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IMPACT OF WATER MIST EXTINGUISHER CONSTRUCTION ON PARAMETERS OF GENERATED DROPS

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Abstract
The paper analyses the impact that the construction of water mist extinguishers exerts on the size of generated drops. The test was based on the examination of three extinguishers of two producers, which have been available in the market in recent years.
The test was carried out with the use of the IPS Drop Spectrum Analyzer (DSA). The device operates by using the photoelectric method to measure the parameters of the extinguishing stream microstructure. There were two measuring ranges: 0÷1 414 μm and 0÷2 658 μm.
The test results present mean diameters of the generated drops, aggregated curves representative of their share as well as the analysis of the quality of spraying the extinguishing medium. The tests have shown that two out of three tested extinguishers do not generate water mist with standard parameters at a distance of 170 cm. The smallest mean diameters of drops were generated by extinguisher B, whereas the biggest ones by extinguisher C The highest level of spraying among all samples was found for extinguisher B. It's Sauter diameter mean amounted to 564.03 μm. Further, it was shown what impact the construction of water mist extinguishers exerts on the size of generated drops.

Keywords: **Construction; Drops; Extinguisher; Sprayed stream; Water mist.**

1. INTRODUCTION

In accordance with the Polish Standard, extinguishers are classified as portable firefighting equipment, which allows for fire to be extinguished. The Standard defines extinguishers as equipment containing an extinguishing medium, which may be discharged thanks to internal pressure, and then directed straight at the source of fire [10]. As they are easy to operate and universal, water mist extinguishers can be now more often found in households and food establishments. Such equipment has a certain firefighting efficiency for class A and F fires, which means they can be used to extinguish burning organic solids as well as burning fats and cooking oils.

With time, regulations concerning safety, health and environment are becoming more restrictive. Currently, greater focus is placed on the protection of the natural environment [3]. For this reason, it has become important to use extinguishing mediums which are effective and environmentally friendly [15]. For centuries, water has been the major and most often utilized extinguishing medium. It is due to its specific heat, high vaporization temperature and excellent cooling properties. As it is non-toxic and easily available, water has become the most often sprayed liquid in terms of protection against fire [2, 7]. Moreover, water mist is considered to be one of the alternative technologies, which are supposed to replace halons [16]. Due to high fragmentation of drops, extending several microns, using water mist extinguishers does not destroy or damage extinguished objects.

Spraying consists in liquid spreading into drops when it receives appropriate mechanical energy. An appropriately formed spraying nozzle is most often used as an atomizer. The most common form of discharging water in water mist extinguisher nozzles is the decomposition of liquid membranes.

In the case of stream atomizers, with respect to the portable firefighting equipment being the subject of this discussion, liquid membranes are created in nozzles, where opposite liquid flows collide. Atomizers with colliding streams are called cross-flow atomizers. The nozzle of this type creates a narrow stream of liquid which is injected into the flowing gas. The tested extinguishers had a mechanism which created water mist by colliding the water and gas mixture.

In the case of cross-flow atomizers, the type of membrane decomposition depends on the speed with which the liquid coming out of the nozzle collides with the opposite flow. Figure 1 presents a schematic process of two opposite water flows colliding. When two streams collide at a low speed, a membrane is created, which carries symmetrical waves (Figure 1a).

There are only few places on the perimeter of the generated membrane where drops fall off. When streams collide at 20 m/s, asymmetrical waves are created on the membrane (Figure 1b), which cause the membrane to spread into rings. Circumferential waves cause the rings to break into drops. Figure 1c presents how liquids are sprayed at high speed when streams collide and the membrane breaks before waves are created [11].

