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EXPERIMENTAL ASPECTS IN TWO-PHASE JET IN INTERACTION WITH THE FLAME

BY

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Abstract. During the experimental test made on two-phase free jet, the specialized data acquisition equipment for direct measurement and thermal camera were used. Therefore the temperature field values and spectrum were obtained using the two described methods. The interference at the jet-flame boundary and the extinguish process by the warm water is verified. The experimental data and images are displayed in the paper. The pre-heating of liquid water allows a dispersion of that in fine droplets which gives a short time of evaporation, so high heat absorption, that causes an efficient flame extinguish. Using the warm water and an adequate nozzle dimension, a small quantity of water is used, and the damages are reduced.

Keywords: mist jet; infrared image; droplet lifetime; flame extinguish.

1. Introduction

Starting with the eighties, including Montreal Protocol in 1987, researchers looked for clean methods to extinguish fires, as an alternative to

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halons (polluting fire extinguishing agents). A lot of the researches nowadays seek on reducing the droplet size, increasing thus the heat transfer surface, that leads to a quicker fire cooling and suppression (Liu and Kim, 2000, 2001; Beihua and Guangxuan, 2009). Very modest attention was given by researchers at the influence of extinguishing agent temperature.

Concerning the domain of droplets size and its influence on the efficient fire suppression the studies done by (Andersson *et al*., 1996; Santangelo and Tartarini, 2010; Kumari *et al.*, 2010; Chisacof *et al*., 2009-2011), are relevant. The experimental tests start from the premise that the warm water evaporates quickly, and will cool the fire in a shorter time than cold water. As fire suppression takes place faster, the amount of water used will be less and therefore, the collateral damage will be reduced. If warm water temperature will be used, suppression will occur earlier in comparison to the cold water mist.

It is well known that surface tension and the dynamic viscosity of liquid water decrease with the temperature. For the jet fluid atomisation the surface tension play an essential role. Based on data of water obtained from international tables (IAPWS-IF97, 2008), the evolution of surface tension with the temperature is presented in the Fig. 1 (Popa *et al.*, 2012). Regarding this surface tension variation we can see that there is a visible change in the slope around the temperature of 35°C - 40°C. The regression functions of the two zones are presented in Fig. 1.

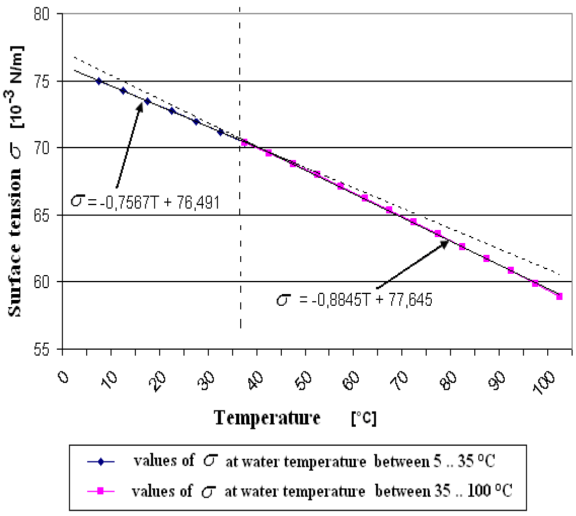


Fig. 1 − Surface tension of water versus temperature.

Other important parameters are the mean diameter range of the droplets and their lifetime in function of the liquid temperature. Fig. 2 presents the theoretical evaluation of these versus temperature (Pavel, 2009).

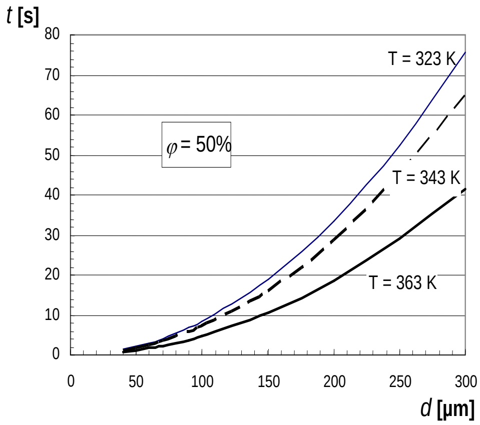


Fig. 2 − Life time versus size droplet at some temperatures.

