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The possibility of replacing solid walls with water curtain applicable to a large underground garage*

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Abstract. *The work is considered the replacement of fire barriers with hard water curtain sprinkler system created by the devices. The main focus is the duration of activation of sprinkler devices and parameters they generate water curtain. It is isolate specific cell cars using water curtain to prevent the spread of fire to neighboring and adjacent cars.*

Key words: sprinkler device, fire, water curtain

1. Introduction

In large public parking with a few hundred or thousand cars the major problem is to ensure the fire safety, respectively the protection of arising the fire and its isolation and turning out. The main goal is to prevent the spread of fire to neighboring cars. This can be done by using of fire walls or as proposed in this work with dense water curtain, which is create of certain of a number of sprinklers located around the cell (Fig. 1).

2. Theoretical formulation of the problem

The idea of the application of eventually change fire walls with dense water curtain comes down to this: Over the burning vehicle arises vertical convective jet whose initial velocity is proportional to the power of fire. This jet is rising in vertical direction over the burning object and turn on the fast sprinkler which are located approximate over the engine of the car. In the first second the water from turn on sprinkler begin to extinguish the fire. Further the convective jet is spreading at the garage ceiling as one side wall confined jet that reaches the water sprinklers from the water curtain. The curtain is turn on and isolates the zone with burning vehicle and it prevent the spreading of fire in other direction.

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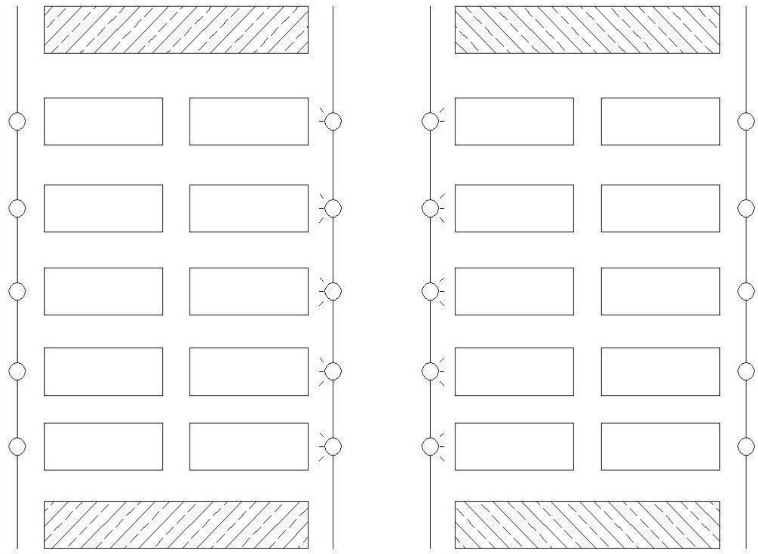

Fig.1

Simultaneously, the automation system is turn on over the relevant area of ventilation system. The system of aeration is operate on the following principle: sucks the smoke and heating air from the burning car and meanwhile not to create a gage pressure it is compressed air in the system.

According Drysdale [3] the velocity over a fire can approximately be determined by:

$$W_0 = 1,9Q^{1/5} \qquad (1)$$

Where W_0 - initial velocity of the fire, m/s, Q - power of the fire, kW

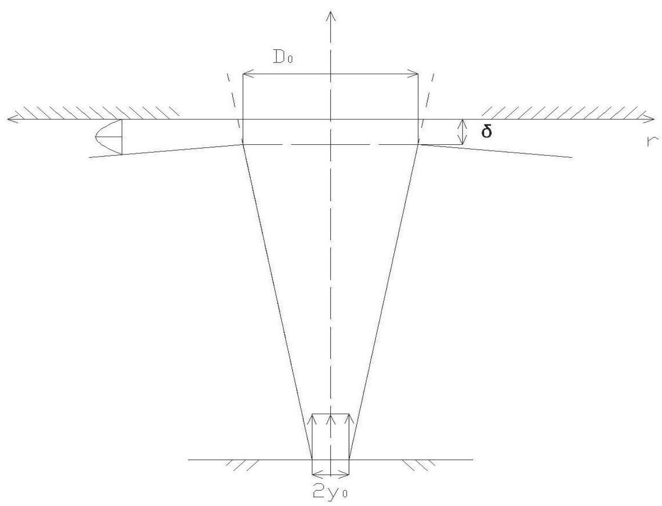

Fig.2

The parameters of convective upward jet (Fig. 2) according to [1] and [2] is calculated using the following relationships:

