# Using the Cutting Extinguisher to Fight Fires at Sea

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## SUMMARY

The Cutting Extinguisher is a Swedish invention that is used to fight fires both on land and at sea. The main application is to fight the fire from a safe area. The extinguisher can cut through building materials using an abrasive additive. Experimental measurements show that the spray is characterized by small droplets. The following characteristic diameters were measured at 10 m distance from the nozzle using 260 bar injection pressure: arithmetic mean diameter $d_{10} \approx 60$ μm and the Sauter mean diameter $d_{32} \approx 170$ μm. The velocity at this distance from the nozzle was approximately 7 $\mathrm{ms}^{-1}$ in the spray core. Droplet diameters decreased significantly when A-foam or X-Fog were mixed into the water, $d_{10}$ decreased to 30-40 μm and $d_{32}$ to 110-150 μm. These measurements support previous explanations of the efficiency of the Cutting Extinguisher and also lead to a more detailed understanding of the extinguishing process.

## NOMENCLATURE

| | |
|---|---|
| $d_{10}$ | arithmetic mean diameter |
| $d_{32}$ | Sauter mean diameter |
| $p_{\mathrm{nozzle}}$ | Pressure at the nozzle |
| $C'''_{abs,eff}$ | A measure of how much radiation is absorbed per unit volume of water. |

## 1. INTRODUCTION

New disruptive technology for applying water mist to shipboard fires has recently been developed: the Cutting Extinguisher. The Cutting Extinguisher method has been proven by onshore firefighting and a number of scientific reports. In the naval setting, the efficiency of water mist introduced to a compartment with a fully developed fire has also been scientifically documented [1].

### 1.1. MISSION CRITICAL SITUATION

In a mission critical or combat situation, time to allow the fire to consume all fuel or for allocating personnel for boundary cooling might not be available. A premature entry procedure could be one of the few options at hand. However, entering a fire compartment at a stage where the fire is starved of oxygen, could feed the hot fuel-rich gases with a current of cold air, and induce a backdraft. This is one of the most hazardous situations a firefighter could face.

## 2. SOCIETAL CHANGE, DECREASING FUNDING AND NEW CHALLENGES

Funding for the military assignments and duties has been steadily decreasing over the past decades. At the same time new international missions have emerged into the military arena. For the Royal Swedish Navy and the Swedish Material Administration (FMV), this has implied doing more for less in order to maintain fast responses to new missions; including more efficient strategies and tactics, bilateral procurement initiatives, life cycle extension, etc.

Societal changes have also introduced a more uniform legal situation, comparing civilian and military sectors of the community. For example the change in the recruitment process, going from a draft organization to professional sailors and soldiers, has led to more civilian regulations being brought into the military organizations. Civilian work environment regulations and other jurisdictions are to be enforced throughout all military levels. Areas where equipment and crew were exposed to high risks, such as vessels' fire resistance/protection and shipboard firefighting were rising on the priority list. Requirements like *more for less* and *thinking outside the box* permeated the whole organization, including the Naval Procurement Command and the Sea Safety School [2].

## 3. THE CUTTING EXTINGUISHER

The Cutting Extinguisher is a mobile high pressure water jet system with penetrating and cutting capabilities. The system ejects approximately 30 to 60 liters water at approximately 200 meters per second through a nozzle mounted in a hand held lance.

The hand lance is connected through a high pressure hose to the main high pressure system (260 bar) and is controlled by the lance operator. The system has the capability to mix an abrasive, cutting agent, into the water, thus enabling the operator to penetrate or cut through virtually any construction material. When the water jet combined with the abrasive slurry has cut through the bulkhead or hatch, the water breaks out into a fine mist due to the high velocity of the jet as it passes through the nozzle.

The Cutting Extinguisher combines some of the main advantages of fixed installed ultra-high pressure water mist fire suppression systems with penetrating and cutting abilities and adds mobility. To minimize the risk of re-ignition of fibrous solid fuels, a Class A detergent may be added by the operator.

As the water mist enters the fire room, the atomized water evaporates and in the process consumes energy and heat. In the process the steam inert the fire gas by decreasing the oxygen fraction. This also cools the fuel surface and shields the fuel from the surroundings [3]. If the Cutting Extinguisher is utilized with a Class A detergent, the shielding is even more apparent [4].