Based on the above results, the authors chosen a range of temperatures that include the 30°C - 40°C interval. Water with these temperatures (13, 30 and 40°C), was used in different fire suppression tests, and the results were compared in order to obtain a domain which can be taken into account by designers for fixed water mist fire suppression systems.

2. Experimental Results

In aim to do the experimental tests we used the enhanced layout based on the experimental plant provided by (Pavel, 2009; Panaitescu *et al.*, 2012). The shape of the warm water spray realized by a 0.6 mm diameter nozzle and 30°C is presented on the Fig. 3. The abundance of wet vapour is observed in special at a height above 20 cm from the nozzle exit.

The temperature values from different heights and the distance from the nozzle axis is displayed on the Fig. 4. From this figure we examine the temperature field temperature on the jet envelope. Due to the variation of the emissivity factor in different jet vertical section the values must by corrected. Unfortunately the correction cannot be realized by the camera software and the information is only a qualitative one. Therefore, a direct contact measurement is recommended (Chisacof *et al.*, 2011)

The direct measurement of some points from the jet was made with thermocouples type K and the data acquisition system. From the Fig. 5, where the values were displayed, we note that the temperature in the same plane with the nozzle discharge becomes to have an important variation up to 25 cm around the jet axis ($z = 0$).

That means that suddenly, at the exit from the nozzle the evaporation of the warm liquid is important. The enlargement of the temperature field at this level may be due of the wet vapor generated at different heights. So, the liquid density being higher than the air, the droplets fall due to gravitational field. From the Fig. 5 we observe for the heights above 25 cm the temperature variation becomes smaller, the difference being under 5 K.

Fig. 3 − Mist jet of warm water.

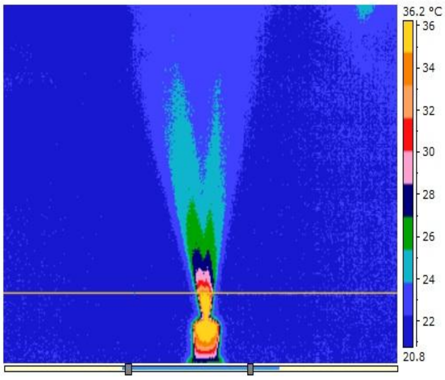


Fig. 4 − Infrared image of the warm mist jet.

This effect occurs due of the heat absorption from the surrounding, which has as the effect the jet cooling. Also, an enlargement of the variation temperature on the horizontal plane with the height is observed. From the Fig. 4 it is observed that the temperature falls in the first 50 cm from the exit nozzle.

Heat absorption potential of the jet, was evaluated using the experimental data at various inlet liquid temperatures for 0.6 mm nozzle diameter. In the analyzed case we present the droplet dispersion from a nozzle of 0.6 mm diameter for two temperatures 30°C. We observe that in the nozzle discharge plane the temperature becomes have an important variation from the 25 cm around the jet axis ($z = 0$). That means that suddenly, at the exit from the nozzle the evaporation of the warm liquid is important.

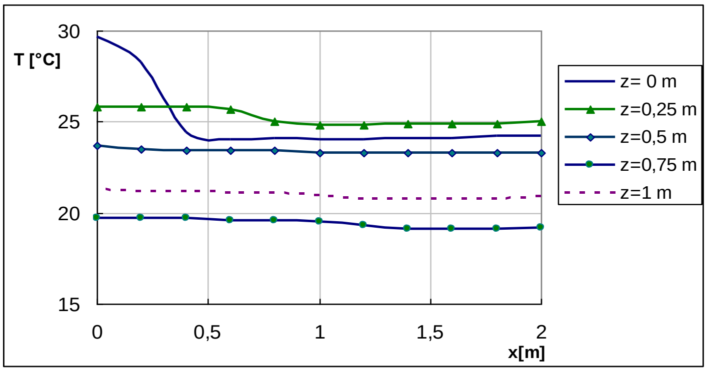
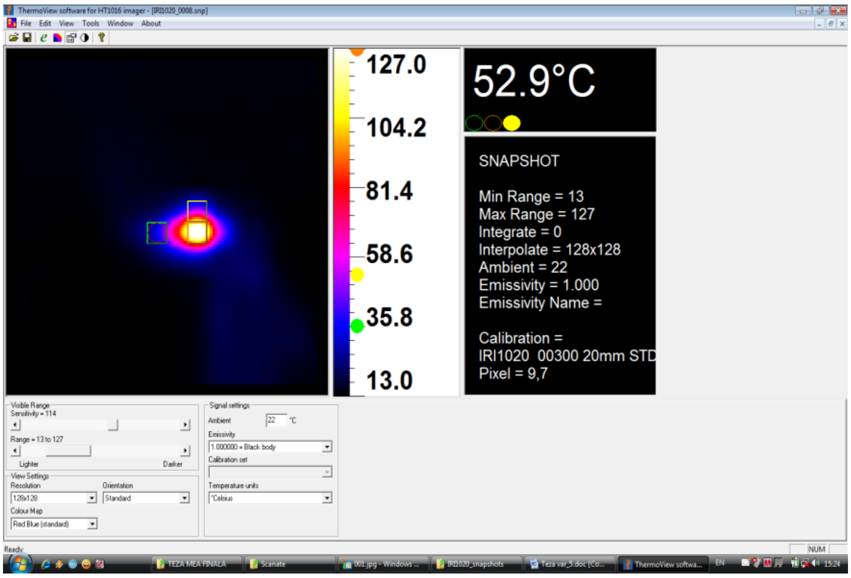


