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Heat Transfer between a Pool Fire and Water Mist Droplets in a Compartment

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Abstract – Technical constraints and standard regulations rendered the engines more efficient but also more prone to fire. Sound insulation and higher operating temperature have increased the odds of fires. The threat is especially prevalent in public transport buses and coaches because the maintenance time is kept as low as possible. Water mist could be a device to extinguish starting fires, even in a cluttered compartment. In this preliminary paper, the interaction between water mist droplets and a n-heptane pool fire is studied through the influence of the nozzle operating pressure on the flow characteristics, water mist cooling performance and heat flux reduction.

***Keywords*:** water mist, heat transfer, pool fire, compartment

1. Introduction

Automatic fire suppression systems have become a concerning issue for transport vehicles. For vehicles with high operational demand such as military vehicles, the fire protection of the engine compartment is usually performed using a total flooding gas system [1]. This technology is very effective, safe, and is not affected by the cluttering of compartment to defend. It could be adapted to civilian use on buses and coaches. However, some employed gases like PFAS are expected to be phased out due to environmental concerns.

A water mist uses small droplets of water as the fire suppressant and can be thought as a hybrid technology between traditional sprinklers employed in buildings and total flooding gas systems. The low consumption of water compared to sprinklers opens the case of using the water mist technology to protect the engine and personnel compartment. The interaction between the mist and the fire plume must first be assessed. Perrin et al. showed that Particle Image Velocimetry (PIV) was suitable to measure the velocity fields of a compartment pool fire [2]. The effects of the ventilation has been studied by Brandt et al. in 2013 for engine compartments [3], while the interaction between the water mist and hot air plume has been studied by Zhou in 2015 [4]. It remains to be seen how the interaction between a real pool fire and a water mist can be influenced by the nozzle operating pressure and if it can be captured using a PIV system

In this paper, the influence of the nozzle operating pressure on the water mist performance is studied. The operating pressure of the water mist is varied, allowing the study of water droplets of different diameters and velocities. To characterise the effect of flow structure and the water mist on the heat transfer, we conducted an extensive examination of mean flow characteristics. The analysis was based on PIV measurements, complemented with sensors capturing the temperature and the heat flux. A n-heptane pool fire served as a fire source.

2. Material and methods

The tests were conducted in a full-scale compartment representative of the engine block of a military vehicle. The compartment has a main large window and two side small windows for the deployment of the 2D PIV system. The windows also served for visual feedback of the experiments. The water mist system is composed of a GW M2 nozzle supplied through copper tubes by a Grundfos CRN1S pump. The sprayed solution consisted of simple tap water.

The PIV system from Dantec Dynamics is comprised of a 120 mJ Nd:YAG laser generating a light sheet that is assumed to be uniform. The camera is a HiSense 4M coupled with a synchronizer. The acquisition frequency is 5 Hz while the laser pulse separation time (Δt) is set to 100 µs. The acquisition window is 40 x 40 cm and is located 50 cm above the pool fire. The air around the flame has been sown using a mist machine. The water mist droplets served as tracers during the spray activation.

The fire source consisted of a n-heptane pool fire from a 24 cm diameter cylindrical steel pan. A tree of 15 type-K thermocouples, 1 mm in diameter, ranged from just above the pan to 90 cm above it, right under the nozzle. The nozzle is positioned right above the pan. Heat flux sensors were positioned nearby the nozzle, slightly offset 20 cm on the left, pointing downwards. The pool fire was lit and left burning for 120 seconds before the water mist was activated for 30 seconds, regardless of whether the fire could be extinguished or not.