If the fire is not situated immediately opposite the penetrated wall, the continuous use of the Cutting Extinguisher water jet will soon saturate the immediate volume and travel towards the fire. The speed of the injected water mist will aid in the process. If controlled ventilation is applied, the effect will appear even sooner: the fire will consume the oxygen between the water mist and the fire, eventually sucking in the water mist into the flames and choking itself.

Examples of penetration abilities have been tested and are described in various reports. FMV conducted tests at early stages of a fire cutting through the following material [4].

- 4 mm mild steel, 10 seconds
- 8 mm carbon-fiber laminates, within 10 seconds
- 50 mm concrete slab, passed without noticing resilience

The Cutting Extinguisher is primarily a tool for rapidly and efficiently cooling fire gases produced by solid or liquid fires from a safe position. By adding a Class A detergent, additional positive effects on solid fibrous fuels will occur.

The Cutting Extinguisher has been tested in accordance with EN-3-7:2004+AI 2007(E), Annex C. According to this standard, the electric current between operator accessed parts (like handle) and earth must not be greater than 0.5 mA when an alternating voltage of 35 kV is applied to a metallic plate. The Cutting Extinguisher fulfills the requirements with the use of water and water and abrasives [5].

The cutting extinguishing method for Fire & Rescue Services has been developed together with the Swedish Rescue Service Agency and Södra Älvsborg Fire & Rescue Services (SERF) and is being enhanced and refined continuously. The concept includes the use of thermal imaging cameras and positive pressure ventilation (PPV), as well as multiple-use of Cutting Extinguishers in large volume fire rooms [6].

The Royal Swedish Navy has adopted the system and method for naval use, as have several other maritime organizations and businesses, such as the German Central Command for Maritime Emergencies (Havariekommando), Swedish Coast Guard, Region Zeeland (NL), Svitzer and Smit Salvage.

### 3.1. CUTTING EXTINGUISHER ONBOARD

In 2001, at approximately the same time as a number of composite Visby Class Stealth Corvettes were ordered from Kockums Naval Shipyards, the Royal Swedish Navy and the Swedish Defence Materiel Administration sought methods for offensive and efficient firefighting from a safe defensive position, to meet the demands of firefighting onboard composite vessels. In addition, the main target was to find systems supplementing and adding redundancy to traditional onboard systems; with high efficiency in suppressing fires, water usage and crew staffing. The system should also be easy to use, understand and train.

Numbers of tests and evaluations were conducted and the results pointed out the Cutting Extinguisher as a reasonable candidate for firefighting onboard composite vessels as well as adding enhancing features to shipboard firefighting on traditional steel hull vessels [4].

The Cutting Extinguisher was found to fill the gap of time between the initial attack and the SCBA-attack, providing the shipboard firefighting crew to [7]:

- Reach the fire without adding oxygen
- Rapidly lower the temperature in the fire room
- Minimize the water use, hence minimize collateral damages and stability issues
- Reduce the number of crew occupied with firefighting
- Enable the crew to fight the fire efficiently from a relatively safe position
- Provide the a method to get an overall faster incident control

In addition, the Cutting Extinguisher may be used as a clearing tool by itself or by adding a guided cutting frame.

## 4. SPRAY CHARACTERIZATION OF THE CUTTING EXTINGUISHER

Water mist is generally interpreted as sprays with water drops of a size up to 1000 micrometers, or 1 mm [8]. Small droplets add a number of features to it as a firefighting media. By atomizing the water into micron size droplets, the surface area of a given volume of water expands dramatically. At a droplet size of 1 mm, one liter of water covers the area of a third of a soccer goal (6 $m^2$). Assuming drops of 1 micrometer in diameter, one liter of water covers an area of approximately 6000 $m^2$, or the area of a football pitch. The surface area exposed by the atomization of the water reduces the time tremendously for the water to transform to steam [3].

## 4.1. SPRAY THEORY

In this section some important aspects of the physics of sprays are briefly described [9].

### 4.1(a) Droplet size distributions

Small droplets (< 2 mm) are in general close to spherical in shape and can therefore be described using a single parameter [10]. Larger droplets are typically distorted by gravity. Different parameters are then used depending on the application. Sometimes the median diameter is used to characterize a spray. This parameter is of lesser interest for water mist, however, since large droplets will carry significant amounts of water and conversely the amount of water in the smaller droplets is low. Since very large droplets are not at all reflected in the median diameter this parameter has not been considered further in this study.

Equation (1) is used to calculate the different diameter relationships. Equation (2) and (3) are derived from Equation (1).

$$d_{ab} = \left( \frac{\sum_{n=1}^{N} d_n^a}{\sum_{n=1}^{N} d_n^b} \right)^{\frac{1}{a-b}} \qquad \textbf{(1)}$$

#### 4.1(aa) Arithmetic mean diameter

$$d_{10} = \frac{\sum_{n=1}^{N} d_n^1}{N} \qquad \textbf{(2)}$$

#### 4.1(ab) Sauter mean Diameter

$$d_{32} = \left( \frac{\sum_{n=1}^{N} d_n^3}{\sum_{n=1}^{N} d_n^2} \right)^{\frac{1}{1}} \qquad \textbf{(3)}$$

$d_{32}$ is the diameter of a droplet whose volume to surface ratio is the same as the volume to surface ratio of the entire spray. $d_{32}$ is particularly important when mass transfer and the active area per volume is important [11, 12]. Therefore $d_{32}$ is an appropriate parameter for water mist since the purpose with the small droplets in water mist is to achieve large surface related effects, such as cooling and evaporation, while using small volumes of water.

## 4.2. LASER DIAGNOSTICS FOR SPRAY CHARACTERIZATION

In order to correctly assess droplets and velocities in a spray it is necessary with a non-intrusive in situ measurement method. Due to the liquid phase of the droplets it would, for example, not be possible to collect them and thereafter characterize their diameters. Laser diagnostics offer the required properties and have therefore been selected as the measurement method. In this section the Global Sizing Velocimetry (GSV) method, used in the measurements, is briefly described.

### 4.2(a) Particle Imaging Velocimetry (PIV)

Particle Imaging Velocimetry [13] is a method to determine two-dimensional flow field velocities in a plane. A more advanced form of the method, stereo-PIV, can be used to derive the third velocity component. A cross-section of the spray is illuminated using laser light formed into a thin sheet. The scattered light is detected using a camera. The illumination is conducted using two laser pulses with a short time separation where images are recorded for each laser pulse. The resulting two images are compared and the distance and direction the imaged objects have moved during the time separation reflects the velocity field.

### 4.2(b) Interferometric Laser Imaging for Droplet Sizing (ILIDS)

Interferometric Laser Imaging for Droplet Sizing [14, 15] measures the size of the droplets in the measuring volume based on its interference pattern after being impinged on by a laser pulse. Therefore this method requires that the sprayed liquid can be considered as optically transparent. These measurements cannot be done for optically opaque droplets. This technique can be used to analyse droplets with diameters in the range between 10 to 700 µm.

### 4.2(c) Global Sizing Velocimetry (GSV)

A simplified description of GSV [16] is that it combines the two measurements methods: PIV and ILIDS. In GSV, the ILIDS technique is used but two images are captured of the interference field, with a time delay between the exposures. The spatial position of the droplets in each image is determined. These locations are near the centre of each individual interference pattern. When the droplet locations are known in each image, and the time delay between the images is known, the velocities can be calculated with computerized algorithms similar to those used in PIV. Figure 1 shows a schematic overview of the experimental setup for drop sizing using GSV.

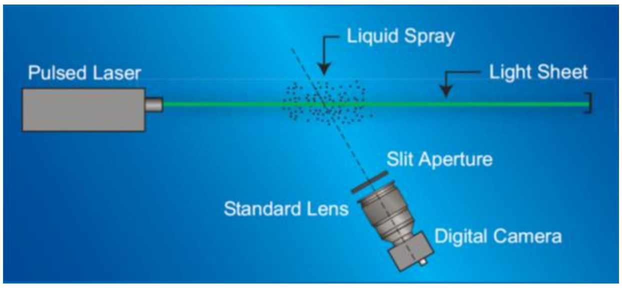

Figure 1: Schematic of the laser diagnostics setup.