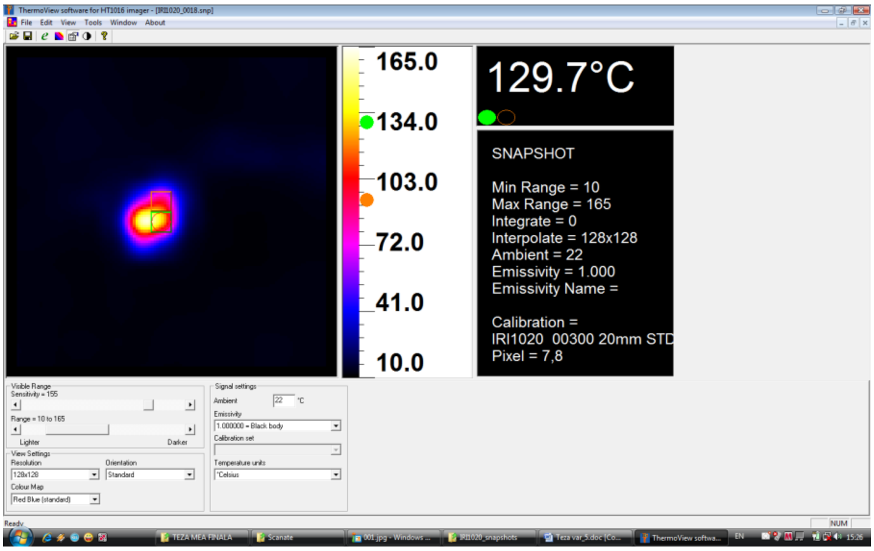
Fig. 5 − Temperature evolution in two phase jet (water inlet temperature 30°C).

The enlargement of the temperature field at this level may be due of the wet phase generated at different heights. So, the liquid density being higher than the air, the droplets fall due to gravitational field. From the same figure we observe for the heights above 25 cm the temperature variation becomes smaller, the difference being under 5 K.

The phenomena visualisation was made with the thermal camera HT 1016. The corresponding images are shown on the Fig. 6. From these images the infrared spectrum of temperature values is displayed on the right band. The flame core is reduced and the environmental temperature around 22°C is dominant (Fig. 6 *a*). The dark blue around the flame represents the water mist dispersed through a nozzle at 30°C. The incidence between the water mist and the flame has as result the flame reduction up to it is extinguished (Fig. 6 *a*). The same experience realised with the mist jet temperature of 13°C, shows us that the rate of flame reduction is lower than in the first case (Fig. 6 *b*). That is due the fact that the rate liquid evaporation is reduced, and consequently, the vapour concentration is weak and the oxygen molar fraction is beyond the low inflammability limit of the concerned fuel. Therefore the combustion time is greater than in the first case. Fig. 6 *c* shows the temperature at the boundary between the butane flame and the jet mist envelope. Due of the reduction of the oxygen concentration in the jet by water pre evaporation, combined with the heat absorption by the vaporized water, the flame cannot penetrate practically in the jet, only in a limited depth.



