THE DANGER OF SMOKE PRESENCE FOR THE BUILDINGS OCUPANTS AND ITS MANAGEMENT IN THE EVENT OF A FIRE

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The smoke produced by fire is composed of fuel gases, solid and liquid particles in suspension. In closed spaces their concentration creates improper survive conditions.

In the smoke composition are also burning gases with extreme dangerous effects.

The carbon monoxide, an effluent at the all fire, represents an extremely danger, because it is highly toxic (the carbon monoxide has for the bloods hemoglobin an affinity about 300 times bigger than the oxygen, formed carboxihemoglobin, which even in small values, induces to the fatal psychometric modifications).

The majority of the nitrogen oxides which results from the fuel of the animal or vegetal materials, in attendance of an insufficient oxygen quantity, don't have any smell, but have a lethal effect.

The sulphurated hydrogen touches the nervous central system, before causing pulmonary edema.

The smoke is composed also by burning gases with extreme dangerous effects.

For the better utilization of high buildings evacuation paths a visibility of 10 – 15 minutes is necessary.

For this reason one must take measures of eliminating the smoke out from the evacuation paths, before it touches critical concentrations.

The utilization of barriers, hamper's smoke, ventilation are traditional methods in the smoke management.

The cleaning of evacuation paths with the fresh air help, represents one of the most useful methods. The burning gases which are in evacuation paths are diluted until the accepted concentration degree is reached.

In the event of a maximum share of 20 % CO_2, and 5 % CO in burning gases, it must be diluted about 20 times, to be obtained the accepted maximum concentration of burning gases in the evacuation paths.

Another efficient method for stopping burning gases is positive pressure ventilation, as one can see also in the article.

Keywords: fire, smoke, gases, toxicity, evacuation.

1. Introduction

Knowing the materials combustion process represents a first stage in figuring out the complex mechanism for fire genesis and propagation.

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Significant amount of smoke and combustion gases, known as combustion products, are generated during burning. Smoke, as a visible product of most of combustion processes, is formed out of unburned particles in suspension, of solid or of liquid (released from the material which burns), of vapors and of gases. Their concentration creates very fast inadequate conditions for people's survival in confined spaces.

Based on experimental data it was found that, in some cases, dangerous concentrations of smoke on classical evacuation routes made of non-combustible materials could be formed in very short time, about 3-4 minutes, before temperature or gas toxicity reaches critical parameters.

From practice, it resulted that at fires occurred in commercial stores and hotels, the smoke that filled their spaces (sales spaces, evacuation paths, staircases, etc.) is performed, generally, in 10-15 minutes.

For a better utilization of evacuation paths, a visibility of 1-15 m is required. We need to take actions to eliminate smoke from access ways and to avoid the smoke to reach critical concentrations.

2. The noxious effects of smoke and combustion gases

The evaluation of fire hazard represented by materials used in various technologies, constructions, transportation or other activity areas (including house appliance) is performed taking into account their combustibility, flames propagation capacity and toxicity of products resulted from combustion.

The smoke, by amount and opacity, reduces the visibility towards exit points and indicators, making the evacuation ways impracticable. The smoke provokes asphyxiation of persons even it they are far from the focal point, due to smoke toxicity.

Often, the smoke caused by fire is the reason of death and, additionally some corrosive compounds produced by smoke cause the degradation of materials in the adjacent zones; metallic elements, part of building structure get weaken and, as result, the intervention of fire brigade must be performed with caution.

The material which burns can be identified on the basis of smoke color, smell and taste. Grey smoke, having a slightly acrid smell, comes from the burning of wood. White-yellow smoke, without irritating effect, is generated by burning of paper, straws and hay. Intensive black smoke is generated by the burning of petrol products, asphalt and tar. Smoke is whitish when it contains water vapors.

Yellow, bluish, white colors and corny, bitter, garlic smells indicate the presence of poisoning substances.

