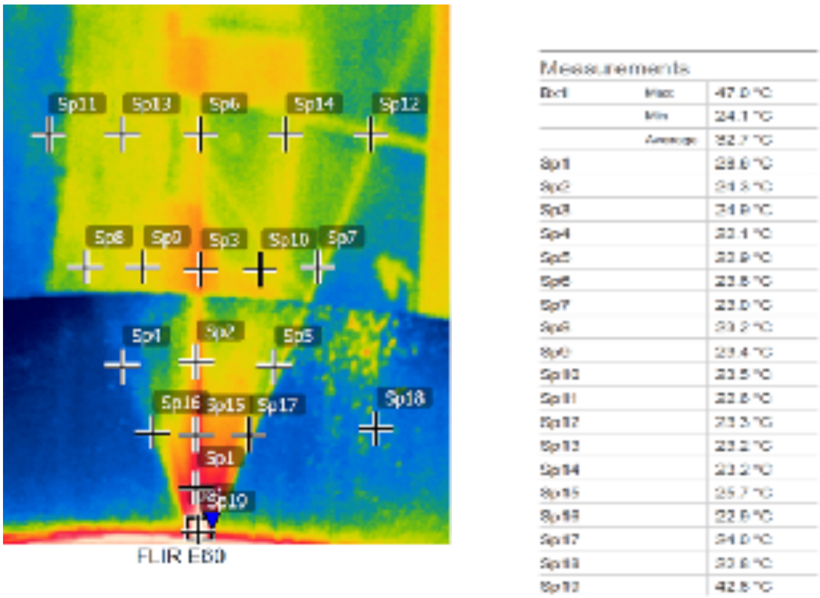

Figure 5: The mist jet cone supplied by the liquid at 52°C

a) Infrared image; b) temperature table

The cloudiness, especially at the liquid temperature of 50°C, shows that due to the high evaporation rate the relative humidity around and, in the jet, increases and the saturation conditions are reached. On the other hand, by growing the evaporation rate, the partial vapour pressure in the jet volume rises, and consequently, the oxygen concentration reduces.

The temperature values are indicated on table from figure 5. We observe that on the vertical axes the temperature is greater that on the horizontal axes at the same level. On the figure 6 the axial temperature evolution for the two cases are displayed. On the other hand, the decreasing in temperature for the 52°C temperature at the nozzle exit, at certain height is more accented than for the jet outgoing at 41°C. That means that the temperature decrease rate is more important for the higher exit temperature, so the saturation of the concerned volume in water vapor increases rapidly for the higher exit temperature.

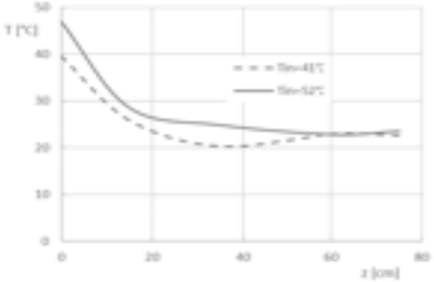

Figure 6 Temperature evolution in the jet axis

## 2 – Heat balance of the analysed extinguish system

The experimental layout allows us to realise a heat balance of the system. The representative equation of the heat balance is:

$$\dot{V}_{fN} \, H_s = \dot{m}_l \left( h_v - h_l \right) \cong \dot{m}_l \, l_v \tag{1}$$

where: $\dot{V}_{fN}$ is the fuel gas in $\mathrm{m_N^3/s}$, measured with the gas flowmeter and corrected in function of the gas temperature and pressure according with the manual instruction [10]; $H_s$ is the higher heating value of the fuel, in kJ/$\mathrm{m}^3_{\mathrm{N}}$ ; $\dot{m}_l$ represents the water mass flow rate effectively evaporated, in kg/s; $h_v$ – specific enthalpy of the generated vapour in the mixture, kJ/kg; $h_l$ – specific enthalpy of liquids at the nozzle exit, in kJ/kg; $l_v$ is the heat of vaporisation of water, in kJ/kg.

In the above equation we used the higher heating value of fuel, because in contact with the liquid phase the vapour born by the combustion process, in contact with the liquid droplets is considered in liquid phase. This phenomenon is supposed to take place, in the case when the final temperature of gases after the flame extinguish, is practically an environmental temperature before the flame ignition. The mass flowrate of the liquid used for the flame extinguish is calculate from the equation 1, using the thermal properties of water and the fuel flowrate consumption $\dot{V}_N$ [11, 12].

At the exit of the nozzle the mass water flowrate $\dot{m}_w$ is measured with the Coriolis equipment. This mass flowrate differs of the mass flowrate $\dot{m}_l$ calculated with the equation 1, because not all this flowrate is used in the flame extinguish, and only a part of this. We may define the mass efficiency of liquid use for the flame extinguish as a ratio between the mentioned mass flowrates:

$$\varepsilon_{fe} = \frac{\dot{m}_l}{\dot{m}_w} \tag{2}$$

Concerning the heat capacity of the liquid water absorption, the heat flowrate theoretically possible to be captured by the $\dot{m}_w$ flowrate is:

$$\dot{Q}_{t\,abs} = \dot{m}_w \left(h_v - h_l\right) \cong \dot{m}_w\, l_v \tag{3}$$

The real heat flowrate is obtained with the effective use of water:

$$\dot{Q}_{r\,abs} = \dot{m}_l \left(h_v - h_l\right) \cong \dot{m}_l\, l_v \tag{4}$$

The ratio between the two heat flowrate represents the thermal efficiency of liquid use, expressed as:

$$\eta_{te} = \frac{\dot{V}_{fN}\, H_s}{\dot{m}_w \left(h_v - h_l\right)} = \varepsilon_{fe} \tag{2'}$$

where the rel. 1 was used. From the relations 1, 3 and 4 practically the same expression of the mass efficiency of liquid and the thermal efficiency for the flame extinguish results (eq. 2).

Because the liquid is heated a supplementary heat flux is necessary for this scope. The heat flux necessary for this scope is:

$$\dot{Q}_{pr\,l} = \dot{m}_w \left(h_{l\,ex} - h_{l\,in}\right) \tag{5}$$

where $h_{l\,ex}, h_{l\,in}$ are the liquid enthalpies at the exit and at the inlet in the water heater 7 (fig. 1).

We define also the thermal power of flame as:

$$\dot{Q}_{t\,fl} = \frac{\dot{V}_{fN}\, H_s}{60} 10^{-3} \qquad \text{[kW]} \qquad (6)$$

with $H_s$ in kJ/m$_N^3$, and $\dot{V}_{fN}$ in dm$^3$ $_N$/min. Consequently, the thermal efficiency becomes:

$$\eta_{t\,e} = \frac{\dot{Q}_{t\,fl}}{\dot{m}_w \left(h_v - h_l\right)} = \frac{\dot{V}_{fN}\, H_s\ 10^{-3}/60}{\dot{m}_w \left(h_v - h_l\right)} \qquad (2'')$$

The effective thermal efficiency of liquid use may be defined as:

$$\eta_{t\,eff} = \frac{\dot{V}_{fN}\, H_s}{\dot{m}_w \left(h_v - h_l\right) + Q_{pr\,l}} = \frac{\dot{V}_{fN}\, H_s}{\dot{m}_w \left[\left(h_v - h_l\right) + \left(h_{l\,ex} - h_{l\,in}\right)\right]} \qquad (7)$$

Using our experimental data, some results applying this model are displayed in the table 1.

Heat balance characteristics of the two phase jet and butane flame Table 1

| Measured parameters | | Calculated quantities | | | |
|---|---|---|---|---|---|
| $\dot{m}_w$ [kg/min] | $\dot{V}_f$ [dm$^3$/min] *at 20°C, p=750 mm Hg | $\dot{V}_{fN}$ [dm$^3$$_N$/min] | $\dot{Q}_{t\,fl}$ [kW] | $\dot{m}_l$ [kg/min] | $\eta_{t\,ef} = \varepsilon_{fe}$ |
| 0,94 | 4,5 | 3,35 | 7,09 | 0,170 | 0,18 |
| 1,24 | 5 | 3,70 | 7,88 | 0,189 | 0,15 |
| 1,483 | 8,2 | 6,06 | 12,92 | 0,310 | 0,21 |
| 1,61 | 9,4 | 6,95 | 14,82 | 0,355 | 0,22 |
| 1,85 | 12,4 | 9,16 | 19,55 | 0,469 | 0,25 |

* the flowmeter used was calibrated for 23°C and 760 mmHg, the correction coefficient for butane, according to the apparatus guide, is 0,812 [10].

The used fuel is butane with the higher heating value $H_s = 128\ 000\,\mathrm{kJ/m_N^3}$ [12]. For the heat absorption we bring the heat of vaporisation of water at triple point $l_v$= 2501 kJ/kg [11]. This point is a reference one for the moist air at 760 mm Hg. The superheated heat of vapour up to the environmental temperature is negligible.

We note that the thermal efficiency of liquid use is reduced, consequently, an important liquid quantity is unused, and the damage produce increases.

**Conclusions**

The paper put in evidence the importance of the temperature and the nozzle shape of a extinguish system supplied by an warm liquid having the town layout pressure in the range of 4-5 bar over the atmospheric pressure. So, it is not necessary a supplementary energy for water pump.

The adequate details of the nozzle system is required in aim to improve the fineness of the liquid particles in the jet, and also for the jet flared. This characteristic allows to have a good efficiency in fire extinguish. The Coanda effect is important in the jet flared.

The use of thermal extinguish efficiency was proposed. A high rate of fluid is unused with the important negative consequences. This may represent an important parameter for the system exploitation.

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