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Maximizing the retention time of inert gases used in fixed gaseous extinguishing systems

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ABSTRACT

The problem of fire safety rooms protected by fixed gaseous extinguishing system is discussed. The structure and parameters of Fixed Extinguishing System-gaseous (FES-gaseous) has been characterized and the characteristics of extinguishing gases applicable in these systems have been described. On the basis of literature including the analysis of known models of determining the retention time the factor defining the length of the retention time have been determined. The density of extinguishing gas has been indicated as the value of a large potential for extending the retention time. It was found that when the difference between the density of gas inside the protected space and the ambient air tends towards zero then the maximum values in the retention time are achieved. Based on the research it was found that the selection of the composition of the extinguishing gas maximizes the retention time. Extinguishing gases with densities close to air density provide the retention times at least several times longer than extinguishing gases currently use in the fire protection. Performed experiments may allow preparation and validation of numerical method for evaluation of retention time in complex geometries.

1. Introduction

Fire safety of buildings and compartments, in which high value assets are located, is crucial in many modern construction works. Protecting such assets stored in a form of computing servers, archives or in other sensitive means against the fire can be troublesome. The most common extinguishing agents we know – water, foams or powders, cannot be used to protect such places, as the possible losses caused by the extinguishing operation may be higher than those caused by the fire. The use of fixed gaseous extinguishing systems (further referred as FES-gaseous) has the lowest risk of losses connected to the extinguishing action. The principal of operation of FES-gaseous is to fill the entire protected volume with extinguishing gas, up to given concentration level. The gas is discharged in the volume through nozzles, and spread evenly within the room, immediately after a fire is detected. The concentration of the gas within protected volume has to be uniform, and should be maintained for a sufficient period of time to extinguish the fire or allow effective emergency action [1].

Despite the fact that FES-gaseous are mainly used for the safety of assets, their use in buildings can be also considered as a feature improving the fire safety of people, as they directly influence a possible fire, limiting possibility of its growth. To successfully put out a fire, it is required to not only distribute the extinguishing gas evenly within the protected volume, but also to keep it inside for extended time, called the retention time or hold time [2,3]. If this time is too short, there is a risk that fire will start over and spread – which is the worst case scenario as the FES-gaseous are designed for a single operation, and thus after first use the area can be considered unprotected.

In the past, the most popular extinguishing gases were halons, but due to European Communities Directive 2037/2000 [4] they were banned in EU because of their aggressive behavior against the ozone layer. Modern FES-gaseous can be divided into three groups:

- chemical extinguishing gasses (ie. FK-5-1-12, HCFC-123, HFC 125);
- inert gases (N_2, Ar and their mixtures);
- CO_2.

Chemical agents involving atoms Br or F are chemically active. They scavenge free radicals, typically H atoms, to reduce the chemical reaction rate and eventually suppress the flame. Inert gases work by reducing the oxygen concentration. The benefit of Inert Gases (IG) is their natural origin and lack of adverse effects on environment. Used with proper caution they are also less dangerous for human, and they do not disintegrate under high

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temperature. The last gas used in FES-gaseous is CO_2, but due to its dangerous effect on humans [5], it is not popular.

2. Retention time

The retention time (also called hold time) it is a period during which the concentration of extinguishing gas will be maintained within the protected enclosure on required level. In accordance with the European standard [6] retention time shall be determined on the following criteria:

a) at the start of retention time, the concentration throughout the enclosure shall be the design concentration,
b) at the end of the retention time, the extinguishant concentration at 10%, 50%, and 90% of the enclosure height shall be not less than 85% of the design concentration.

The flow of extinguishing gas out of protected volume is caused by the difference of hydrostatic pressure between the inside and the outside of it. This difference is caused mainly by differences in density between the air and extinguishing gasses. Due to this difference, the gasses are flowing out of protected area through various leakages, and are replaced with air. The rate of this depends on the leakage area and the pressure difference between areas [7,8]. In the best scenario, the room protected with FES-gaseous should be perfectly air-tight, but the experiences of the authors show that it is not possible to achieve that in a real working building. Leakages are especially dangerous in high rooms with small area of the floor. Possible solutions to this problem are constant application of extinguishing gas through the time required for fire safety operations or permanent inerting of protected volume with nitrogen obtained from air.

The above mentioned solutions generate additional costs, and are difficult in implementation. In authors opinion, it is possible to prolong the retention time by simply adjusting the extinguishing gas mixture, so its density is as close as possible to the density of ambient air. This greatly reduces the hydrodynamic forces between the fluids, thus reducing the exchange of gasses between the rooms.