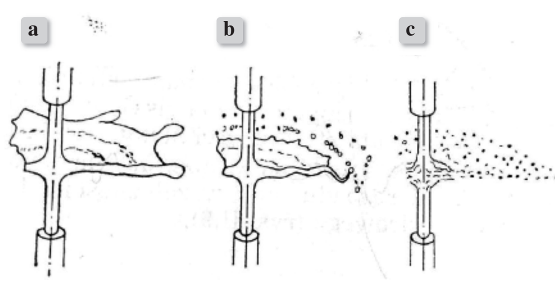

Figure 1.
Decomposition of a membrane created by opposite, colliding flows a) symmetrical waves, b) asymmetrical waves, c) spraying of liquid. Source: [11]

2. METHODOLOGY AND OBJECT OF TESTS

The tests were performed in the Fire-Fighting Equipment Facility of The Main School of Fire Service in Warsaw. In order to eliminate the impact of weather conditions, all tests were carried out indoors. The analysis focused on three water mist extinguishers of two Polish producers. For the purposes of the research, they were called A, B, C. Despite a similar water mist creation mechanism, i.e. the collision of opposite flows of water and gas mixture, the tested objects differ in terms of construction.

The tested extinguisher A has a following tank: height – 485 mm, width: 183 mm, inlet: 28 mm, volume: 10.3 dm^3, which holds 6 l of water. The total weight of the ready-to-use extinguisher amounted to 10 960 g on average during the tests. The propellant may be nitrogen or air, whose pressure at 20°C is 15 bars. The maximum allowed pressure Ps is 18 bars. The set of components producing water mist consists of a turbine, intake tube of 383 mm, aeration tube of: 372 mm, cylinder head, discharge hose of: 575 mm and an atomizer with eighteen nozzles in two circles, nine pieces each (Figure 2a). The label on the tank informs about the size of test fires – fire-extinguisher efficacy 13A, 40F.

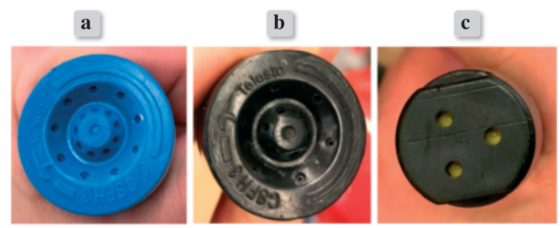

Figure 2.
Spraying nozzles in tested extinguishers. Where: a) Water mist extinguisher A 6l 15bars, b) Water mist extinguisher B 6l 12bars, c) Water mist extinguisher C 6l 15bars
Source: own study

The extinguisher B consists of a tank with height of 615 mm, width of 160 mm and an inlet diameter of 28.45 mm. The volume of the tank is 10.9 mm^3 and holds 6 l of de-mineralised water. The total weight of the ready-to-use extinguisher amounted to 11 080 g on average during the tests. The propellant may be nitrogen, whose pressure at 20°C is 12 bars. The maximum allowed pressure PS is 17.2 bars. The set of components producing water mist is the same as in the case of A, with some parameters changed. The intake tube is: 539 mm, aeration tube is 530 mm, discharge hose: 560 mm and an atomizer with twelve nozzles in two circles, six pieces each (Figure 2b). Fire-extinguisher efficacy presented on the label is 13A, 40F.

The other tested extinguisher C has a tank with a height of 440 mm, width of 160 mm, inlet diameter of 28.4 mm and volume of 7.5 dm^3, which holds 6 l of the extinguishing medium. The total weight of the device

