EXPERIMENTAL CLEAN ETHANOL POOL FIRE SUPPRESSION BY USING WARM WATER MIST

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The present work tries to clarify by experimental results, some phenomenological aspects concerning the use of water mist jet of different temperature for the liquid fuel fire suppression. In order to study the effectiveness of the suppression of an ethanol pool fire with one water mist nozzle, a series of experiments were conducted under different conditions in a closed space. The water temperature generating water mist ranged from 15 °C to 30 and 40 °C. The temperatures graphics in three points situated above the flame at different heights, throughout all the 15 fire suppression tests, allowed the authors to present findings concerning different effects and limitation of suppression, for each temperature (15, 30 and 40 °C). Due of its behaviour, the water mist systems are now used including in electrical zones.

1. INTRODUCTION

Starting with the eighties (including Montreal Protocol in 1987) researchers searched for clean methods to extinguish fires, as an alternative to halons (environment polluting fire extinguishing agents). In a lot of the researches starting backthen to nowadays, emphasis was placed on reducing droplet size, increasing thus the heat transfer surface, that leads to a quicker fire cooling and suppression, [1, 2, 3]. Also, some attention was paid to the use of various additives [4]. Very little attention was paid by researchers at the temperature of the extinguishing agent (water that generates mist) on fire suppression. Therefore, this paper aims to present original findings of the authors – they obtained information on the influence of the temperature of suppression agent (water generating water mist), on the suppression efficiency.

Sprays have been employed in the field of fire control and suppression for many years and water has been the most employed fluid. Water mist plays its role

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in a strong direct action in fire suppression. Also a reduced quantity of fluid is required for fire suppression, the residual damage diminishes. Water mist brings a *low quantity* of stored water needs, with respect to traditional sprinkler. Due of this fact the application in naval and even in aerospace area may be exploited [5, 6, 7].

Since ethanol is increasingly used as a clean fuel, one can imagine that in the future it will be used more and more and the deposits of ethanol will need to benefit of the best type of fixed fire protection systems possible [5, 8].

Experiments have shown that boil-over or spillage is not present when water mist is discharged into the burning oil at high temperature (greater than 300 °C), [9]. The same authors (Santangelo and Tartarini, 2010) have also carried out an experimental and theoretical research on portable water-mist systems with respect to a variety of fire scenarios. Among these latter, flammable liquids, cooking oil and wood cribs stand as the most interesting applications. Different portable extinguishers have been developed to the purpose and generally good effectiveness has been achieved in suppression and extinguishment, provided that suitable water-flux density and spray momentum are imposed [9]. A recent interest in water-mist systems has been shown for fire protection in tunnels. This application represents a real challenge in terms of harms and damages [6].

However, for the presented situation, extinction is successfully achieved in an enclosure of 9 m³ for water-flow rates as small as 10 litres per minute [8].

### 2. PARTICULAR PROPERTIES OF WATER DROPLETS

The surface tension and the dynamic viscosity of liquid water decrease with the temperature, [10, 11, 12, 13]. For the jet fluid atomisation the surface tension plays an essential role. Based on water data obtained from international tables [14], the evolution of surface tension with the temperature is presented in the Fig. 1. Reginind this variation, we can see a visible change in the slope angle (a break of the line), around the temperature of 35°C–40°C (Fig. 1).

Based on the above finding, the authors choses a range of temperatures including the 35°C–40°C interval. Water with these temperatures (15, 30 and 40 °C), was used in different fire suppression tests, and the results were compared in order to obtain a set of rules to be taken into account by designers of fixed water mist fire suppression systems. In experimental tests below, one starts from the premise that warm water evaporates quickly, cooling the fire in a shorter time than cold water.
As fire suppression takes place faster, less water will be used reducing the collateral damage. If warm water temperature is used, suppression occurs earlier, the temperature values of the fire are smaller and less damage results, in comparison to conventional water mist [15, 16, 17].