The time of retention is described by three popular models:

a) model with a sharp interface between extinguishing gas and air (Fig. 1), presented in NFPA 2001 [9]
b) models with wide interface between the gas and air (Fig. 2), presented in EN 15004 [6] and ISO 14520-1 [10];
c) model of continuous mixing of extinguishing gas with air, at a constant rate within the volume – valid for areas in which the air is constantly moving (Fig. 3) [6,9,10].

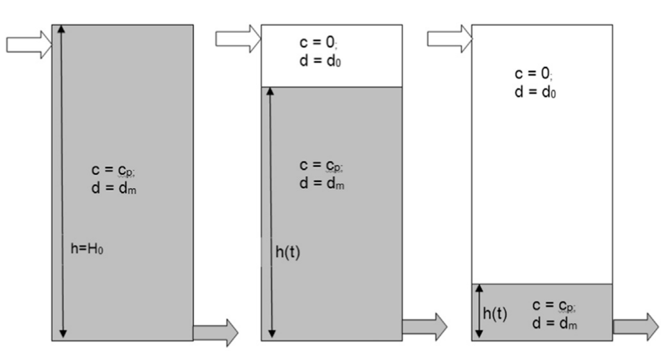

Fig. 1. Retention of extinguishing gas – sharp interface model (authors work, based on [1]).

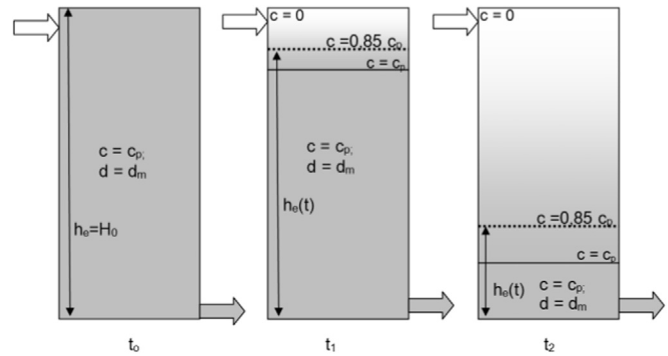

Fig. 2. Retention of extinguishing gas – wide interface model (authors work, based on [1]).

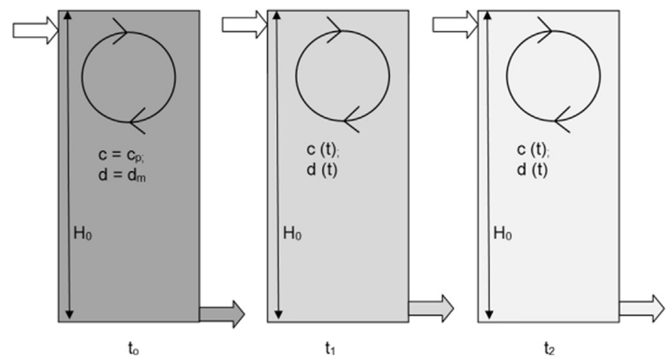

Fig. 3. Retention of extinguishing gas – continuous mixing (authors work, based on [1]).

The models assumes isothermal conditions inside the compartment and outside, no ventilation, a matched pressure inside and outside the compartment and air density at 20 °C , 1.013 bar, humidity 0%.

The performed experiments and analyzed models did not include the effect of heat generation within the fire. This followed the assumption, that gaseous extinguishing systems are supposed to activate in the incubation stage of fire, in which the smoke is generated but the heat generation is limited.

Gas volume flow rate trough leaks may be expressed as [7]:

$$\dot{q} = \alpha A\left(\frac{2\Delta p}{\rho}\right)^{n} \tag{1}$$

where:

q – gas volumetric flowrate [m^3/s];
Δp – hydrostatic pressure differences on both sides of the wall [Pa];
ρ – the density of the gas flow [kg/m^3];
n, α – leakage characteristics; depending on the shape and roughness of leaks;
A – leakage areas [m^2].

The rate of descent of the interface layer can be represented by the following differential equation, where A_p is the cross-sectional area of the enclosure, assumed to be constant [11].

$$\frac{dH_{gr}(t)}{dt} = \frac{q(t)}{A_p} \tag{2}$$

where:

A_p – cross-sectional area of the enclosure.

Retention time may be obtained by integrating Eq. (2), as presented in European [6] and international [10] standards: