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Extinction of gas burner with minimum water flow rate discharge from a water mist

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Abstract. Fire extinguishing systems tend to be optimized by impinging a reduced amount of water, with controlled droplet diameter distribution. This paper investigates the minimum water flow rate required for extinguishing a fire experimentally. A gas burner is placed under a water mist nozzle to expose the fire to a controlled water discharge, gradually increasing the volumetric flow rate injected. The water mist consists of a full cone jet, generated thanks to a single nozzle, with a 100 to 300 μm particle diameter. One of the specific characteristics of water mist is the injection of small particle diameters. Thanks to their high exchange surface between droplets and the ambient, the evaporation rate is increased, which contributes to facilitating fire extinction. The main mechanisms involved in the extinction process are the cooling of the reaction zone and the reduction of the oxygen concentration by putting steam directly in this reaction zone. Some research works were published to correlate the required water flow rate to extinguish a fire but based on small-scale tests, typically with HRR lower than 50 kW. This paper aims to check whether or not these relations can be applied to higher heat release rates and higher flow rates in order to determine the critical water flow rate that extinguishes the fire. A set of normalized parameters have been used to comprehend the extinction phenomenon and to analyse the experimental data. The tendency of averaged results shows a predictable extinction rate and consolidates literature data.

Keywords: *Suppression; evaporation; water mist; burner; scaling.*



1. Introduction

Water mists produce small droplets and often deliver a small water flow rate. They are widely used worldwide for different applications, such as public buildings, tunnels or ships. Water mist can be used following two objectives: controlling or extinguishing the fire. This paper considers only the extinction strategy. In NFPA standards [1], a water mist is defined as a spray for which 99% of “the flow-weighted cumulative volumetric distribution of water droplets is less than 1000 μm ”. Such systems are of great interest compared to other firefighting systems using water (sprinkler) with coarser droplets and higher water volumetric flow rate as only a limited amount of water is needed to extinguish the fire. In Jones & Nolan [2], one of the reasons cited to explain the efficiency of water mist is that, for a given volumetric flow rate, small droplets will be easily evaporated as the surface area between water and fire plume is higher, compared to fewer large droplets. Water mists have shown rapid extinction of flames in Rasbash [3] when placed over a fire with liquid fuel: extinction mechanisms for water sprays are governed by the cooling of the reaction zone, evaporation rate of droplets (therefore dilution of reactant), and consequent radiation attenuation. On the opposite of water mists, the suppression mechanism mainly involved for sprinklers is the fuel surface cooling [4].

For indoor applications with a restricted volume available for clear water storage, (public buildings, ships, industrial plants...) it is of great concern to optimize the water volume required for extinction [5]. Therefore, the suitable amount of water when designing a system may only be determined through a relevant study of the potential fires and their corresponding heat release rate and the corresponding required water flow rate. The water mist influence on the fire should be first study for open fires [3] before to analyze its effects on enclosed fires.

Normalized relations to describe the minimum water flow rate discharge from water mist nozzles leading to extinction of an “open fire” were first introduced by Heskestad [6,7] for heptane pool fires at 2.4 kW and 43 kW. Water mists introduced were placed at 0.61 m and 1.828 m above the fire source, with water flow rate up to 2 L/min and mean drop diameter of 144, 230 and 270 μm . Those experimental data showed a negligible effect of the initial spray angle on the fire extinction rate. The mean diameter has been investigated but its effect upon fire suppression has not been commented by [6] and was not considered in the analysis. However, other parameters, such as the nozzle diameter or the distance between the nozzle and the fire source were identified as key parameters. After a rigorous dimensional analysis, new parameters were introduced by [6], namely the effective nozzle diameter D_{ne} [m], defined in Equation (1).

$$D_{ne} = \left(\frac{4\dot{m}_w^2}{\pi M \rho_w} \right)^{1/2}, \quad (1)$$

where \dot{m}_w is the mass water flow rate injected by the nozzle [$\text{kg}\cdot\text{s}^{-1}$], $M = \dot{m}_w u_d$ the momentum of the water discharge [N] with u_d the initial drop velocity [$\text{m}\cdot\text{s}^{-1}$], and ρ_w the water density [$\text{kg}\cdot\text{m}^{-3}$]. D_{ne} is a key parameter when determining the normalized flow rate for extinguishing a fire. This notation enables one to compare water mists with different nozzle shapes. These observations led to,

$$\dot{Q}_w / D_{ne}^{5/2} = f \left(\dot{Q} / D_{ne}^{5/2}, H / D_{ne} \right), \quad (2)$$

where \dot{Q}_w is the water volumetric rate discharged by the nozzle [$\text{m}^3\cdot\text{s}^{-1}$], \dot{Q} is the fire heat release rate [kW] and H the distance between the nozzle and the burner surface [m]. Experimental results were consistent with a normalized relation stating that the extinction water flow rate is proportional to D_{ne} , the Heat Release Rate (HRR) and nozzle height. Volumetric flow rates investigated by Heskestad are lower than 2 L/min and the ratio H/D_{ne} between the height of the nozzle to the burner’s surface and the effective nozzle diameter is almost constant at 1400 for the different configurations [6].

More recently, Tanaka [8] compared experimental and numerical results when a water mist is set over a propane gas burner with HRR ranging from 3.7 kW to 40.2 kW. The water volumetric flow rates are lower than 1 L/min. Median volumetric droplets diameters are ranging from 172 to 242 μm . However, the influence of this parameter over fire suppression has not been investigated.

The primary aim of this project is to conduct an experimental study to determine the minimum flow rate required for extinction of an “open fire” and compare it with existing literature data. Propane burner is used with \dot{Q} varying in the range of 23.2 to 139.2 kW, significantly higher than HRR studied in the literature [6, 8]. Volumetric flow rates of 3.5 and 5 L/min were studied to consolidate the relation established by [6] in higher range of water flow rates. Considering Heskestad and Tanaka’s work, higher ranges (both for water and propane flow rate) presented here aim to check if Heskestad’s relation is valid within these intervals.

2. Experimental set-up

Two water mist nozzles, TG03.5 and TG05, from the company Spraying Systems and Co., were chosen. They both generate full conical jets, similar to those used by [6], with the discharge of 3.5 L/min and 5 L/min of water at 6 bars of operating pressure (and respective K factor of 1.4 and 2 L/min/bar^{0.5}). According to the technical documentation [10], the spray angle is respectively 46° and 59°. The water pressure and the extraction rate are set manually. The compressor provides air with a maximum pressure of 10 bars. The pressurized air is stored in a 10 L tank. The discharge pressure is manually modulated to cover a range between 0 and 6 bars. The volume flow rate injected through the water mist nozzle is manually controlled thanks to the flowmeter placed before the nozzle. *Figure 1* shows a schematic of experimental configuration.

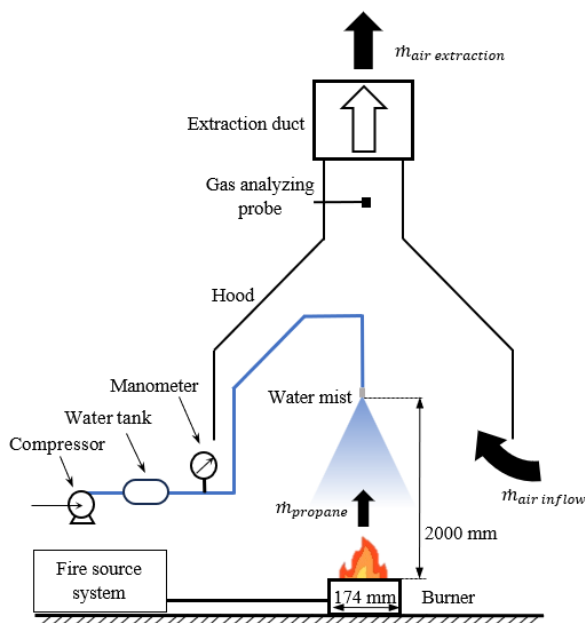


Figure 1: Schematic of the studied configuration

The gas burner has a square shape, of 0.174 m side. A mass flowmeter is used to specify the injected mass flow rate. The flame is a turbulent diffusion flame as defined by [11]. The mass flow rate of the gas burner was varied between 0.5 and 3 g/s with a step of 0.5 g/s. The extraction duct ensures that the fire is well ventilated. The gas analyzing probe inside the extraction duct measures oxygen concentration of the fire smoke. $\dot{m}_{propane}$ is negligible compared to $\dot{m}_{air inflow}$. Thus $\dot{m}_{air inflow}$ is supposed equal to $\dot{m}_{air extraction}$ and is later referred to as \dot{m}_{air} . The HRR is calculated based on the oxygen consumption method [12], using the following equation,

$$HRR = E_{O_2} \dot{m}_{air} \frac{M_{air}}{M_{O_2}} (X_{O_2}^0 - X_{O_2}) , \quad (3)$$

where E_{O_2} represents the heat of combustion per mass of oxygen consumed (12.9 kJ/g_{O₂}), \dot{m}_{air} the mass flow rate of air extracted by the duct, M_{air} the molar mass of air, M_{O_2} the molar mass of dioxygen, $X_{O_2}^0$ the initial concentration of oxygen and X_{O_2} the concentration of oxygen during the experiment. To be comparable with diffusive flames, the value of the Froude number [13] ($F_r = \rho u^2 / (\Delta\rho gL)$ with g the gravity, L the characteristic length and $\Delta\rho$ the difference between the ambient gas density and the flame density) was estimated for the gas burner. It was found to be sufficiently low to belong to diffusion flame range, to ensure comparison with liquid pool fire of the literature.

The gas burner is set to a stable mass flow rate and burns freely for the first three minutes of the experiment. Then the aspersion begins and the water mist discharges water at 1 bar for one minute. If the fire is not extinguished within one minute, the water mist pressure is set to 2 bars for one minute, and so on until 6 bars. The experiment stops whether the fire is extinguished, or the fire is not

extinguished after one minute with water mist pressure at 6 bars. The one-minute criterion is set based on observation: as the minimum water discharge must extinguish rapidly the fire, if the fire is not extinguished within one minute, then the water discharge will either not extinguish the fire or extinguish with unpredictable time. The water mass flow rate (thus the pressure) under which the fire is extinguished is noted as the minimum mass flow rate inducing extinction. The different volumetric flow rates measured during the experiments are summarized in *Table 1*. The Sauter mean diameter was measured 5 cm below the nozzle at 6 bars and is about 227 μm . This diameter is assumed to vary along with the flow rate, however this evolution has not been studied here. Each configuration is replicated three times to get a certain evaluation of the uncertainty of experiment, except for a mass flow rate of 3 g/s with TG05 which has only been performed once. The HRR used in the dimensionless analysis as \dot{Q} will be approximated in the following by multiplying the gas rate with the heat of combustion of propane (i.e. 46.4 MJ/kg from [13]). The HRR calculated from the oxygen consumption (*Equation (3)*) will be used to assess the attenuation of the fire as shown in *Figure 3*.

Table 1: Volume flow rate for different pressure

		Water pressure (bar)					
		1	2	3	4	5	6
Volume flow rate (L/min)	TG05	2.4	3.3	3.8	4.3	4.6	5
	TG035	1.7	2.3	2.9	3	3.3	3.5

3. Experimental results

To better understand the influence of volumetric flow rate, represented in our test by the operational pressure, and to establish a minimal flow criterion, understanding the fire's physical response to this quantity is an important issue. *Figure 2* shows the different stages of the flame behavior when the water pressure (thus the volumetric water flow rate) is increased stepwise, considering a 2 g/s propane burner (\dot{Q} is about 92.8 kW) and a TG5 nozzle. The first picture without water mist shows the flame in free-burning conditions. The effect of water mist activated with low pressure (1 bar) over the burner is neglectable. The flame height and stability remain unperturbed. From 2 bars, the water mist impacts the fire consistently as the flame decreases in size and is sometimes blown off the surface of the burner. During this unstable regime, the fire can easily be extinguished, but can also still be burning until the water mist pressure reaches 6 bars. As described by [3], flame height is gradually reduced until the fire becomes unstable. When the flame behavior is highly unstable, the extinction can occur at any time and the extinction time cannot be predicted with accuracy.

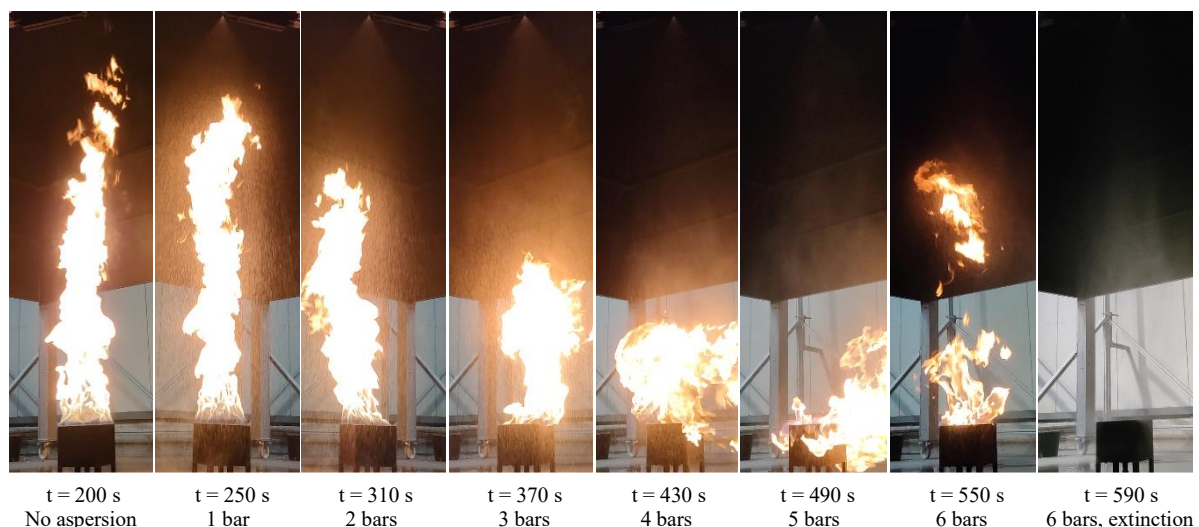


Figure 2 : Evolution of the fire while exposed to a volumetric flow rate increased stepwise (2 g/s).

The divergence of results for each configuration confirms the unstable behaviour of the fire, as three identical tests do not give identical results. *Figure 3* shows the HRR of three identical tests (TG05 with propane mass rate of 2 g/s). Extinction was reached for 4.3 L/min for the first test, and for 5 L/min for the two other tests. The normalized HRR without aspersion (in green dashed line) is stable over the experiment, showing that there is no leakage of smoke due to the hood extraction. The normalized HRR is the HRR measured using *Equation (3)* divided by the maximum HRR obtained to better represent the HRR attenuation. The dotted lines show the extinction time.

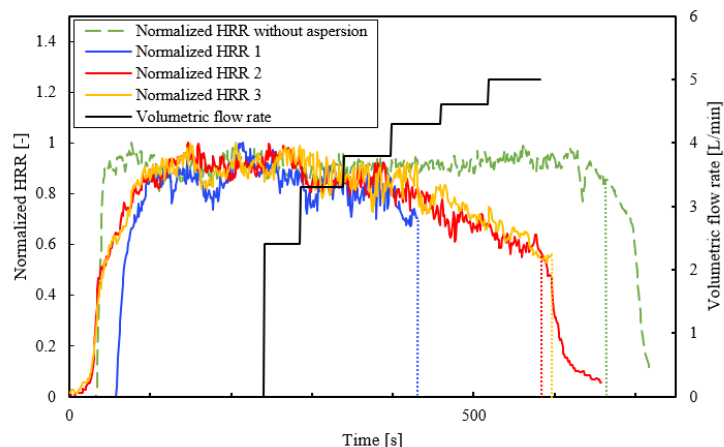


Figure 3 : Normalized HRR and volumetric flow rate injected by the nozzle TG05 against time.

The HRR slowly decreases when the injected water flow rate is increasing. Fire suppression occurs at water pressure equal to 6 bars. The HRR seems to decrease when the water pressure is constant. This observation can be interpreted as the level of oxygen is slowly returning to stable state, and the inertial time of the whole system. The normalized relation of *Equation (3)* applies for many different fires, disregarding various parameters such as the flame height or the type of fuel.

The normalized flow rates for extinction are presented in *Figure 4*. Results presented by [6,8] are compared to the results of the present study. As presented above, the divergence of results is not negligible (from 1 to 33% of relative error), therefore averaged results of each configuration are presented with error bars. The symbols represent the mean values for each test and the error bars represent the minimal and maximal value over the 3 repeatability tests.

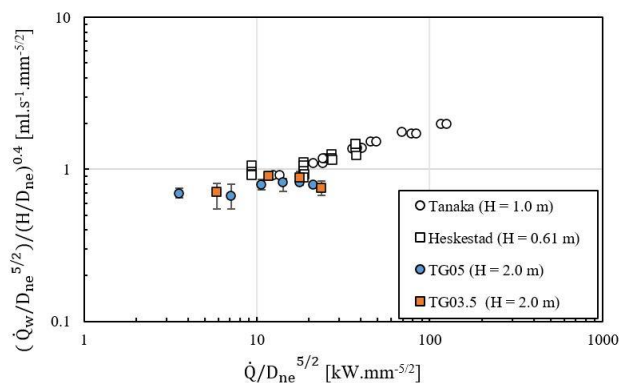


Figure 4 : Normalized flow rate for extinction [6,8].