a



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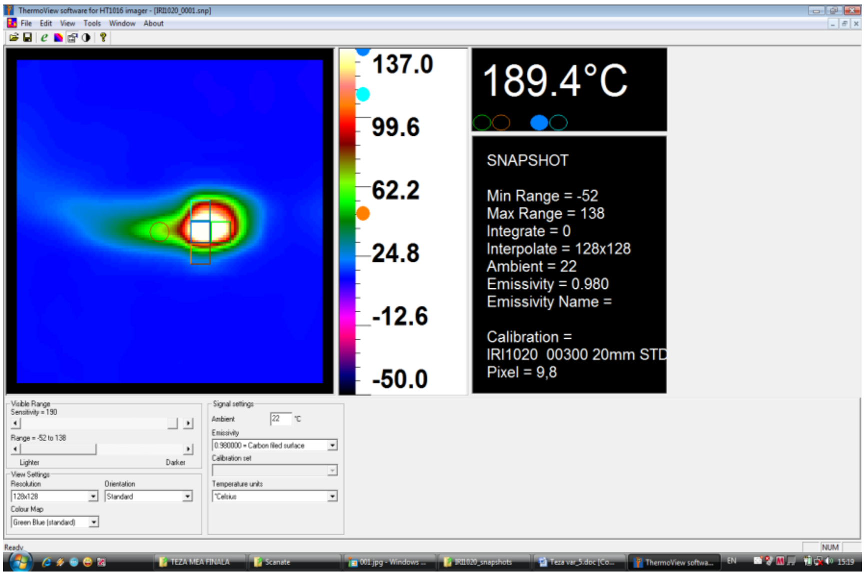

c

Fig. 6 – Infrared images at the mist jet – flame contact (thermal camera type HT 101).

Based on this observation we may conclude that the improvement of extinguish efficiency is realised with a warm jet mist, having at the nozzle exit the temperature of 30°C. Our experiments show that in the butane case this temperature gives a shorter time extinguish interval. The explanation of this process is based on the fact that the pre evaporation fraction of liquid water is relatively reduced and the latent heat absorption by the flame is quiet sufficient for the flame extinguish. If the 13°C is used the initial evaporation is negligible.

In this sense must precise that thermophysical properties of water have an important role, especially the surface tension and the dynamic viscosity that decreases, which allows a shorter time of evaporation.

Our experiences with butane fuel gave the initial water temperature of 30°C as an appropriate one. The air concentration for the flame sustainability is in the range from 1.9-8.5% air fuel ratio (Sarlos *et al.*, 2003). By using the other fuels the mist temperature must be experienced.

3. Conclusions

1. The present study provides practical information concerning the liquid temperature influence of the jet dispersion and structure. The life time evolution of the droplets in function of the liquid temperature, diameters are shown. The case study analysis gives us the jet cone shape, its amplitude in function of the liquid temperature and the surrounding properties.

2. The experimental results illustrate that the warm liquid plays an important role in overall evaporation process: the droplet size and lifetime, jet boundary layer respectively. The measurement made in two modes, by direct contact and by infrared distance image capture are complementary, each of them giving the temperature values in the jet cone and on its boundary. The infrared pictures taken on the fire jet junction, allows us to evaluate the influence of the water temperature at nozzle exit. The impact of the water mist concerning the extinguish performance was applied on the butane flame.

3. The droplets distribution in the jet cone may furnish the place with the high values of heat absorption and consequently, the zone with an efficient fire extinguish. This fact generates a decrease of the temperature below the flame stability and an oxygen concentration reduction. Consequently, the flame failure may occur. The liquid rate for the extinguish process is reduced and the damages are limited.

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ASPECTE EXPERIMENTALE ÎN JETURI BIFAZICE, ÎN INCIDENŢA CU FLACĂRA

(Rezumat)

Pe parcursul realizării experimentelor în jeturile bifazice s-au folosit aparate performante cu achiziţie de date, inclusiv o termocameră în infraroşu. Se obţin astfel, în spectrul infraroşu prin nuanţe de culori, gradienţii de temperatură, precum şi valorile aferente. Impactul între apa rece şi flacără, datorită duratei foarte scurte de interacţiune, nu permite evaporarea rapidă a lichidului, acesta fiind folosit în mică măsură, restul fiind pierdut. Din contra la injecţia apei preîncălzite, evaporarea este mult mai abundentă, iar stingerea flăcărilor de combustibil gazos devine mai eficientă. Prin folosirea apei calde şi a unui ajutaj de dispersie de dimensiuni adecvate, consumul de agent de stingere este redus, iar deteriorările colaterale se reduc.