## 4.3. EXPERIMENTAL SETUP

The Cutting Extinguisher was fixed on a mount on a table, 1.2 m above the floor. The GSV measurement equipment was fixed in a metallic cage as shown in Figure 3 (the cage was also clad with a tarpaulin and the sprays were sectioned through a slit, not shown here). The distance, *z*, between the measurement point and the investigated system was varied by moving the rolling table; see left part in Figure 2. All measurements except two were performed in the center of the spray from the Cutting Extinguisher, or in the centre of one of the spray plumes from the other systems.

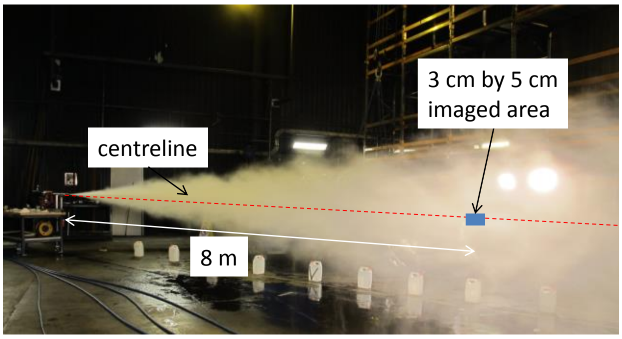

Figure 2: The Cutting Extinguisher positioned 15 m away from the measurement point. The measurements were performed in a cage (not seen here) to the right of the image. The position of the 8 m measurement is indicated.

The measurement area is relatively small, on the order of 3 cm by 5 cm. It is possible that size distributions and in particular velocities varies depending on in which part of the spray the measurements are made. The approach in this project was to measure in the most dense parts of the spray. The rationale for this was that most water is transported in the denser parts and therefore the results from those parts are more representative for the fate of the water than the results from less dense parts.

Figure 3: Water proof implementation of the laser diagnostic drop sizing. The aluminum cage was also covered by a tarpaulin, not shown here.

## 4.4. RESULTS

In this section the results for volumetric flow, diameters and velocities are presented. An observation made in particular for the Cutting Extinguisher is that a few meters from the nozzle exit the spray becomes unstable with vortices developing at the spray edges. Further, in the measurement images this can be seen since some images contain densely spaced droplets while other images, for the same operating conditions, contain much more sparsely spaced droplets. It is therefore important to average results over several images. In this study 30 images were analysed for each operating condition, corresponding to a time average of 30 s.

### 4.4(a) Volumetric capacity

The volumetric capacity was simply measured by filling a certain volume and measuring the time elapsed. Using 200 bar as the $p_{nozzle}$ pressure the flow was 49 $lmin^{-1}$, and for 260 bar the flow was 57 $lmin^{-1}$.

### 4.4(b) Droplet sizes

Figure 4 and 5 show how the droplet size histogram depends on the injection pressure. Since the variation was quite small, from 200 bar to 260 bar, the effect is not very large. It can, however, be observed that when the injection pressure increases the kurtosis of larger droplets is reduced and the histogram becomes more compressed towards smaller droplets, resulting in smaller arithmetic and Sauter mean diameters. The y-axis in the figures shows the number of counts for each size bin. The number of counts is a qualitative indicator of the drop density, but is not necessarily directly proportional to this density.

In two measurements, additives X-Fog and a foaming agent (A-foam) were mixed in the water (1-2%).

It two measurements the measurements were performed at a radial (horizontally) position of 40 cm and 80 cm, respectively, from the centerline of the spray.

The estimated uncertainty is ±10 %.