- The velocity of the upward jet:

$$u_m = B_u^{"} D_0^{1/3} \Delta T_{пл}^{4/9} x^{-1/3} \quad (2)$$

- The temperature difference

$$\Delta T_m = T_m - T_{ok} = B_{\Delta T}^{"} D_0^{1/3} \Delta T^{8/9} x^{-5/3} \quad (3)$$

Where D_0 - initial diameter of the heat source in case of the fire burning car, m; $\Delta T_1 = T_{пл} - T_{ок}$, K; $\bar{x} = \frac{x}{D_0}$; constants $B_u^{"}$ and $B_{\Delta T}^{"}$ have values $B_u^{"} = 0,222\left[m^3 K^{9/4}\right]$ and $B_{\Delta T}^{"} = 0,71\left[m^{1/3} K^{9/8}\right]$.

These values satisfy the case when $\bar{x} = \frac{x}{D_0} \geq 3 \div 3,5$. The choosen size of the burning car which is create from the fire $D_0 = 0,5m$ and height of the garage $H = 3 \div 4,5m$, which means that $\bar{x}$ will fulfill the above condition

In a relatively short distance to ceiling the high power of the fire (conditionally accepted for $Q = 1500W$ and temperature $T = 600K$) velocity and temperature of the rising convective jet did not significantly change

For obtaining initials velocities $W_0 = 8,2m/s$ at chosen power of fire, the convective stream reach the ceiling for different time at different heights of garage cells and this time is given in Table 1

Table 1

h,m	3	3,5	4	4,5
Δt, s	0,36	0,43	0,49	0,55

This means that for a time less than $\Delta t = 1s$ sprinklers over burning car will be activated and will turn on and exstinguished process will started.

In next moment reaching the ceiling the convective jet is transformed into wall radial jet which is evolve at ceiling in all directions, steering to so-called "fast" sprinklers form the water curtain. Due to the short distance to the ceiling and high temperature of the flow the initial weight and velocity does not change. Because of the big difference in the densities of convective flow and the environment $\rho_{jet} < \rho_{env}$, the last "pressed" to the ceiling and don’t allows her extension. It is assumed that the initial value of ring jet is determined according to fig.3 from the initial diameter $D_0 = 0,5m$ and thickness b_0.

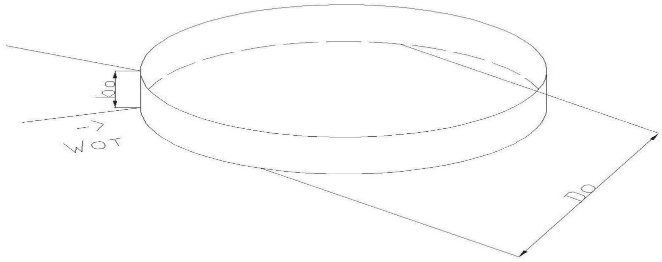

Fig.3

The initial parameters: diameter, thickness and velocity of the wall radial jet are defined as follows:

- The velocity at initial section after turning it on 90^0 is assuming equal to half of initial velocity of upward jet

$$W_{0T} = 0,5W_0 \tag{4}$$

For example when $W_0 = 8,2m/s$ then W_{0T} is equal to $4,1m/s$

- The initial width b_0 of the jet will be as following:

$$b_0 = \frac{V_0}{\pi D_0} \tag{5}$$

Where $V_0 = \frac{\pi D_0^2}{4} W_0$ is the initial volume of the flow

It is asuming that for the time of reaching of the ceiling the temperature and density are not changed

Using the above values for D_0 and W_0 for b_0 is getting:

$$b_0 = 10mm \tag{6}$$

The section at which the flow is expanded is determinated by the expression:

$$S = 2\pi rb \tag{7}$$

If for b is accepted the equation according [1] then:

$$b = cr \tag{8}$$

Where: $c = 0,27$ is a constant and r is the distance from the center of the circle described above the flow (Fig. 3).

Replacing (8) in (7) is follow:

$$S = 2\pi cr^2 \tag{9}$$

Respectively.

$$S = 1,6959r^2 \tag{10}$$

Obtaining S it could be calculated the average velocity of the ceiling at current distance r from the center over the fire (Fig.3):

$$U_{pm} = \frac{W_{0T}}{S} \tag{11}$$

The calculation of $U_{pm} = f\left(r\right)$ at a different distance from the device is given in Table 2.

Table 2

$l = 1m$	$U_{PM1} = 2{,}41m / s$
$l = 2m$	$U_{PM1} = 0{,}604m / s$
$l = 3m$	$U_{PM1} = 0{,}268m / s$
$l = 4m$	$U_{PM1} = 0{,}15m / s$

If an average velocity to reach a current at distance l is assuming by:

$$\Delta U_{PM} = \frac{W_{OT} - W_{PM}}{2} + U_{PM} \tag{12}$$

It can be found the time that the wall jet is reach at current distances ie time of activation of so called „fast” sprinklers which is given in Table 3.

Table 3

l, m	$\Delta t, s$
$l = 1m$	$\Delta t \sum 0{,}55 + 0{,}35 = 0{,}9s$
$l = 2m$	$\Delta t \sum 0{,}55 + 0{,}855 = 1{,}4s$
$l = 3m$	$\Delta t \sum 0{,}55 + 3{,}27 = 3{,}82s$
$l = 4m$	$\Delta t \sum 0{,}55 + 4{,}155 = 4{,}7s$

This means that in the first two seconds will trigger on all sprinklers at distance 2 m from the burning car. For longer distances remote sprinklers will operate at condition that the temperature of the burning car do not fall too quick.

For maximum calculating time of 4,7 seconds could not be expected too much drop of the temperature, which leads to the conclusion that the ceiling temperature will be much greater than the starting temperature of "fast" sprinklers.

According to Figure 4, for time $\Delta t = 4{,}7s$ will be start from three to five fast-acting sprinklers standing at distance between them l_1.

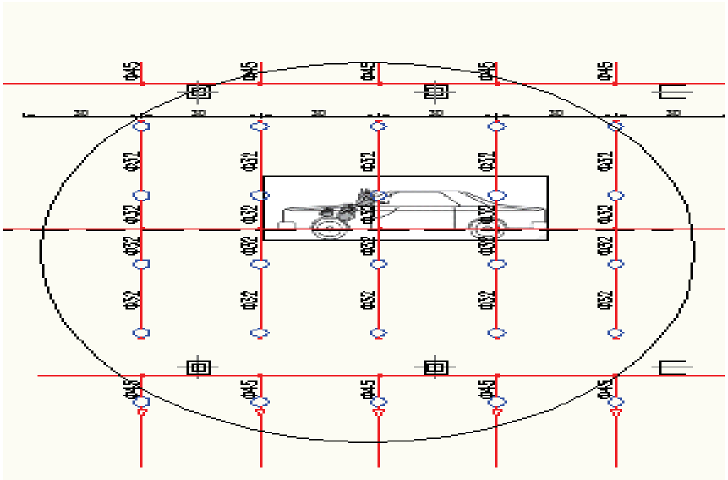

Fig.4

In the vicinity of the burning car to sprinkler curtain $l \leq 2m$ will trigger from 3 to 5 fast sprinklers. At a longer distance will trigger maximum of three quick sprinklers of water curtain plus this over the burning car and eventually this one which are lying in the range of $l = 4m$ ceiling sprinklers so that the number of activated sprinklers will be increase [5].

To create a smokeless zones under smoke floating layer according to[6] is design and install ventilation exhaust systems for smoke and hot gases. This ventilation systems for smoke and hot gases is a scheme of safety equipment designed to perform a positive role at unexpected fire. The smoke is drawn in the direction of the non carrier bulkhead from velocity of 2 m / s to 5 m / s. Quoted above standard allowed velocity from 5 m / s, but it should be take in mind that this velocity would affect negatively and lead to the merging of streams of pure air.

From [6] follows that the density of the thermal load in the rooms for the storage of combustible materials according to their purpose, is determined the heat capacity of the prevailing materials. Ventilation systems to remove smoke and heat systems(VSRSH) have to reach its design performance level within 60 seconds from receiving the command signal. Each VSRSH systems have to ensure the supplement of sufficient fresh air that enters the room for the expense of the flue products.

