LIQUID WATER SPRAY USE FOR THE FIRE EXTINGUISHING IN ROOM

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Lucrarea prezintă o anumita abordare teoretică privind procesul de evaporare a picăturilor dintr-un jet de lichid care se dezvoltă într-un amestec aer-vapori. Unul din principalele scopuri ale lucrării este acela de a estima timpul de viață al unei picături de lichid, funcție de dimensiunea sa şi de umiditatea aerului. Pe baza particularităților proceselor de transfer aferente evaporării picăturii, rezultă modul în care trebuiesc conduse cercetările experimentale. În articol se analizează modul cum temperatura inițială a lichidului influențează împrăştierea şi finețea de pulverizare.

În continuare se prezintă aspecte specifice jetului bifazic şi a calității evaporării, obținute pe instalația experimentală propusă. Rezultă astfel modalitatea de creştere a puterii de stingere a flăcării de către jetul cu ceață. Se constată astfel, că utilizarea jetului liber cu lichid cald constituie o metodă adecvată pentru a modifica compoziția mediului şi de a reduce concentrația de oxigen sub limita de inflamabilitate. Fluidul de lucru utilizat este apa pură, care constituie un fluid ecologic.

The paper presents a certain theoretical approach concerning the droplet evaporation processes from the liquid jet, sprayed in an air vapour mixture. One of the main aims of the paper is to estimate the life time of the liquid droplet, in function of its dimension and of the air humidity. From the particularities of the transfer phenomena involved in the droplet evaporation, the way in which the experimental tests should be lead results. The influence of the liquid temperature on the spray atomisation in the surrounding was exposed

The aspects regarding the experimental tests were mentioned as the jet development followed by the evaporation quality. The enhancement of the fire extinguish efficiency by using the preheated liquid was revealed. The free jet of warm liquid water represents an adequate way to change the surrounding composition, than the oxygen concentration fall under the ignition limit. By using the clean water as working fluid the ecological demand of the proposed system was realised.

Keywords: droplet evaporation, liquid jet dispersion, two-phase jet, droplet life time, fire extinguish.

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1. Introduction

The modern systems used to put out the fire, must have a short time reaction in aim to move the main causes and to limit the damages. The important works in this field were provided by Morita et al. [1], Mostafa and Elghobashi [2] and Liu [3]. On the other hand, the fire extinguish systems must have an important mobility with a certain liquid quantity of water. One of the system which may satisfy these exigencies may be represented by the liquid water sprayed in the small droplets, so called mist or fog equipment [4], [5]. Actually, the water is used frequently for this aim, being an available fluid, no toxic, no pollutant, and having an important absorption capacity of the heat [3], [6]. The liquid water is sprayed in the very small droplets in aim to form the fog. The dimensions of the pulverized droplets are recommended to be in the range of 10 to 50 μm. In the contact with the hot gas the simultaneous transfer processes at high rates occur. A supplementary turbulence due to the huge volume rate of the vapour born by evaporation is realised. In fact, the vapour born by the liquid evaporation pushes the other gaseous compounds from the space and consequently, a high concentration of sprayed substances appears.

2. Theoretical aspects of the evaporation in two phase jet

The basic works treating the evaporation process of the liquid droplet evaporation in the atmosphere were given by Mills [7], Taine and Petit [8], Yuen and Chen [9] and Abramzon and Sirignano [10]. All these papers take account of the thermal and the vapour concentration equilibrium between liquid droplet surface and its surrounding. On this basis, the evolution of the droplet diameter with the time ant its life time is analysed. For an efficient mass transfer the number of the droplets of small diameter must be high in aim to have an important mass and heat exchange surface. Consequently, a fine dispersion of the liquid jet in small droplets is required (see table 1).

Table 1

Droplets characteristics for one litre of liquid

Droplet diameter [μm]	1000	100	10
Number of droplets	$1{,}91\cdot10^{6}$	$1{,}91\cdot10^{9}$	$1{,}91\cdot10^{12}$
Total surface [m^2]	6	60	600

Based on the evaporation physical model the life time of the droplet is [11]:

$$t = \frac{\rho_l d_{po}^2}{8\rho D_{v,a}(\omega_s - \omega_e)} \quad (1)$$

where: d_{po} is the initial droplet diameter, in m; ρ_l- liquid density, in kg m^{-3}; ρ - gaseous density of the air vapour mixture, kg m^{-3}; ω_s – mass vapour concentration at the saturation state, kg$_{vap}$ kg$^{-1}_{air-vapour}$; ω_e - mass vapour concentration in the environment (air – vapour) kg$_{vap}$ kg$^{-1}_{air-vapour}$; $D_{v,a}$ - vapour diffusion coefficient of the vapour in the air, in m^2 s^{-1}.

The life time for a droplet is a function of its dimension, the environmental temperature and the surrounding thermal conductive ity. Andersson et al [4] proposed the following relation for the lifetime of the droplet, for the diameter range of 0,1–1mm:

$$t = (d_p l_v \rho_l)/(2\lambda\, \Delta T\, C_2) \quad (2)$$

where: d_p is the droplet diameter, in m; l_v – latent heat, in J kg^{-1}, ρ_l- liquid density, in kg m^{-3}; λ – heat conductivity of the surrounding gas, in W m^{-1} K^{-1}; ΔT – temperature difference between the gas and liquid, in K; C_2 –an experimental constant, in m^{-1}.

In the diagram from the figure 1 is shown the droplet life time evolution in function of the droplet diameter and temperature difference ΔT. For the calculus we have used the relation (2). We observe a reduction of the droplet life time with the temperature difference between the gas and liquid, and especially with the droplet diameter.

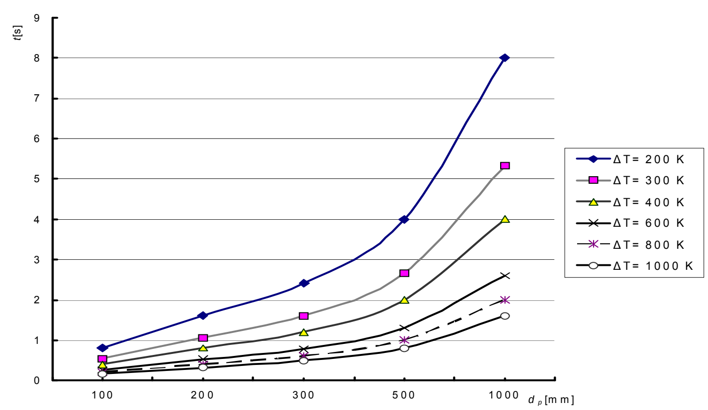

Fig. 1. Droplet lifetime evolution with ΔT and diameter

The evolution of the droplet lifetime in function of the pressure drop at the exit of the water nozzle is another important aspect. It is obvious that the high discharge pressure leads to the short penetration time of the droplets, for a certain length, due to the high velocities. On the other hand, the life time of the droplet is conditioned by the intensity of heat transfer process. In aim to have the optimum cooling effect with a total evaporation of the liquid droplet for a certain length must find the adequate diameter range of the droplets.

The effect of the cooling with the water sprays depends of the penetration length of the droplet in the air. We observe that for the same initial pressure, the big droplets have a short residence time and consequently, for certain process transfer intensity, the evaporation of the liquid contained by the droplet is partial. By enhancing the initial velocity, due to the rise of the initial pressure discharge, for the same droplet diameter, the penetration time diminishes.

For the high droplet velocity and for the weak heat and mass transfer processes due to the partial evaporation, it is possible that the liquid fall on the floor. In this case a part of the active fluid is lost.

Evaporating model of a droplet implies the simultaneously mass, heat and momentum transfer processes. Also, the thermophysical properties of the sprayed liquid and of the surrounding gas have a crucial influence in both phases. Due of the liquid evaporation the gaseous surrounding of the droplet has a variable concentration in vapour, and a variable temperature too. This continuous variability of the air humidity in the space leads to the different life time for the same droplet diameter.

In the first phase we consider that at the different temperature of the surrounding, the relative humidity of this is constant (e. g. φ = 50%, for surrounding temperature of 50˚C (323 K), 70˚C (343 K) and 90˚C (363 K)). The evolution of the life time in the above conditions, after Pavel and Chisacof [11], is presented on the figure 2.

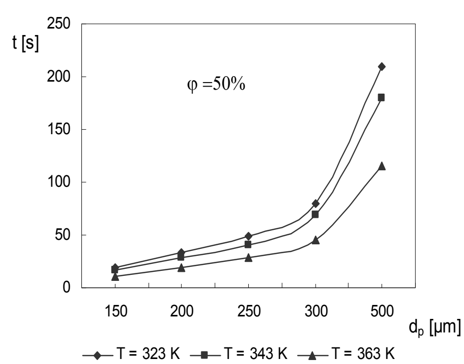

Fig. 2. Lifetime evolution with the surrounding temperature and droplet diameter

As it was expected, the life time of the droplet diminishes if the temperature increases and consequently, the evaporation rate enhances.

Quantitatively, we observe that for the droplet diameter up to 250 µm, the life time is weakly influenced by the surrounding temperature. For the droplet diameter greater than 250 µm the life time becomes practically double for the surrounding temperature of 323 K in comparison with that of 363 K.

In the dispersed liquid jet we find o wide range of droplet diameter. We consider, in the analyzed liquid jet, a distribution of the droplet diameter in the range of 100 µm to 500 µm, with the following amount: 10 % of 100 µm, 20 % of 200 µm, 30 % of 300 µm, 20 % of 400 µm and 10% of 500 µm. This kind of droplet distribution is often met in the liquid jet used for the fire extinguish. The relative flow of the gaseous phase is considered the laminar one at the constant temperature of 40°C. In these conditions the life time of the droplet increases with the saturation degree in vapour of the gaseous phase. In the figure 4 is shown the mean life time variation with the relative humidity of the air for the mentioned distribution. From the figures 2 and 3 we observe that the evaporation rate increases for the reduced relative humidity values and for the high temperature of the surrounding air (Pavel et al. [12]).

From the above analysis the droplet evaporation rate, in the two phase jet, is determined mainly by the relative humidity and the temperature of the surrounding. Another decisive parameter for the transfer processes is represented by the droplet diameter which imposes the life time limitation.

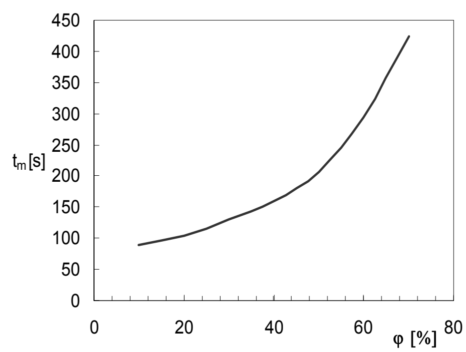

Fig. 3. Mean life time variation with the relative humidity of the air, at 40°C

For a certain penetration length of a droplet in the gas phase, the complete evaporation imposes the small diameters and a low relative humidity combined with a high temperature of the surrounding. This kind of conditions may be fulfilled even by the gaseous flame of the fire.

3. Experimental layout

The experimental test bench is shown in the figure 4 [13]. The cold water supplied by the laboratory network passes the flowmeter and is driven to the tank coil. The oil from the tank is heated by an electrical resistance. The hot oil is used as the heating fluid for the water coil. In aim to enlarge the test temperature domain of the water supplying the jet nozzle and to avoid the evaporation of water, we have used the oil as intermediate fluid. The level liquid indicator and sensor were used to control the heating processes. The control of the temperature water supplying the jet is ensured by the electronic thermostat and sensor assemblage.

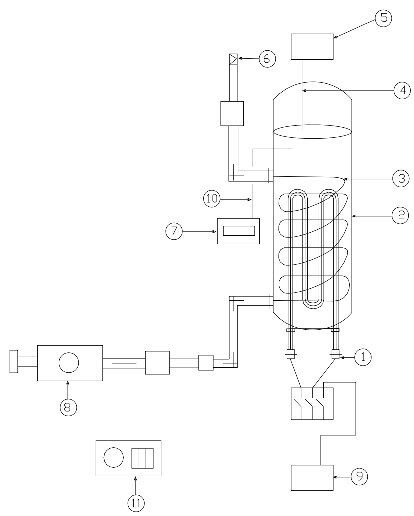

Fig. 4. Experimental layout
1 – electrical resistance; 2 – oil tank; 3 – water coil; 4 – water level indicator; 5 – water level sensor; 6 – water coil nozzle ; 7 – electronic thermostat; 8 - water flowmeter; 9 - electrical current contour; 10 – thermostat control sensor; 11 – electrical control panel

Another important equipment of the test layout is represented by the nozzle with a swirl chamber. The swirl device, shown in the figure 5 has the function to create the vortex in liquid before that be pushed out through the nozzle orifice. On this way a short length of the liquid jet is obtained and a breaking jet is realised in a small droplets.

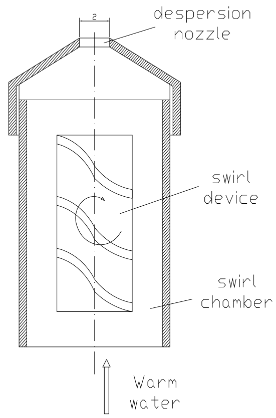

Fig. 5. Water dispersion nozzle with swirl device

The figures 6 and 7 display the views of the experimental core equipment.

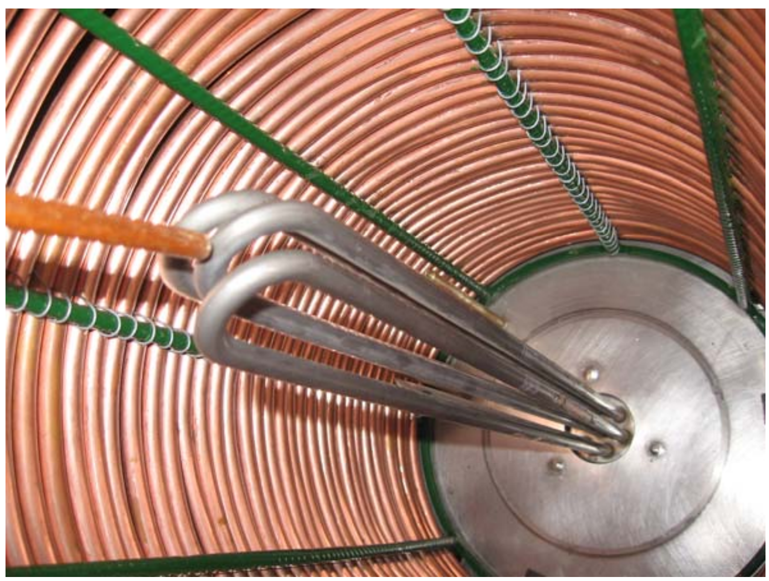

Fig. 6. View of the oil heater with the electrical resistance and water cooper coil

Fig. 7. View of the nozzle assembly water atomizer

Based on the above considerations, we have tested on the experimental plant the two phase jet which is sprayed in the air with a reduced relative humidity. The liquid temperature at the discharge head of the nozzle was modified in aim to put in evidence its influence on the droplet dimension and on the evaporation rate. The exit nozzle diameter is 2 mm and the liquid water pressure is of 3,4 bar. The first test set was realised with the liquid of 13°C. From the picture shown in the figure 8 we observe that the jet form is the conical one and at its boundary is formed by the visible liquid droplets (a lot of droplet diameters in the range of 0,1 to 1 mm). Due of the low rate of the liquid evaporation at this temperature the big diameters of the droplet result. For the same geometrical arrangement of the plant and for the other feed liquid temperature the tests were done. The figures 9 and 10 show the two phase jet development for the liquid temperature of 20°C and 40°C.

Fig. 8. Liquid jet development at 13°C water temperature

Fig. 9. Free two phase jet at 20 °C

We observe that by increasing the liquid temperature the droplet dimension diminishes. On the other hand, the evaporation rate increases as we may see from these pictures. These tests provide us some information for the adequate parameters choice of the jet equipment when the two phase jet is used for the flame extinguish.


Fig. 10. Two phase jet at 40°C water temperature

Another set of experiments was made using burner with the butane flame. The picture from the figure 11 shows the fact that the flame disappeared at the conical limit of the two phase jet. This means that the flame existing conditions inside the conical volume of the jet are not present.


Fig. 11. Flame behaviour at the contact with the two-phase jet

The cloudiness, especially at the liquid temperature of 40°C, shows us that due to the high evaporation rate the relative humidity around the jet boundary increases and the saturation condition is reached. On the other hand, by increasing the evaporation rate, the partial vapour pressure in the surrounding rises, and consequently, the oxygen concentration reduces. This phenomenon occurs probably, due to the fact that the surrounding humidity rise by the liquid evaporation, and consequently, the flame temperature reduces. On the other hand, due to fact that the volumetric water vapour rate rises, a significant reduction of the oxygen concentration appears. These two processes, which occur simultaneously, led at flame extinguish at the jet boundary.

4. Conclusions

The present study provides information concerning the liquid temperature influence of the jet dispersion and structure.

The life time of the droplets in function of liquid discharge parameters and of the surrounding humidity and temperature was displayed.

It has been shown that the liquid spray evaporates in the contact with the surrounding, changing the gas mixture concentration. This fact generates a reduction of the temperature below the flame stability, due to the heat absorption for the liquid evaporation. By increasing the vapour concentration in a gaseous phase, the oxygen concentration diminishes. Consequently, the flame failure occurs.

The reasons which lead to the experimental conception of the stand test were described.

The application techniques using a swirl device for the liquid jet breaking, combined with the preheated liquid which provides the fog, the extinguish performance enhancement of a butane flame is realised.

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