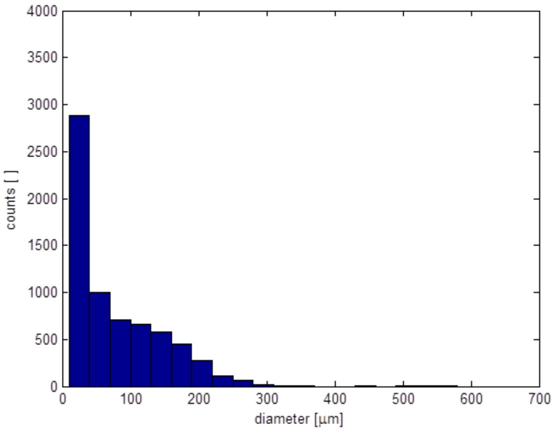

Figure 4: Drop size distribution from the Cobra along the centerline 10 m from the nozzle. $p_{nozzle}$=200 bar.

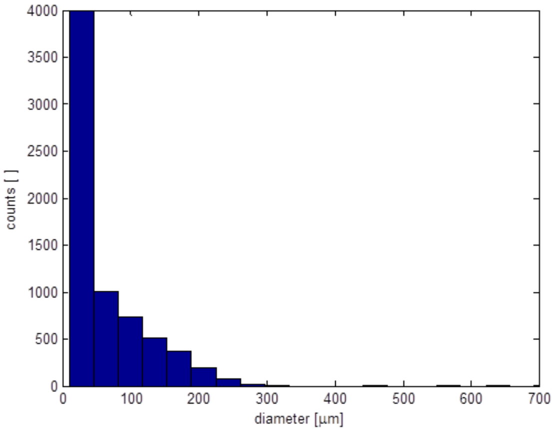

Figure 5: Drop size distribution from the Cobra along the centerline 10 m from the nozzle. $p_{nozzle}$=260 bar.

Table 1, 2 and 3 shows the result from all measurements.

Table 1: Arithmethic mean diameter, $d_{10}$.

| $p_{nozzle}$ [bar] | z [m] | 8 | 10 | 15 |
|---|---|---|---|---|
| | comment | $d_{10}$ [μm] | | |
| 200 | | 60 | 77 | 85 |
| 260 | | 46 | 62 | 86 |
| 260 | A-foam | | 33 | |
| 260 | X-Fog | | 38 | |
| 260 | R=40 cm | | 64 | |
| 260 | R=80 cm | | 43 | |

Table 2: Sauter mean diameter, $d_{32}$.

| $p_{nozzle}$ [bar] | z [m] | 8 | 10 | 15 |
|---|---|---|---|---|
| | comment | $d_{32}$ [μm] | | |
| 200 | | 157 | 174 | 174 |
| 260 | | 160 | 170 | 196 |
| 260 | A-foam | | 149 | |
| 260 | X-Fog | | 109 | |
| 260 | R=40 cm | | 127 | |
| 260 | R=80 cm | | 97 | |

Table 3: Horizontal velocity.

| $p_{nozzle}$ [bar] | z [m] | 8 | 10 | 15 |
|---|---|---|---|---|
| | comment | $d_{32}$ [μm] | | |
| 200 | | | 6 | 4 |
| 260 | | | 7 | 5 |
| 260 | A-foam | | 6 | |
| 260 | X-Fog | | 5 | |
| 260 | R=40 cm | | 4 | |
| 260 | R=80 cm | | 3 | |

## 5. USING THE CUTTING EXTINGUISHER TO FIGHT FIRES AT SEA

### 5.1. STANDARD NAVAL SHIPBOARD FIREFIGHTING

Pre-action preparations and training is of essence to combat fires successfully. Preparations also cover structural protection, fixed fire suppressing systems, equipment control, awareness and readiness.

On live incidents, standard procedures for firefighting tactics onboard conventional vessels include four main actions:

1. Early Detection - Alarm,
2. First Attack,
3. Containment, Control,
4. BA-Attack - Safe Re-entry Procedure.

Primarily, early detection is of essence to extinguish the fire in its growth stage, before the fire has fully developed.

Secondly, immediately after detection and alarm, the first attack is made by personnel detecting the fire. By using fire extinguishers or other means to suffocate the fire and/or removing the fuel, the crew and the ship might avoid a larger incident.

Third step, if the initial procedures fail, is to contain the fire in the fire compartment. Sealing off the area to prevent the fire to spread, removing fuel, and to minimize oxygen supply, is made to buy time for the fourth step to muster. To contain the fire, automatic, semi-automatic or manual fixed installed fire suppression systems, if present and deemed proper action, should be engaged.