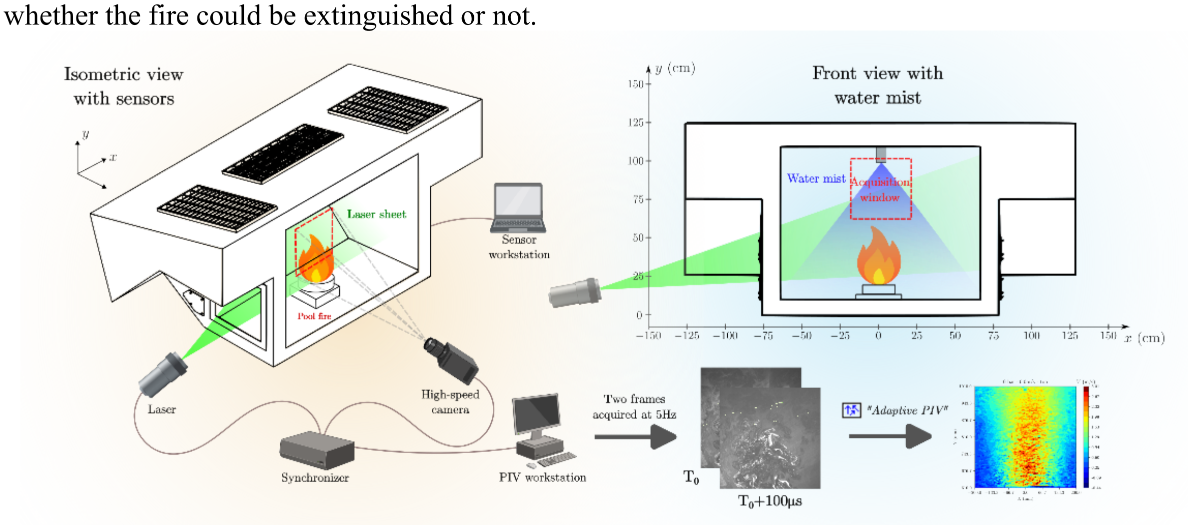

Fig. 1: Scheme of the compartment and acquisition chain.

3. Results and discussion
3.1. Flow characteristics

Figure 2 presents the flow of air and water droplets from PIV measurements. From Figure 2a and Figure 2c, it can be seen that the speed of the entrained air above the flame is quite low, at around 2 m/s in the middle of the fire plume. Figure 2b shows that the water mist spray cone is not uniform, because droplets velocities are much sharply defined and pronounced on the left side than on the right side. Figure 2c is obtained by tracking the vertical component of either the fire plume or the droplets' velocity along the central axis, highlighted by a dashed line on Figure 2a and 2b. The droplets are quickly decelerating after they leave the nozzle, independently of the operating pressure. There are two concurrent explanation to this phenomenon. The momentum of the droplets is opposed to the momentum of the fire plume. Second and more importantly, the droplets are quickly evaporating due to the high temperature of the fire plume. The average temperature one second before the spray is activated is 215°C just below the nozzle and 643°C just above the pan. The evaporation of the droplet reinforces the loss of momentum from the already light droplets. The peak velocity if similar for 3 and 7 bar operating pressure, respectively -13.5 m/s and -13.8 m/s while the peak velocity for the pressure of 12 bar is -24.5 m/s.

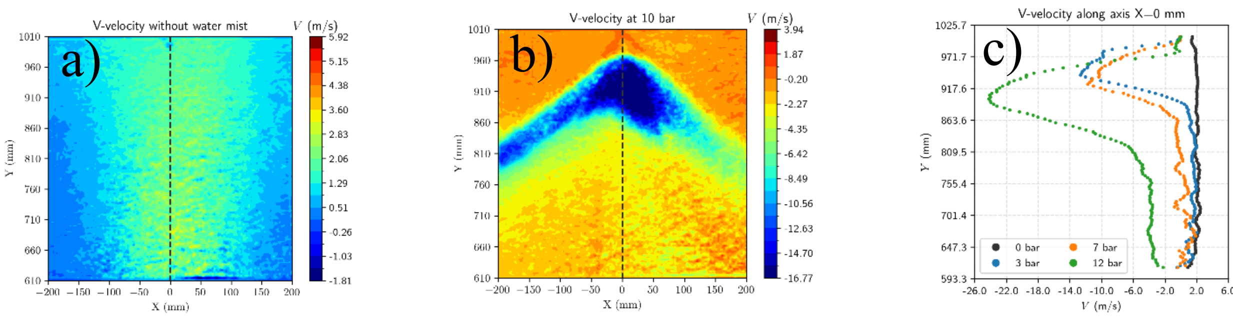

Fig. 2: Flow characteristics a) without water mist b) during water mist activation at 10 bar and c) comparison of spray velocities

3.2 Water mist cooling performance

The cooling performance of the water mist can be studied using the heating rate, which the derivative of the temperature with respect to time. The values have been averaged by a moving window algorithm. On the Figure 3, the heating rate is initially increasing as a result of the ignition and the fire growth. 30 seconds after ignition, the temperature stabilizes at around 750°C. At 120 seconds, the water mist is activated (dashed line on Fig. 3, Fig. 4a and Fig. 4b). This translates into a sharp drop in the heating rate, corresponding to the cooling and extinction of the flame. The drop is observed for the 12 bar case, because this is the only case where the momentum is strong enough to penetrate the flame region and effectively suppress the fire. Following the fire suppression, the temperature ceases to decrease as much and returns to a value closer to ambient.