3. Thermal impact

Heat transfer by convection and radiation is define according to [5]. Thermal effects are expressed by the intensity of the heat flow $h_{nbt}, W / m^2$ to the surface of the element and is determined with taking into account the heat transfer by convection and radiation, such as:

$$h_{nbt} = h_{nbt,c} + h_{nbt,r}, W / m^2 \tag{12}$$

where: heat transfer by convection $h_{nbt,c}$ is given by the relationship

$$h_{nbt,c} = \alpha_c \left(\theta_g - \theta_m\right), W / m^2 \tag{13}$$

radiation heat transfer $h_{nbt,r}$ is given by the dependence:

$$h_{nbt,r} = \Phi \varepsilon_m \varepsilon_f \sigma \left[\left(\theta_1 r + 273 \right)^2 - \left(\theta_m + 273 \right)^4 \right], W / m^2 \tag{14}$$

Convection component of the intensity of the heat flow is determined by:

$$h_{nbt,t} = \alpha_c \left(\theta_g - \theta_m \right), W / m^2 \tag{15}$$

where: α_c is the heat transfer coefficient by convection $\left[\frac{W}{m^2} K \right]$; θ_g is the gas temperature near the exposed fire element [^{0}C], θ_m is the surface temperature of the element [^{0}C]

The coefficient of heat transfer by convection α_c is determined by the nominal curves "temperature-time". At indirectly heated surface elements the intensity of heat flow h_{nbt} is determined by the relationship (15) where $\alpha_c = 4\left[\frac{W}{m^2} K \right]$. The coefficient of heat transfer by convection has value $\alpha_c = 9\left[\frac{W}{m^2} K \right]$, considering that it is include the effects of heat transfer by radiation. Radiating components of net heat flux per unit surface area is defined as:

$$h_{nbt,r} = \Phi \varepsilon_m \varepsilon_f \sigma \left[\left(\theta_1 r + 273 \right)^2 - \left(\theta_m + 273 \right)^4 \right], W / m^2 \tag{16}$$

where: Φ factor of configuration, ε_m emitting surface element, ε_f transmission of fire, $\sigma = 5,67.10^8 \left[\frac{WK^4}{m^2} \right]$ constant of Stefan - Boltzmann, θ_r is the effective temperature of the radiation environment [^{0}C], θ_m is the surface temperature of the element [^{0}C]. Transmission of fire is taking equals $\varepsilon_f = 1$

4. Determination of the intensity of the water curtain

Because of the difficulties associated with the construction of fire walls aт normalization of fire stations and sections for that it is making experiments at these areas with aim to reduced such proportions that the primaraly split up do not disturb of the process. In many cases, such as in buildings of first degree of fire resistance, as already noted, firewalls did not provide the detriment of fire safety. In connection with this arise there is a need of using such fire barriers that could effectively limit the spread of fire and at the same time would give some freedom for internal layout of buildings with different functions which is the case of water curtain.

The effectiveness of water curtains is assessed according to the amount absorbed heat.

It is known that the dependence of the growing of the temperature of the source of radiation of maximum energy emission is moving to the side of the shorter waves. This follows from the law of Vin:

$$\lambda_{\max,T} T = 0,29 = const \tag{17}$$

where: λ is the wavelength in m, T - temperature at the surface of water curtain, ^{0}K.

5. Required flow rate of the water curtain

The specific task is solved at given characteristics-density of the radiation heat flux, 1500 W/m^2; density of the irradiation protected material, 900 W/m^2; height of the hole -4 m; length of the hole - 6 m; pressure of water in sprinkler - 0.6 MPa (6 atm) and the radius of the water drops -0,0006 m ($600\mu m$).

Optical density of the curtain:

$$\delta = \frac{2,303 \log q_{изл}}{q_{кр}} = 0,51 \tag{18}$$

Thickness of the curtain:

$$R = \frac{\delta}{c} = \frac{0,51}{2,8} = 0,182m \tag{19}$$

Flow rate of the water curtain for 1 m^2 of lateral surface is defined by:

$$Q = 0,666\mu\rho \frac{rR}{H}\sqrt{2gh} = 0,467\frac{l}{s}m^2 \tag{20}$$

For the whole surface of the water curtain:

$$Q^H = 11,2l / s \tag{21}$$

Water curtains are constructed so that the entire hole to be irrigate with finely dispersed water. For this purpose sprinklers are placed over the hole and next to it. When they are placed at the top of the hole it is possible to remain unprotected areas through which is possible a penetration of hot gases.

Sprinkler heads which are used to spray jets are spaced 0.5 m in protecting small holes and 1.25 - 1.5 m in protecting large holes. For sprinkler heads water curtain which are situated at a distance greater than 3 m, it is required head pressure of the water 4-6 mH_2O .

6. Conclusions:

It is made an approximate fast and easy to implement analysis and calculation of water curtain, which replacing the fire walls with water curtains.

It is possible to complicate the design task with the numerical simulation of the object, which could hamper by time the current work.

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