If the fixed installed fire suppression systems fail, boundary cooling of the ship structure is of essence. Since conventional ships normally is constructed with mild steel, a highly heat conductive construction material, the heat from the original fire is likely to travel through the construction and ignite other cells/compartments. Boundary cooling requires vast amounts of water applied to the decks and bulkheads surrounding the initial fire compartment. Depending on the size of the initial fire compartment, a sufficient number of personnel are required to operate the nozzles applying water for boundary cooling.

Forth step is the re-entry procedure, BA-attack on the fire compartment. This cannot be done in a safe way until the fire has been suppressed or reached its decay stage. The latter adds time to the total lapsed time to get in control of the fire. During this time, boundary cooling must be applied continuously [17].

## 5.2. COMPOSITE VESSEL SHIPBOARD FIREFIGHTING

The tactics for shipboard firefighting on composite ships are initially similar to standard procedures. However, containment is not relevant since boundary cooling is obsolete – the modern sandwich construction itself isolates the desired cooling of the externally applied water. Given the fire zone in question is classified, i.e. is isolated with fire resisting material and having fixed installed fire suppressing systems or other means, there are some time available to suppress the fire prior to constructional damage occur. If the fixed fire suppression systems are breached, or if the actual fire is induced by weapon or accident at an area deemed a low or a non-fire hazard zone, time to suppress and get in control of the fire is even less.

## 5.3. ROYAL SWEDISH NAVY SHIPBOARD FIREFIGHTING

Adding the cutting extinguishing method to the standard shipboard firefighting procedure, some extra preparations had to be made. Since all crew are to be able to handle the Cutting Extinguisher, the personnel are trained accordingly. To eliminate risks of aiming the hand lance at places on the deck or bulkheads which have obstacles on the opposite side, *Cutting Extinguisher Attack Points* (CAPs) were marked at pre-defined places: a bright red S on a white field. Hatches and doors are also considered pre-defined attack points, but are not marked – since they open, they usually don't have obstacles on opposite side [18].

When it comes to procedures, the third action encompasses the Cutting Extinguisher attack, thus called Second Attack:

1. Early Detection - Alarm,
2. First Attack,
3. Second Attack, shown in Figure 6,
4. BA-Attack - Safe Re-entry Procedure.

The initial two actions are the same as in standard shipboard firefighting procedures, they are also the same independently whether it is an incident onboard a composite vessel or a steel hull vessel.

Figure 6: Cobra Attack – Second Attack onboard Visby Corvette.

The third step has the Cutting Extinguishing method included as a first choice or as a complement to fixed installed fire suppressive systems – depending on the assessment of the situation.

Onboard at steel hull vessel, using the Cutting Extinguisher at pre-designated attack points might well make external boundary cooling and fixed fire suppression systems redundant – making the incident handling less crew demanding, both in numbers and with respect to exposure to danger. It will also reduce the quantity of water needed to control the fire. Since the time from detection to applying the Cutting Extinguisher method normally is less than mustering crew for boundary cooling, the time for the fire to develop in the exposed compartment is held at a minimum, thus reducing the risk of spreading and impact on the mission as such. The actions taken are generally monitored by thermal imaging cameras.

When fighting fires onboard a composite vessel, the third step includes the Cutting Extinguisher as well as fixed installed fire suppression systems where available. Boundary cooling from the outside is not an option since the bulkheads and decks insulates both heat and cooling.

For composite vessel firefighting, time is even more crucial, since the structure itself has less resistance against heat. Prolonged exposure could result in adding fuel to the fire from the structure, as well as adding structural damage to the vessel at an earlier time frame than on a steel construction.

The forth step is again similar to standard naval shipboard firefighting, with a major difference in ambient temperature at the fire compartment. The high pressure water mist has efficiently decreased the temperature to 100 °C-150 °C. The forth step could also be initiated earlier than otherwise, due to less time elapsed. If the structure has been damaged or skewed, the Cutting Extinguisher and/or the cutting frame could be used as clearing tool to make way for final BA-attack and damage assessment.