3. EXPERIMENTAL SETUP AND DATA

A number of 15 suppression tests were performed. The conditions of all tests were similar, only the temperature of water generating the water mist was different. Fig. 2 presents the design of the test room. Pressure of fire extinguishing agent is 120 bar, the volume of the fire enclosure is 8.95 m³, dimensions are as in Fig. 2. Direction of the water mist jet is horizontally placed and not vertically, because of the need of interaction time between water mist drops and flame (in terms of temperature measurements). Fig. 3 displays the ethanol pan and the flames at the liquid surface. The fire was set on an ethanol pan of 30 × 40 cm, containing 1 liter of combustible.
The thermocouples situated on the centerline of the ethanol pan fire, at three different elevations (see explanations at Fig. 2) gave detailed temperature graphics, by using computer data acquisition [17]. As there were five different tests for every
water temperature, an average of parameters values was made for each temperature, to have reliable data.

Fig. 4 presents the temperature evolution in time, at different levels, for each initial temperature of water. Roughly, we observe that the maximum temperature of the flame, at the height of 20 cm, is obtained for the cold water of 15 °C. For the same level, the smaller flame temperature is obtained for the warm water of 40 °C. On the same figure, we observe that the group of curves at 180 cm level, are located in the temperature interval of 65–95 °C. The curve corresponding to initial water temperature of 40 °C, is situated above the other two. That means that the partial pressure vapors is important and consequently the oxygen concentration decreases. In accordance with the steam tables, the partial pressure of water vapor is 0.25 bar, that means that dry air pressure is 0.75 bar, and the oxygen concentration is 15.7 %. The same oxygen concentration decreases at 3.23 % for 95 °C at 180 cm height. It is well known that the ignition oxygen concentration is 14 % for the ethanol vapour [18], so practically we are situated below this concentration, which means that the conditions for the flame existence vanishes.

On the same figure we observe that at the same initial water temperature the maximum value of temperature at a certain level, is obtained at a certain time. As, for the initial water temperature of 40 °C, at 180 cm height, the temperature range from 95 to 100 °C, has a time interval around 10 seconds, starting from second 7.

Fig. 3 – Images taken during tests. From left to right: ethanol pan fire before the water mist discharge, and during the water mist discharge.

In the range of mentioned temperatures, the mean pressure of vapor is situated around 0.9 bar, the correspondent oxygen concentration is 2.1 %, thus any burning stops. This is a very important effect of the warm water use as a suppression agent.
For the other two tested water initial temperatures, which are smaller than 40 °C, we observe in Fig. 4 that the temperature values at the same level of 180 cm, are below 70 °C and the flame stability may continue involving negative damages.

We note that the results apply to conditions under which experiments were carried out for the considered time interval.

![Fig. 4 – Average temperatures obtained from the 15 fire suppression experiments.](image)

**4. RESULTS AND DISCUSSIONS**

The following Figs. 5 and 6 present the comparison between the curves, separately grouped three by three, depending on the position of the thermocouples: 20 cm (Fig. 5), 100 cm (Fig. 6). Also, all these figures contain the regression temperature function for each level. Fig. 5 displays the linear regression equations for the three experimental obtained curves, having a linear form:

\[ T = a + b \cdot t, \]  

where \( T \) is the temperature in °C and \( t \) is time in seconds. The values of regression coefficients are displayed on Fig. 5. It is also observed in Fig. 5 that the curve values for temperatures of 30 °C and 15°C hit at the first second, values close to 200 °C and one of them (M – 20 cm – 15 °C) reaches to about 265 °C and the other
one (M – 20 cm – 30 °C) to about 248 °C. To obtain accurate values at the point of maximum difference on the graphic, 39 seconds (t axis), one needs to replace t in the two equations of the respective linear regression, with the value 39. For M – 20 cm – 15 °C is obtained \( T = 267.65 \) °C and for M – 20 cm – 30 °C is obtained \( T = 248.01 \) °C. The result is a maximum difference between the two curves of 7.33%. Therefore, using a temperature of 30 °C to create water mist, will lead to a temperature of the environment reduced by 7.33%, in comparison to the temperature of 15 °C (M – 20 cm – 15 °C). As the tests were not performed in the same initial temperature, the claimed values are arbitrary, given the conditions.