Around 230 seconds, the same kind of trend is observed for the lower pressure cases as well as the no water mist case (0 bar). It corresponds to the natural extinction of the flame because all the fuel has burnt out. However, one can see that the fire is extinguished quickly for the 7 bar case, followed by the 3 bar and no water mist case. This phenomenon could be due to some water remaining in the pan even though the mist was unable to extinguish the flame. The leftover water is diluting the fuel and make it less flammable. Because the water mist spray penetrates the flame region more at 7 bar than at lower pressure, more leftover water is introduced and the flame is extinguished sooner.

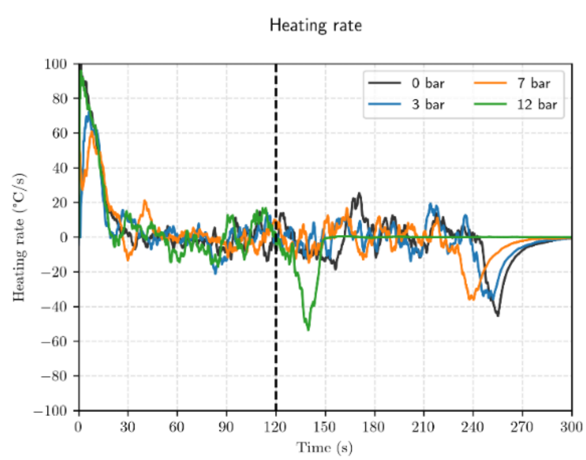

Fig. 3: Heating rate for different pressures. The dashed line corresponds to the activation of the water mist.

3.3. Water mist heat flux reduction

Figure 4 presents the convective (Figure 4a) and radiative heat flux (Figure 4b) for the different water mist operating pressures. After the spray activation, the convective heat flux increases while the radiative heat flux stays constant or decreases. This is explained by the dynamic of the flame during suppression. At higher pressures, the flame is pushed back downward. The hot gases subsequently escape along the plane normal to the spray axis and then rise upward. During this phase, the flame seems to expand greatly as seen on Figure 4c. The flame and water spray are generating a lot of turbulence. The hot gases are being swept near the heat flux at the top and induce and lot of convective transfer. This often undesirable effect can be mitigated using diluent agent such as twin-fluid nitrogen nozzle or chemically reacting additive [5].

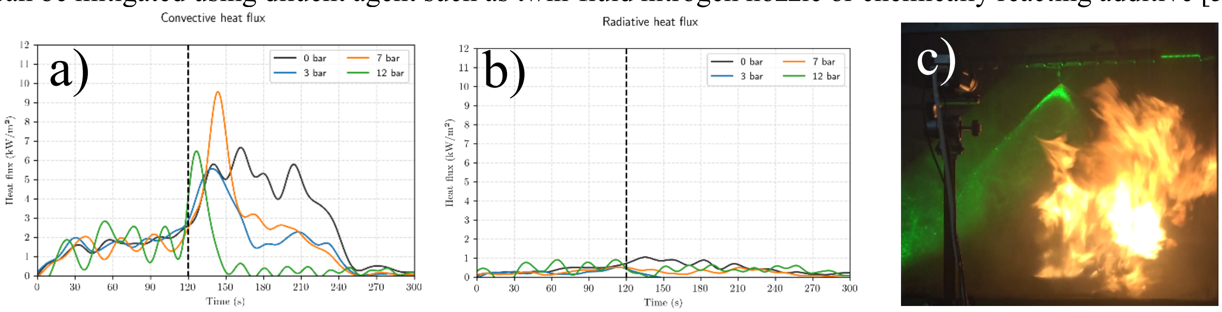

Fig. 4: a) Convective heat flux b) Radiative heat flux c) Flame pushback after water mist activation

4. Conclusion

In the low-pressure water mist setup presently studied, the performance of the water mist is more reliant on the spray momentum to suppress the fire than its ability to smother the flame by oxygen dilution, flame cooling or heat flux reduction. Further tests should be carried out to study whether this technology can effectively suppress fires in the presence of cluttering elements in an engine compartment.

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