## 6. DISCUSSION

In this section a general discussion about the measurement results is given followed by a discussion of how the results relate to various mechanisms which are important for water mists in fire extinguishing. The discussion focuses on the areas where small droplets are an advantage. Applications where water mist is typically not used, such as total flooding for example, are not considered in this context. The results for the Cutting Extinguisher are in general quite consistent and the spray can be characterized by a $d_{10}$ of 60 μm and a $d_{32}$ of 170 μm. Moreover, measurements with foaming agent or X-Fog show that the diameter decreases significantly, as expected due to the reduced surface tension, resulting in an increased Weber number for a given diameter.

### 6.1. COOLING EFFECTS

The droplets extract heat from flames and hot gases by heating the water from room temperature to 100 °C, and by evaporation where the extracted energy is used to induce a phase change from liquid to gaseous water. The rate of transport of energy to the droplet depends on the surface area of the droplet and the relative velocity of the droplet as compared to the air [6]. The heat energy transferred to the droplet per unit time is proportional to the droplet's surface. The heating rate is proportional to the transferred power per unit volume. Therefore $d_{32}$ is useful when comparing the heating rate of the droplets. Assuming a $d_{32}$ of 900 μm for conventional systems, the relative surface to volume ratio between the conventional systems and the Cutting Extinguisher is approximately $900/170 \approx 5$. The significance of this is that the generally smaller water droplets from the Cutting Extinguisher heat up much faster and extracts more power from the flames and hot gases. This in turn will lead to an accelerated evaporation, resulting in enhanced inerting.

### 6.2. INERTING (REDUCTION OF THE PARTIAL PRESSURE OF OXYGEN)

The fire can be efficiently controlled if the air is partly replaced by water vapour. This reduces the partial pressure of oxygen. This can reduce or even extinguish the fire. For example when the oxygen concentration is reduced from 21 % to 13 % (wood fire) or to 7% (petroleum fire) the fire will self-extinguish [6]. The evaporation rate in gas will be enhanced for fine mists. Fast evaporation can also be achieved by pointing the spray at a hot surface. In this case it is not obvious how much the droplet size affects the evaporation rate. This will depend on the hot surface temperature, hot surface structure, etc. Clearly, when the mist is injected blind into an enclosure there is no reason to assume that the spray will hit a particularly hot surface. In this perspective a fine mist will unconditionally enhance the evaporation rate, and thereby also the rate at which the oxygen partial pressure is reduced. It should be pointed out that inerting can be greatly inhibited if fresh air is entrained in the spray. Therefore, using a nozzle that can interact with the fire without the introduction of fresh air greatly enhances the extinguishing capacity of such a system, e.g. if the extinguisher can be introduced into the compartment through a minimal hole. Indeed, in such cases the system may even act to entrain vitiated air from the fire back into the combustion environment further enhancing its performance.

### 6.3. REDUCTION IN RADIATIVE HEAT TRANSFER

One of the major advantages with fine water mist is its ability to absorb heat radiation from a fire. This will reduce the radiative heat transfer, thereby reducing the fire spread, but it will also enhance the heating and evaporation of the droplets due to the absorbed heat radiation. In Figure 7 the volumetric absorption efficiency [19] for water droplets exposed to heat radiation corresponding to a 900 °C black body radiation is shown. This property, $C'''_{abs,eff}$, is a measure of how much radiation is absorbed per unit volume of water.

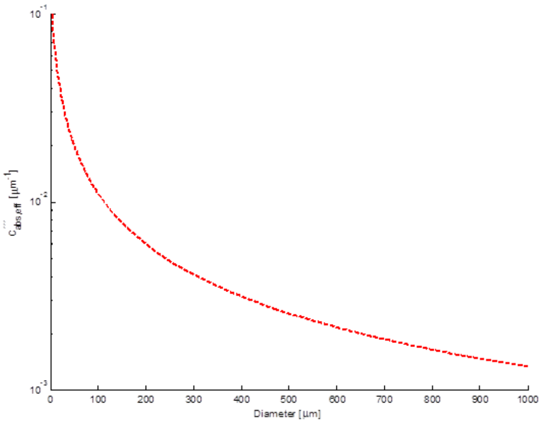

Figure 7: Volumetric absorption efficiency as a function of droplet diameter. A radiation source corresponding to 900 °C black body radiation has been assumed. Adapted from [19].

