CONCLUSIONS

An analytical model has been developed for the estimation of the critical conditions for flashover during application of water-based fire suppression systems. Two limiting cases of spray behavior (purely convective heat transfer and complete evaporation) have been considered. It has been shown that the equations of droplet motion and heat transfer can be solved analytically with sufficient accuracy in the case of convective heat loss and predominance of tangential velocity.

The minimum water flow rate required to prevent flashover has been found as a function of droplet size distribution in the spray and fire geometrical and physical parameters. Critical water discharge rate in the case of water mist system is approximately 40 times less than that for a conventional sprinkler. In both regimes the amount of water required to prevent flashover is significantly less than delivered by commercial fire suppression systems under regular operating conditions.

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The New Approach to Determination Fire-Extinguishing Concentrations of Gas Compositions.

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ABSTRACT

The article is discussing methods of extinguishing concentration (EC) determination of gas compositions which intended for volumetric fire suppression. The article marked, that the "cup burner" method appears to be insufficiently objective and universal. This fact indicates, that in case of using this method we always receive overstated EC value in comparison with real conditions of fire suppression. The article offers a more objective way of EC determination that is the "cylinder" method which is based on introduction of the cup with a fire hearth in prepared environment. The EC value is determined as relation between extinction time and EC value. We made analytical research of accumulation process of extinguishing substance in reaction zone of diffusion flame. The accumulation is made by its diffusion transfer from environment. From the results of our research we determined an extinction time equalled 10 seconds. The EC value determines from the diagram "extinction time – EC". After processing of the results we have the following: EC for 23 halon is 8.5 % vol and for halon 125 - 7.3 %vol.

KEYWORDS: extinguishing concentration, "cup burner" method, "cylinder" method, extinction time.

INTRODUCTION

Today many countries conduct studies in order to find new "clean" agents of fire extinguishing systems, which can be alternative to brom-containing halons. Moreover it is very important to get adequate values of fire-extinguishing concentrations of these agents, which will be in conformity with the real conditions of volumetric fire extinguishing. There are two methods of determination of fire-extinguishing concentrations (EC): 1) "cup burner" method (in many countries it was adopted as standard [1]); 2) "cylinder" method. "Cup burner" method is in influence of air flow, with additions of fire-extinguishing substances, on flame of burner with heptane. "Cylinder" method [2] is in creation certain fire-extinguishing environment in hermetic cylindrical vessel of 50 l volume and bringing source of fire (small crucible with burning heptane) in this environment. To our opinion, "cup burner" method is not enough adequate for real conditions of fire extinguishing. Typical dependence of fire-extinguishing

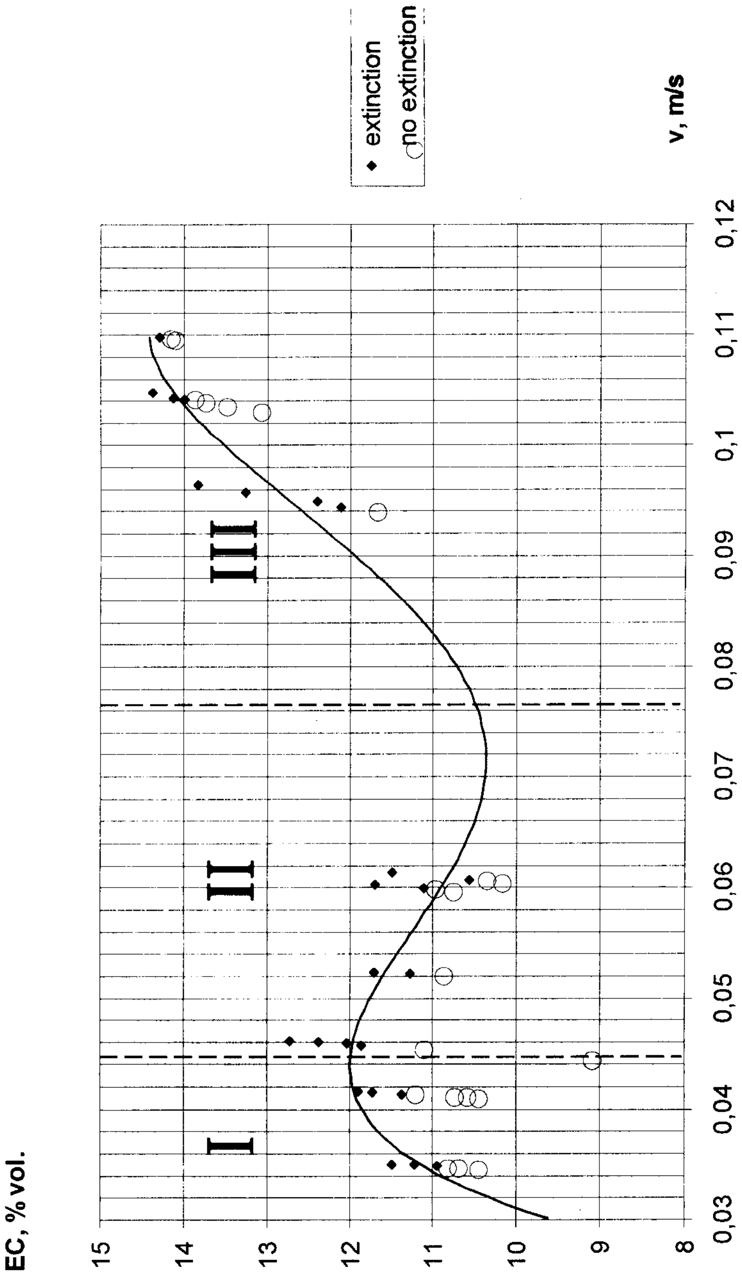

Fig. 1 The dependence of extinguishing concentration CF_3H (EC, % vol.) on intensity of flow (v, m/s)

concentration on flow intensity is shown on fig.1. It easily could be seen that EC's rise with increase of intensity of forced convection. The dependence has complicated character and can be divided into three zones. In the first zone EC rises continuously with some slowing to the zone end. Rise in EC links with volume increase of reaction zone in diffusion flame of fire source under increase of oxidant intensity flow. The intensity of air flow at this moment is less than intensity of natural convection in flame. To the zone end spread of flame is slowing down because of increase of inhibitor's supply. In the second zone flow rates of air and flame are equal and they create favourable conditions for supply of extinguishing mean to the zone of flame. That is why EC is increasing. Obviously, the second zone of "cup burner" method corresponds to optimum conditions of fire extinguishing flow rate of 0,06 – 0,07 m/s corresponds to this zone. In the third zone the flow rate of oxidant exceeds the flow rate of convection motion in flame and supply of fire-extinguishing composition in flame becomes worse. Thus EC values increase again in the third zone. In this case we face the problem: what should be the value of flow intensity in order to define EC. It is necessary to underline, that, as you can see from fig.1, extinguishing of diffusion flame with help of accompanying air flow with additions of fire-extinguishing substance takes place with bigger flow rate, than in immovable environment. In such situation we have rise in flow rate of fire-extinguishing substances and rise in price of fire-extinguishing system. When we use "cylinder" method these difficulties are eliminated and what is very important the principle of relation between fire source and fire-extinguishing environment is adequate for real conditions of volumetric fire extinguishing.

EXPERIMENTAL

Scheme of "cylinder" set-up is presented on fig.2.

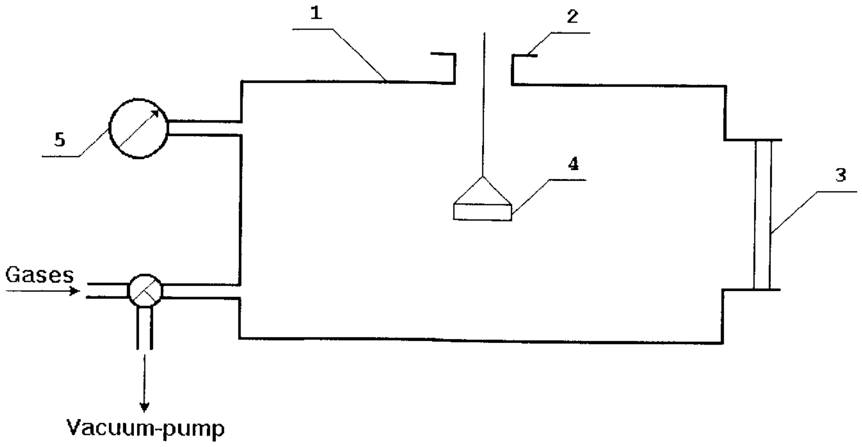

Fig. 2 The scheme of the set-up "cylinder":
1 - vessel V = 50 l.; 2 - hatch for feed of fire hearth; 3 - looking window;
4 - cup with burning n-heptan; 5 - vacuum-gauge.

The given environment is prepared by partial pressure of components of air composition with fire-extinguishing additions or by means of supply of estimated values of substances, which have relatively high temperature of boiling. This environment should be prepared in an evacuated vessel. It is important that steam concentration in the vessel must not exceed the dew point. After supply of fire-extinguishing component in the vessel the pressure with help of air should be lead to atmospheric. "Cylinder" method has one more advantage that is possibility to use relatively high-boiled substances. During experiment it is necessary to fix an extinction time. According to experimental results diagrams in coordinates "extinction time – fire-extinguishing concentration" should be built.

RESULTS AND DISCUSSION

Research results of fire-extinguishing ability 23 (CF_3H), 125 (C_2F_5H) halons are illustrated on fig. 3, 4. In order to define FC it is necessary to choose an extinction time. Theoretically we can consider on tangency point in dependence "extinction time – fire-extinguishing concentration". For more detailed analysis it is necessary to consider conditions of supply and presence of fire-extinguishing substances diffusion flame zone in case of constantly changing correlation of kinetic and mass exchange process in flame which characterising the famous expression [3]:

$$\frac{1}{K^*} = \frac{1}{K} + \frac{1}{\beta}$$

where:

K^* - effective process rate;

K - kinetic characteristic of process;

β - mass exchange coefficient.

Below you will see an attempt of analytic solution of the problem, which is based on the following assumption. Supply of inhibitor in flame is made by diffusion transfer in direction of normal to the flame surface. Fire extinguishing realises through decrease of active center's concentration, which is equal C_0 in case of absence of inhibitors. Concentration of inhibitor in the air is assumed equal C(x,t), where x- coordinate, t – time. Then alternation of inhibitor's concentration in the result of diffusion will be:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial t^2} \qquad (1)$$

where D – diffusion coefficient.

Assume that a beginning condition:

$$C(x,0) = C_\infty \qquad (2)$$

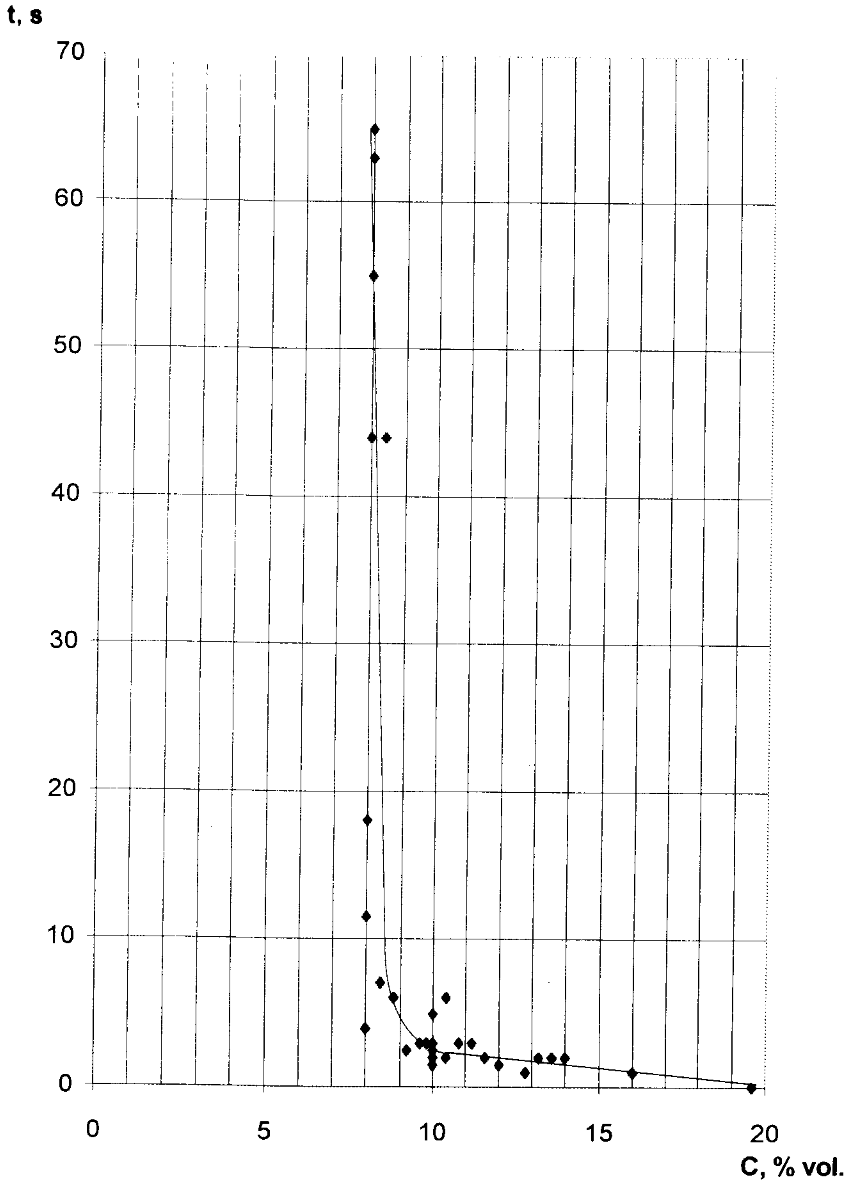

Fig. 3 The dependence of extinction time (t, s) on concentration (C, % vol.) of CF_3H

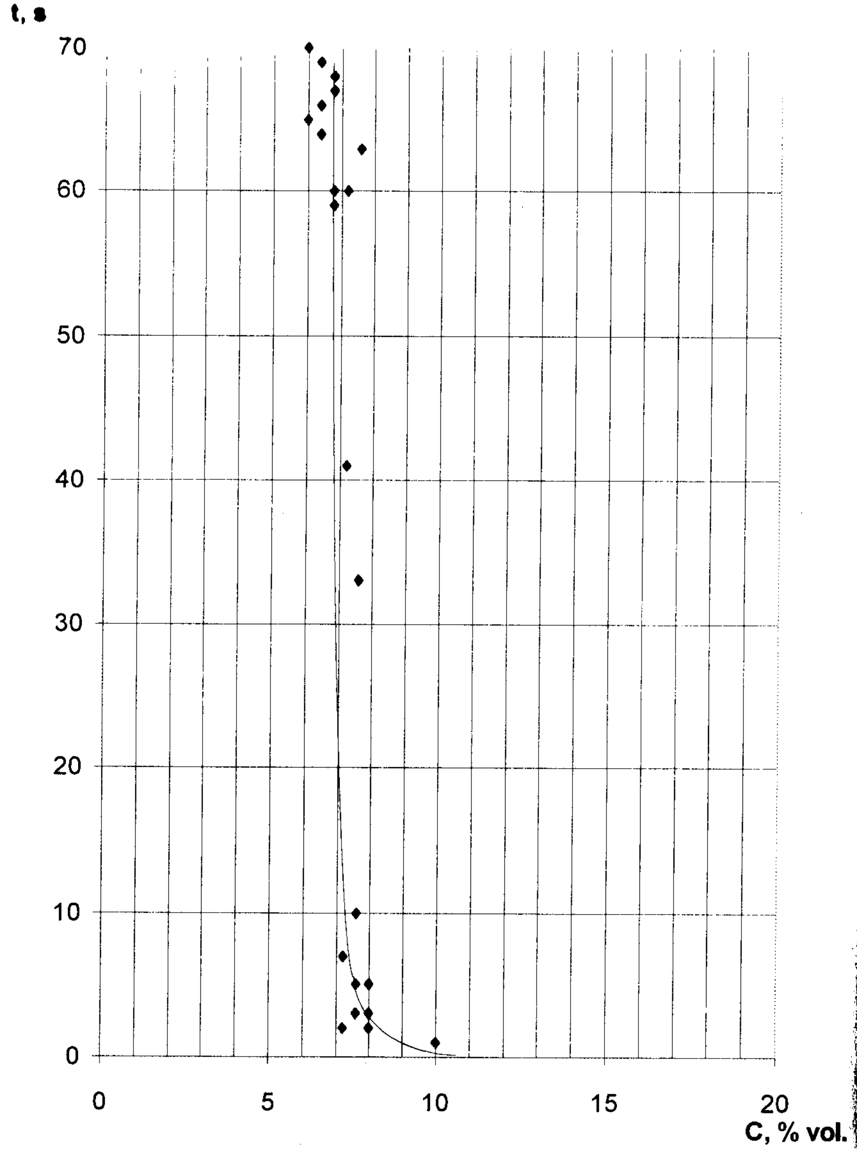

Fig. 4 The dependence of extinction time (t, s) on concentration (C, % vol.) of C_2F_5H

Inhibition of flame is determined by

$$C_a = C_0 - KC(0,t) \tag{3}$$

where K – constant of reaction rate.
Diffusion flow of inhibitor to flame surface is proportioned to C_a.
Then boundary condition will be:

$$D\frac{\partial C(0,t)}{\partial x} = \alpha(C_0 - KC(0,t)) \tag{4}$$

where α - proportioned coefficient.
Assume the following extinguishing condition:

$$D\frac{\partial C(0,t^x)}{\partial x} = 0 \tag{5}$$

where t^x – extinction time.
In order to solve (1), (2) and (5) we introduce dimensionless variables:

$$\xi = X / l, \quad r = t / t_0 \tag{6}$$

where
l – flame thickness,
t_0 – time scale.
Transform (2) and (5) to the following:

$$\frac{\partial C(\xi,r)}{\partial r} = \frac{Dt_0}{l^2}\frac{\partial^2 C(\xi,r)}{\partial \xi^2} \tag{7}$$

$$\text{Assume } \frac{Dt_0}{l^2} = 1\text{, that is } t_0 = \frac{l^2}{D} \tag{8}$$

$$\frac{\partial C(0,r)}{\partial \xi} = \frac{\alpha l}{D}(C_0 - KC(0,\tau)) \tag{9}$$

Introduce dimensionless concentration:

$$U = 1 - C/C_\infty \tag{10}$$

Then (7) will be:

$$\frac{\partial U(\xi,r)}{\partial r} = \frac{\partial^2 U(\xi,r)}{\partial \xi^2} \tag{11}$$

and (2) goes into

$$U(\xi,0) = 0 \tag{12}$$

with regard to (10):

$$\frac{\partial U(0,r)}{\partial \xi} + \beta U(0,r) = \psi, \tag{13}$$

$$\text{where } \beta = \frac{K\alpha l}{D};\ \beta\psi = \frac{\alpha l}{D}\left(K - \frac{C_0}{C_\infty}\right) = \beta - \frac{\alpha l C_0}{D C_\infty} = \beta\left(1 - \frac{C_0}{K C_\infty}\right) \tag{14}$$

where β and ψ - dimensionless complexes.
Extinguishing condition will be:

$$\frac{\partial U(0,r^x)}{\partial \xi} = 0 \tag{15}$$

$$\text{where } r^x = t^x/t_0 \tag{16}$$

and the following solution will be:

$$\frac{\partial U}{dr} = \frac{\partial^2 U}{\partial \xi^2} \tag{17}$$

$$U(\xi,0) = 0 \tag{18}$$

$$\frac{\partial U(0,r)}{\partial \xi} + \beta U(0,r) = \beta\psi \tag{19}$$

$$\frac{\partial U(0,r^x)}{\partial \xi} = 0 \text{ or } U(0,r^x) = \psi \tag{20}$$

You can see from (19) that expressions in (20) are interchangeable.
Solution of the sum (17)-(19) will be:

$$U(\xi,r) = \frac{\beta\psi}{\sqrt{\pi}} \int_0^r H(\xi,v) \frac{dv}{\sqrt{v}} \tag{21}$$

$$\text{where } H(\xi,r) = e^{-\frac{\xi^2}{4r}} + \beta \int_0^\infty \exp\left[-\frac{(\xi+\eta)^2}{4r} + \beta\eta\right] d\eta$$

It is easy to show that:

$$H(0,r) = 1 + \beta e^{\beta^2 r}\sqrt{\pi r}\left(1 + \mathrm{erf}\beta\sqrt{r}\right) \tag{22}$$

$$\text{where } \mathrm{erf}\beta\sqrt{r} = \frac{2}{\sqrt{\pi}} \int_0^{\beta\sqrt{r}} e^{-v^2} dv \tag{23}$$

Then

$$\frac{2\sqrt{r^x}}{\sqrt{\pi}} + \beta \int_0^{r^x} e^{\beta^2 v}\left(1 + \mathrm{erf}\beta\sqrt{v}\right) dv = \beta^{-1} \tag{24}$$

Equation (24) is a condition foe determination of extinction time t^x.

Mark $\frac{\beta^{-1}}{2\sqrt{\pi}}$ through “A” and $\frac{\beta}{2\sqrt{\pi}} \int_0^{r^x} e^{\beta^2 v}\left(1 + \mathrm{erf}\beta\sqrt{v}\right) dv$ through “F”, we have:

$$\tau^x = (A - F)^2 \frac{t^x}{t_0} \text{ and } t^x = \tau^x t_0 (A - F)^2 t_0 \tag{25}$$

Diffusion coefficient value of compositions of fluorine- iod-containing substances estimated with help of [4] is D = 0,07 sm^2/s. In order to estimate the value of l in the expression (8) we assume that l equals the thickness of light zone of diffusion flame and according to [5] equals approximately 10 mm. Analysis of expressions (24), (25) shows that value of the first factor in (25) is closed to 1. With regard to these assumptions we have from (25) extinction time $t^x \sim 15$ s. Assume this with some safety margin $t^x = 10$ s. This value is very closed to the tangency point of the dependence "extinction time – fire-extinguishing concentration". With regard to this condition according to dates on fig. 3, 4 we will have the following values of EC for 23 and 125 halons:
23 halon – 8.5% vol.
125 halon - 7.3% vol.

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