The theoretical amount of burning gases, resulted from specific chemical reactions, can be stoechiometrical calculated. Combustion is incomplete in many cases, substances which intervene in reaction cannot be exactly known. The concentration and the nature of combustion gases depend upon chemical composition of materials which burn, by available oxygen amount and combustion temperature. Most of combustible materials content carbon; when carbon burns, dioxide carbon is generated. When the amount of air is insufficient, monoxide carbon is generated with an extremely noxious effect. Other gases might be generated during combustion process: $H2S$, NO, phosgene, $SO2$, HCl, $NH3$, HCN, etc. Inhalation of combustion gases constitutes the main reason for death in fire.

Monoxide carbon is generated at most of fires (especially during the smoking fire or with insufficient air). It represents the highest danger because it is extremely toxically (monoxide carbon has an affinity for hemoglobin in blood 300 times higher than oxygen, forming carboxyl- hemoglobin which even at low values induces fatal psycho-movement modifications.

Dioxide carbon produces death at concentrations below 20%; at concentrations 3-20% produces headaches, brain congestion, and reduction in hearing capacity.

Most of nitrogen oxides generated by combustion of vegetal or animal materials do not have any smell in presence of an insufficient amount of oxygen, but they have lethal effect.

H2S affects neuraxis before provoking lung edema.

Plastic materials, which are often used recently, (construction elements, finishing elements, house appliance, electric insulation, etc.) generate noxious gases or corrosive gases by burning. Together with phosgene, ammonia, aldoform and especially chlorine hydride produces suffocation symptoms and affects lung system but, at the same time, has a corrosive effect and destroys the technological installations and apparatus, computers, instruments, etc.

3. Factors which influence smoke propagation

Movement of smoke particles from the fire focal toward the ambient around may be done by diffusion, natural convection or forced convection.

In case of latent burnings, usually smothering (cotton, wood and plastic) the generation of heat is latent and the movement of smoke particles is made by diffusion, spreading in the entire room; and stratification of smoke occurs at the same time. The smoke accumulates in layers with descending temperatures toward the inferior parts of the enclosure.

In case of normal burning, due to generation of hot air and hot burning gases eddies, the movement of smoke particles is made by convection.

The smoke particles form an inverted cone above the focal; when the cone moves up, smoke particles and burning gases get mixed with the ambient air leading to cooling of the mixture and reducing of smoke particles circulation speed.

Smoke movement is caused by the following:

- Difference of temperature between outside and inside (Archimedes type forces ;
- Thermal energy caused by fire (thermal pressure);
- Pressure caused by exterior air currents (wind);
- Acclimatization systems inside building.

These factors have a lower or a higher weight, according to the place the fire was generated (hot areas) or far from those (cold areas). The movement of smoke in hot areas is conditioned, mainly by the heat flux generated by burning.

In cold areas, in which the amount of heat accumulated in smoke and in burning gases is reduced, movement of smoke is conditioned by temperature differences between interior and exterior, wind actions and the action of acclimatization systems.

Movement of smoke inside a building depends upon other factors such as: building characteristics, respectively characteristics of construction elements and installations, if they can become propagation ways for smoke. In some cases, due to building configuration, the natural ventilation cannot be used for controlling the movement of smoke. Exterior air parameters, especially the wind, have a contribution to movement of smoke. As result, mechanical ventilation is required. The advantages of this are as following: control on smoke evacuation, independent of climatic conditions, versatility in exploitation, automatic operation, reduces expansion of smoke in the entire building.

The exterior temperature influences the thermal draft which is a source for spreading the smoke.

The wind could influence smoke spreading process creating proper conditions for horizontal circulation of air. This creates overpressures and depression on the opposite facades. These pressures modify the aerodynamic balance of rooms and location of neutral plane for the room in which the fire has occurred.

Movement of smoke on vertical direction inside building can be caused by expansion of gases which get hot, by draft generated during fire, by ventilation and acclimatization systems which are in operation, by pressure of wind. Smoke propagation can be blocked by tightness of room compartmenting elements, by overpressure or by fresh air currents which circulate from opposite direction to natural movement of smoke.

A part of the generated heat in the area of focal is accumulated inside of burning gases mass and supplies energy which provokes further smoke spreading inside the building. Basically the phenomenon arises from the following: heated up gases expand at the beginning of fire and as, result, the inside pressure increases and a part of the smoke generated by fire is evacuated through poor tightness of doors, windows and other holes.

For example, by heating up the ambient up to 300˚C the amount of evacuated gases is equal to half of room volume. Burning gases are lighter than air and create an accessional force which puts the smoke under movement; the smoke reaches the ceiling and then starts moving horizontally, alongside the ceiling, accumulating thicker layers of smoke.

Air pulling speed towards flames generated by fire depends upon the size of fire and the distance between the base of fire and the lower side of hot gases. When the fire is big, the pulling flow rate is proportionally big. If the door of the room in fire is opened, a cold current of fresh air is generated. This air enters into the room at the lower part of door and smoke goes out like thick clouds to the corridor at the upper part of the door, at 2/3 of door height. The neutral axle is at 1/3 of door's height, measured from the floor level.

After certain experiments it was concluded that through a door having 2 m height and 0.75 m width, at the ambient temperature of 200˚C, smoke flow rate could be about 60 KG/min, which means that each m^2 of door receives 40 kg/min. In case the door is closed, smoke volume which enters through tightness is about 0.01 kg/sec (0.6 kg/min). This value looks very inconsiderable at the first sight, being 200 times lower than the value corresponding to an opened door, but it may lead to a reduction of visibility to 5 m in a normal corridor between two staircases having 30 m length in 5 minutes time. When surface or number of doors is high, smoke flow rate entered inside a building is through its tightness increases considerable. Situation becomes severe when there are windows which may break due to heat generated by fire in the inner walls. The smoke gets spread from the room in fire to the corridors, to the staircase, then to vertical direction toward the upper floors.

In case the fire occurs at an inferior floor during cold session the smoke spread fast toward the upper floors due to big difference between inside and outside. During warm season, when outside temperature is higher than inside temperature, direction of wind currents gets inverted; as result the evacuation ways under the floor which is on fire will be invaded, especially if the fire is situated at a floor above the neutral plane.

Generally, it is admitted that the density of smoke is equal to density of air at the same temperature, increased by 1-3%, according to composition.

High temperature generated by fire is another factor which contributes for spreading of smoke inside building.

4. Management of smoke

Management of smoke includes all methods that could be used to modify movement of smoke.

Use of barriers, of ventilation and of chimneys is the traditional method for smoke management.

The effectiveness of barriers is limited as propagation, due to shortage of drainage ways.

The fans and the chimneys are limited by the fact the smoke must be ascendant enough and to cope with any other force which might perturb the movement.

Smoke barriers are generally used for compartmenting of high ambient showing high risk for fire and having the following effects:

- Smoke evacuation installation is more efficient due to low rate between evacuation surface and contribution of fresh air;
- To be avoided that smoke and burnt gases to spread in the entire volume of air inside;
- Extinguishing the fire is more efficient as long as smoke remains in the area of focal, leaving the other adjacent sectors clean.
- Damages caused by fire are diminished (the other areas remain clean and “fresh”)
- Generation of secondary fires to be prevented by coordinating the hot gases toward evacuation openings.

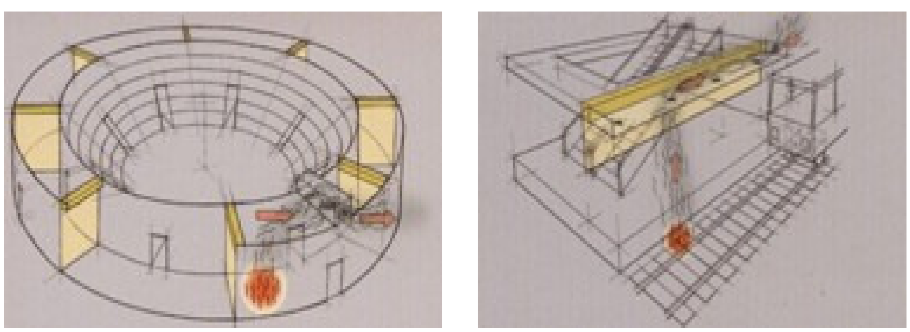

Fig. 1 Examples of steam barriers.