As an example, comparing the $d_{32}$ diameters 170 μm and 900 μm gives a ratio in volumetric absorption efficiency of 5. However, a rigorous evaluation should average over the product of the size histograms and the volume of the droplets.

### 6.4. TRANSPORT PROPERTIES

Small droplets promote the fire suppressing mechanisms not only because of the mechanisms themselves (that is cooling, inerting, and radiation absorption) but also indirectly because smaller droplets will stay airborne longer than larger ones, leaving more time for these mechanisms to act on the fire.

It has been shown [3] that a droplet with 100 μm diameter entering gas phase atmosphere of 400 °C will have a lifetime of 0.2 s and will fall 30 mm before being totally vaporized. For a 1 mm droplet the corresponding values are a lifetime of 230 s and a falling distance of 680 m! Although these calculations have been performed with different diameters than those measured for the Cutting Extinguisher and the conventional systems in this study the comparison is still relevant. The Sauter diameter, $d_{32}$ describes a typical diameter of the droplets and therefore the comparison between the measured $d_{32}$, 170 μm vs. 900 μm, is not too far from the numerical examples in reference [3]. In short this shows that when a large proportion of the water is carried in the large droplets these droplets will fall to the floor or hit a wall before being entirely evaporated. These differences in transport properties will reduce the gas cooling and inerting capacity, as well as incur larger property losses due to water damages for conventional systems as compared to high pressure water mist systems.

There are typically two contradictory requirements on the spray: rapid evaporation of droplets and strong mixing induced by the spray. Smaller droplets lead to rapid evaporation but also typically reduce the mixing. However, by using a high injection pressure the velocity and the total water amount of the spray is increased. This clearly compensates the lower mixing potential for small droplets but it is unclear by to what degree. More research is needed on this subject [6].

## 7. CONCLUSION AND OUTLOOK

Experimental measurements show that the spray from the Cutting Extinguisher is characterized by small droplets. The following characteristic diameters were measured at 10 m distance from the nozzle using 260 bar injection pressure: arithmetic mean diameter $d_{10}\approx 60$ μm, Sauter mean diameter $d_{32}\approx 170$ μm , and volumetric mean diameter $d_{30}\approx 110$ μm. The latter value confirms previous theoretical estimations that $d_{30}\approx 0.1$ mm. The velocity at this distance from the nozzle was approximately 7 ms$^{-1}$ in the spray core. Droplet diameters decrease significantly when A-foam or X-Fog agents are mixed into the water, $d_{10}$ drops to 30-40 μm and $d_{32}$ to 110-150 μm. Droplets also seem to be smaller outside the spray core at an off center distance of 80 cm from the spray axis. The volumetric capacity was 57 lmin$^{-1}$.

These measurements confirm earlier explanations of the efficiency of the Cutting Extinguisher, and also lead to more detailed understanding of the extinguishing effect. Cooling, inerting and radiation absorption becomes more effective with these small droplet diameters than for systems with larger droplets. Furthermore, the fact that small droplets are more prone to follow the air flow than to fall to the floor means that the time available for these suppression mechanisms to act on the fire becomes longer with smaller diameters.

The high pressure system also gives high velocities. The high speed and high flow creates a high momentum spray that pushes the water mist long distances into an enclosure fire, making it possible to act on fires distant from the nozzle despite the small droplets. This could also have the additional benefit in certain circumstances of entraining vitiated air into the fire by the turbulence created.

The droplet sizes for the Cutting Extinguisher were well characterized. For a better understanding of the transport properties information about the velocity field is needed however. The measurements presented here were of a quasi-zero-dimensional type. In order to map out flow effects, such as turbulence for example, two-dimensional information on a relatively large scale, say 1 m by 1 m, would be required. It is therefore proposed that the GSV-measurements presented in this report are complemented with PIV measurements which would give the desired information. Quantitative measurements on the inerting effects in ventilated enclosures would also be of great interest.

## 8. REFERENCES

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