The studied range of normalized flow rate is for $\dot{Q}/D_{ne}^{5/2}$ between 3 and 30 $\text{kW}/\text{mm}^{5/2}$, which is lower than the range studied by [6,8]. The H/D_{ne} ratio is around 1400 for [6], around 960 for TG05 and 1174 for TG03.5. These new results are in great accordance with the correlation presented in *Equation (3)* published by [6] and extended by [8] for low flow mass rates. Fuels studied by [6] were only liquids

(alcohol, petrol, kerosine...) while only gaseous propane was studied by [8]. This difference in fuels does not lead to any noticeable difference in behaviour.

4. Conclusion

Extinction of a gas burner with water mist tests were conducted in a well-ventilated environment. The tests involved two water mists, spraying over a propane burner. The HRR set to the burner was ranging from 23 to 140 kW approximately, and the water flow rate was ranging between 1.7 and 5 L/min.

The effective nozzle diameter is a key parameter in the study of the minimum flow rate for extinction, and the relation between the heat release rate and the minimum volumetric water flow rate required for extinction introduced in the literature is validated for smaller $\dot{Q}/D_{ne}^{5/2}$ ratio. Normalized flow rate for extinction is of great interest when predicting the quantity of water needed. According to Heskestad, droplets size does not seem to affect the results since this parameter is not considered in the dimensionless analysis.

Under-ventilated scenarios will be investigated in future work. The impact of water mist and minimum water flow rate for extinction in confined spaces will be studied and compared to well-ventilated results.

References

- [1] NFPA 750 (2023), Standard on Water Mist Fire Protection Systems, NFPA, Quincy, MA, USA
- [2] A. Jones and P. Nolan (1995) Discussion on the use of fine water sprays or mists for fire suppression, *Journal of Loss Prevention in the Process Industries* 8, 17-22
[https://doi.org/10.1016/0950-4230\(95\)90057-V](https://doi.org/10.1016/0950-4230(95)90057-V)
- [3] J. Rasbash, Z. W. Rogowski and G. W. V. Stark (1960) Mechanisms of Extinction of Liquid Fires with Water Sprays, *Combustion and flame J.*, Vol. 4, 223-234,
[https://doi.org/10.1016/S0010-2180\(60\)80026-0](https://doi.org/10.1016/S0010-2180(60)80026-0)
- [4] N. Ashgriz (2011) Handbook of Atomization and Sprays Theory and Applications, *Springer*
- [5] H. M. Iqbal Mahmud, K. A. M. Moinuddin, G. R. Thorpe (2016) Experimental and numerical study of high-pressure water-mist nozzle sprays, *Fire safety journal* 81, 109-117,
<http://dx.doi.org/10.1016/j.firesaf.2016.01.015>
- [6] G. Heskestad (2002) Extinction of gas and liquid pool fires with water sprays, *Fire safety journal* 38, 301-317,
[https://doi.org/10.1016/S0379-7112\(02\)00085-1](https://doi.org/10.1016/S0379-7112(02)00085-1)
- [7] G. Heskestad (2002) Scaling the interaction of water sprays and flames, *Fire safety journal* 37, 535-548,
[https://doi.org/10.1016/S0379-7112\(02\)00012-7](https://doi.org/10.1016/S0379-7112(02)00012-7)
- [8] F. Tanaka, D. Kato (2023) Experimental and numerical study on fire extinguishing by water spray, *Fire safety journal* 141,
<https://doi.org/10.1016/j.firesaf.2023.103984>
- [9] H.-Z. Yu, X. Zhou and J. Carpenter (2017) Physical scaling of water mist fire extinguishment in industrial machinery enclosures, *Fire safety journal* 91 596-605
<http://dx.doi.org/10.1016/j.firesaf.2017.03.033>
- [10] Spraying Systems Co. (2019) Industrial Hydraulic Spray Products, Catalog 75D-M HYD
- [11] E. Gengembre, P. Cambray, D. Karmed and J. C. Bellet (1984) Turbulent Diffusion Flames with Large Buoyancy Effects, *Combustion Science and Technology* 41, 55-67
<http://dx.doi.org/10.1080/00102208408923822>
- [12] S. Brohez (2002) Etude des feux de substances chimiques en milieu confiné, Faculté Polytechnique de Mons.
- [13] M. J. Hurley, D. Gottuk, J. R. Hall, K. Harada, E. Kuligowski, M. Puchovsky, J. Torero, J. M. Watts and C. Wieczorek (2016) SFPE Handbook of Fire Protection Engineering, Springer New York