Fig. 5 – Experimental medium temperature values for the thermocouple placed at 20 cm elevation.

For the thermocouple in elevation 100 cm (Fig. 6), the polynomial regressions have the following form (in order for temperatures of 15, 30 and 40 °C):

\[ T = a + bt + ct^2 + dt^3. \]  

(2)

As the starting point for the two polynomial regressions are closer one to each other, in the following, one will compair the values M – 100 cm – 15 °C and M – 100 cm – 30 °C, at second number 31. For M – 100 cm – 15 °C one obtains \( T = 64.49 \) °C and for M – 100 cm – 30 °C, \( T = 59.89 \) °C. The result is a maximum difference between the two curves, of 7.12%. Therefore, the use of 30 °C temperature water to create water mist, will lead to a 7.12% drop of temperature, in comparison with the use of water at 15 °C (M – 100 cm – 15 °C).

After a similar analysis, for the height of 180 cm thermocouple, it results that by using warm water, the combustion conditions are no longer fulfilled.
From the above analysis, based on the experimental data plotted on Figs 4-6, in function of period of time, height and under the considered conditions, result the following:

- the temperature at 100 cm elevation above the fire pan remains approximately constant at a value of 61 °C for water mist generated with water at 15 °C;
- the temperature values, at 100 cm elevation, for water mist at 30 °C, maintains close to the value of 65 °C;
- the temperature values, at 100 cm elevation, for water mist at 40 °C remained constant around 70 °C throughout the graphic;
- the temperature at 180 cm elevation above the fire pan for all three cases has a sinuous value, with many intersecting, but on average we can say that the results obtained in terms of suppression efficiency, are increasingly in the following order: water mist at 40, 30, 15 °C;

Also, in the case of 20 cm elevation above the fire pan, the order is reversed, meaning that water mist at 15 °C has a smaller suppression efficiency than the other two values.

From our observations it results that the maximum suppression effect is given by water mist at 40 °C, but in the second half of the interval, maximum suppression effect it given by water mist generated by water at 30 °C temperature.
5. CONCLUSIONS

From the above analysis were found the associations between water temperatures, used to create water mist and the effectiveness of fire suppression as:

– overall, for optimal suppression in all three points placed on the height, above the fire pan (20 cm, 100 cm and 180 cm) is preferable to choose the water temperature of 30 °C;
– if a temperature drop is needed at the elevation of 100 cm, it is advisable to use cold water (15 °C);
– for best results in the flames area, at 20 cm elevation, one can use both 40 and 30 °C water mist. The water at 30 °C temperature in the final point of the graph in fig. 4, implies a decrease of 19.6 °C compared to the situation of cold water of 15 °C);
– if a decrease in temperature at 180 cm level is required, it is recommended to use cold water at 15 °C, that is more effective in suppression, than the water at 40 °C.

The experimental results give the fundamental information to develop the proposed system and allow an application for the future ethanol storage system.

The preheat of the liquid agent allows a fine droplet distribution in the jet. This fact allows the enhanced mass and heat transfer processes during the evaporation, and consequently, a short time of action on the fire seat. Also, the protection of the ceiling is ensured due of the high temperature of gas vapour mixture, in this case the vapour dislocates the oxygen.

The described water mist fire suppression system, using a clean agent, is a recommended alternative to other pollutant fire protection system (e.g. halon). In the experimental tests have been employed mainly the modern, precise and sensible thermocuples and hygrometers, using the data acquisition system and the computer.

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