Fixed or mobile flexible smoke barriers, even the combination of the two, are the most used in the first phase of fire.

Pressurization is used to control the spreading of smoke generated by fire inside buildings. The systems which use pressurization produced by mechanical fans are called smoke control systems.

In order to be efficient, smoke control system must produce pressure difference in the desired direction in case of fire.

It was found that the differences of pressures alongside closed doors vary by max 5 Pa.

Dilution of smoke with exterior air could be used to maintain an acceptable level of noxious gas concentrations inside a compartment which is adjacent with the compartment contaminated by smoke.

The dilution could be used by firemen to remove the smoke after the fire was extinguished.

Sometimes, when there are opened doors, the smoke enters in protected places. Ideally, the doors are opened for short times during evacuation.

The smoke which entered in spaces far from fire could be removed by introducing the air from outside to dilute the smoke.

What comes next represents a simple analysis of smoke dilution in spaces free of fire.

Let's suppose that at *t=0*, a compartment is contaminated by a certain concentration of smoke and after that remains intact, no more smoke enters the compartment. We may suppose the contamination is uniform. Concentration of smoke could be expressed as [1]

$$\frac{C}{C_a} = e^{-a\Theta} \qquad [1]$$

Dilution rate can be expression by the following equation:

$$a = \frac{1}{\Theta}\ln\left(\frac{C_0}{C}\right) \qquad [2]$$

Where: C_0 – initial concentration, C- concentration at moment Θ, a – dilution rate (load/min) and Θ – duration until the generation of smoke is over (min).

A space could be considered as being “relatively safe” is contamination concentration is lower than 1% as compared to concentration just in the vicinity of fire [2].

Actually, it is impossible to ensure a uniform concentration in the entire compartment. It is possible that the highest concentration to be close to ceiling due to accessional forces.

In case of maximum quota of 20% dioxide carbon, respectively 5% monoxide carbon in the burning gases, these must be diluted 20 times in order to achieve the maximum admitted concentration.

Taking into consideration the dilution factor established with approximation, it is considered that for dilution of burnt gases generated in the evacuation ways the required dilution rate is at least 1:100.

The volume of fresh air is given by this dilution rate; the volume of fresh air is given by the volume of burnt gases current entered inside evacuation ways.

"Smoke load" is taken into consideration for calculation of staircase ventilation and lift cage for buildings having many floors.

"Smoke load" represents the total amount of smoke generated during the burning of materials located in the area of fire. It is expressed as a multiple of total surface of burnt materials and optical specific density of smoke. The amount of smoke generated on material surface unit it is conditioned not only by its properties, but by the amount of oxygen in the atmosphere, ambient temperature, type of burning (with flame of smothering) and also by the way the material which burn is laid down.

6. Conclusions

In order to solve smoke evacuation issue we must take into consideration the danger represented by smoke for people and as a consequence, the need to act as soon as possible and as efficient as possible, with adequate means, to evacuate them and rescue them.

High buildings and buildings with big surface as well as subsurface constrictions which do not have windows could be abandoned only on proper evacuation ways in case of danger. The rescuing teams must enter these buildings only on these ways. From this reason, the evacuation ways must be maintained usable even during fire. This request says that in case of fire, low concentrations of burnt gases and smoke to be allowed inside evacuation ways. There are two possibilities to keep the evacuation ways free of smoke: first method-burnt gases entering the evacuation ways to be strongly diluted, second method-use overpressures inside evacuation ways to stop entering the burnt gases.

REFERENCES

[1]. *ASHRAE (1995)* Applications Handbook.
[2]. *McGuire, J.H. TAMURA (1971)* "Smoke control in high-rise buildings." CBC 134. Ottawa: National Research Council Canada.
[3]. KLOTE, J.H. MILKE J.A." Design of Smoke Control Management Systems", *ASHRAE and SFPE ,Atlanta, GA 30329,1992.*
[4]. BUTHER E.(1976): "Smoke control by pressurization"