have not been changed for more than a century since the first sprinklers were introduced in practice, new efficient means of fast fire detection, as well as opportunities of programming algorithms of any complexity for operation of fire suppression systems have been developed. These observations inspired the authors to use the state-of the-art engineering solutions to enhance overall efficiency of both sprinkler and deluge systems. The idea of dynamic group activation by an electric signal from either conventional sprinkler or thermal/smoke/optical sensor was presented in Ref. [3] and then introduced in Ref. [4]. More recently, it was favorably explored in the series of experiments undertaken in Ref. [5]. Based on the analysis of the limitations inherent in conventional water-based fire suppression systems, the following avenues and requirements for improvements have been identified in Ref. [4]:

- To reduce damage from fire, fire suppression system must be activated at the early stage of fire growth (implementation of this requirement will increase false alarm probability);
- To reduce damage from spilled water, the wetted area must be

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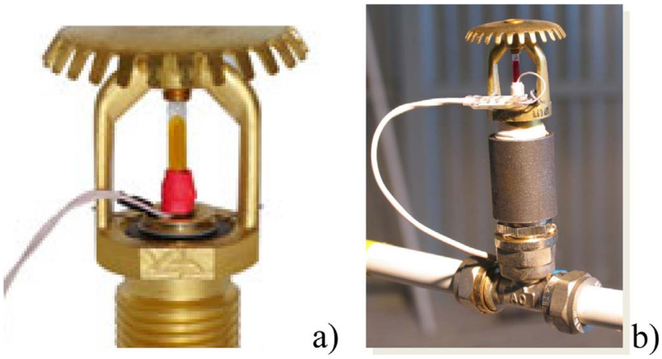

Fig. 1. Electrically controlled sprinkler: a) – heating element on the glass bulb; b) – installed sprinkler.

bounded by the fire size at time instant of system activation;

- There must be an option of quick termination of water supply after fire suppression is complete or in case if false alarm is confirmed;
- There must be an option of displaying the information on activated sprinklers and the operation of the entire system for remote control by an operator.

Enforced sprinkler activation by the electric signal is the engineering solution that makes it possible to obey the above-listed requirements. Previous attempts to implement enforced sprinkler activation are reflected by the patents [6,7]. Controlled sprinkler activation is mentioned in the Russian fire code, [8], and the work is currently in progress to update ISO regulations by introducing requirements to this new technology. However, prior to [4] this idea had not been developed up to a level of serial manufacturing. In Ref. [4], the option of controlled sprinkler activation was implemented in the starting device, which consists of the heating element placed on the glass bulb, Fig. 1. Being switched on by the external signal, the element warms the bulb up to the break-up temperature.

The electric signal triggering the sprinkler activation can be generated in a number of ways, including optical and temperature sensors or smoke detectors. Also, such a signal can be generated by a sprinkler, which is thermally activated after heating the bulb to the break-up temperature.

The method of group enforced activation combining conventional (independent activation of each sprinkler due to heating and break-up of the bulb) and deluge (simultaneous activation of a prescribed section) operation principles was presented in Ref. [4] and is analyzed in this work. In no wind conditions, the first thermally activated sprinkler indicates location of fire origin. Once the fire origin is localized, a number of adjacent sprinklers are activated to cover not only the fire source itself but also the adjacent area. The key point here is to keep the wetted area as small as possible yet ensuring fire suppression. As such, a number of sprinklers simultaneously activated as a group should be in a range of 6–9 items. The group can be considered as a section similar to that in a deluge system. However, such a section is not assigned a priory; rather, it is dynamically defined depending on location of fire origin.

Additional potential advantages are discussed in Ref. [4] including possibility of designing the activation algorithm to allow for the effects of airflows produced by natural or forced ventilation and smoke extraction systems and by movement of fire load, capability to display information about all the activated nozzles at the remote console.

Despite of the above-listed potential advantages of this novel fire suppression technology, practical experience of its performance is yet to be elaborated. The purpose of this paper is to numerically assess efficiency of the group enforced activation and to compare suppression dynamics for a growing fire source impacted by the automatic sprinkler systems of two types: with conventional (thermal) and new (group enforced) activation.

2. Problem setup

We consider a simplified problem setup focusing on two phenomena:

1. Growth of the fire source, which is assumed to be a flat horizontal burning surface.
2. Activation and operation of the sprinklers mounted beneath the ceiling.

After one or more sprinklers activate, the dynamics of fire suppression is governed by the following phenomena:

1. Interaction of spray(s) with the rising fire plume and the flame.
2. Wetting the surface of the fire load.

Transient fire growth and reduction of the burning rate due to wetting strongly affect the regimes of flame-spray interaction.

The simplest possible compartment geometry corresponds to a large empty compartment with horizontal ceiling. To avoid the effects of smoke layer accumulation below the ceiling, we consider 20×20 m square compartment with open side walls (Fig. 2). Both floor and ceiling temperature is maintained constant equal to ambient air temperature of 27 °C. The fire load is replicated by the centrally located square shape combustible surface 12×12 m, flush with the floor level. The heat release rate per unit surface area is set constant if no wetting occurs. Fire ignites at a central point of the combustible surface, and the boundary of the burning surface propagates outwards at a pre-assigned constant velocity V_0, thereby creating the circular fire source with the t^2 growth of the heat release rate: $Q = \alpha t^2$, where $\alpha = \pi V_0^2 Q''$ is the growth coefficient, Q'' is the heat release rate per unit surface area, t is the time after ignition. The heat release rate per unit surface area, Q'', is assumed to be constant which implies no fuel burn-out during the period of interest. In evaluating total heat release rate we assume complete volatile oxidation which corresponds to over-ventilated conditions. Thus, the heat release rate is proportional to the burning surface area, $A = \pi (V_0 t)^2$. In the simulations, we set V_0 =1 cm/s. Combustible volatile composition is represented by the generic molecule CH_4O.

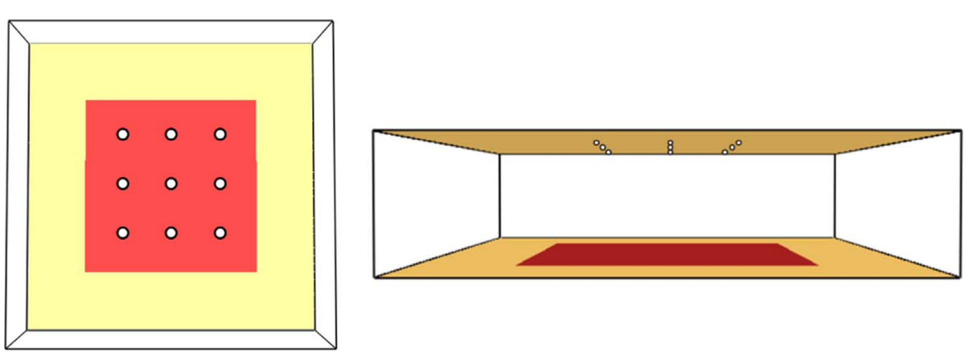

Fig. 2. Computational domain with the fire load and sprinkler locations: left – top view, right – side view.