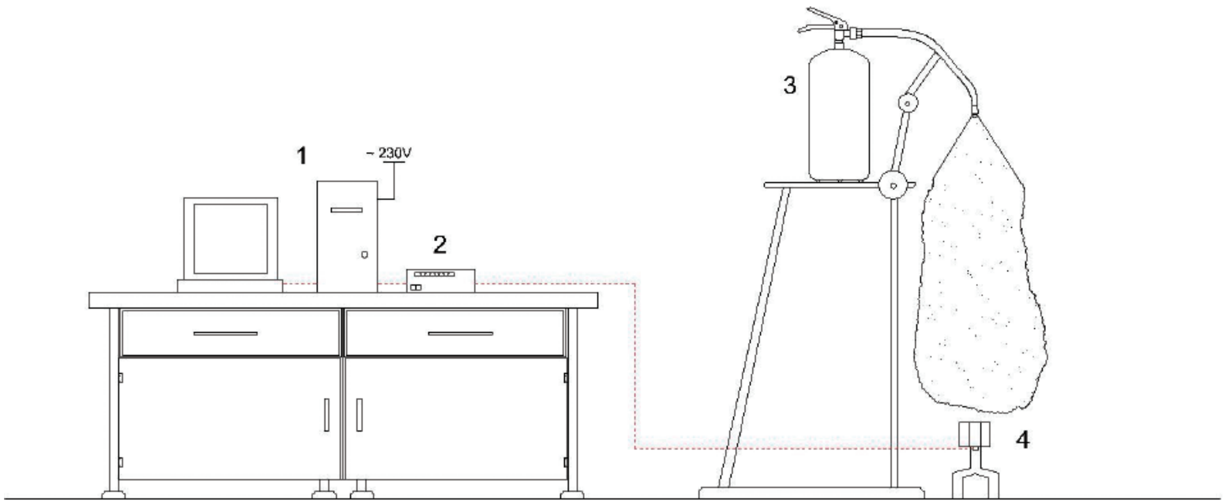

Figure 3.
Scheme of the test bench, where: 1 – computer and software, 2 – drop spectrum analyzer, 3 – tested extinguisher, 4 – measuring probe of the drop spectrum analyzer. Source: own study

amounted to 9 810 g. during the tests. The propellant is nitrogen. The pressure inside the tank at 20°C is 15 bars. The maximum allowed pressure PS is 18 bars. The water mist producing equipment consists of an intake tube which end in a net of 400 mm, cylinder head, discharge hose of 535 mm and an atomizer with nine nozzles (Figure 2c). Fire-extinguisher efficacy presented on the label is 13A, 25F.

The objective of the test was to determine the impact that the construction of water mist extinguishers exerts on the size of generated drops. The scope of the test included determining the following: mean quantitative diameters of drops D_n, mean surface diameters of drops D_s, mean diameter by volume of drops D_v, weighted mean of diameter by volume of drops (Sauter) D_a, uniformity of spraying J, level of spraying D_{xy}.

In the course of the test, extinguishers were filled in while maintaining a relative tolerance of 0 to 5% of the nominal load. Extinguishers were filled in with the gravimetric method with adopted water density of 998.203 kg/m^3, corresponding to the density at 20°C [4].

The measurements were performed with the IPS Drop Spectrum Analyzer (DSA). The device operates by using the photoelectric measurement method for the parameters of the extinguishing stream microstructure (Figure 3). Thanks to the electronic system placed inside the measuring probe, the analyzer converted the light signal into an electrical impulse, corresponding to given drop diameters. DSA measures diameter from 0.5 to 3 000 mm. The maximum measurement error of the DSA system is 2.5% [5]. Essential components of the analyzer are a PC, signal converter, power cables and support stand.

There were two measuring ranges. Water mist extinguishers A and B were tested within the range of 0÷1 414 μm, and for extinguisher C it was 0÷2 658 μm.

The complete discharge of a tested extinguisher was adopted as the criterion of finishing a test. During the tests, the distance between the atomizer and the DSA probe's axis was 1.7 m. In order to eliminate the impact of counting drops which bounce back from the ground, the measuring probe was placed at a height of 500 mm therefrom. Each type of extinguisher was tested 3 times.

3. TEST RESULTS AND ANALYSIS

Table 1 presents test results of the distribution of drop size. It allows to determine whether the stream generated by the extinguisher is water mist. $D_{v0.90}$ and $D_{v0.99}$ refer to range of diameters by volume determined for groups of particles of 90% and 99%, respectively.

Table 1.
Ranges by volume for groups of 90% and 99%. Source: own study

Water Mist Extinguisher	$D_{v0.90}$ (mm)			$D_{v0.99}$ (mm)		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
A	1040÷1045	1271÷1276	1271÷1276	1320÷1326	1370÷1375	1370÷1375
B	990÷996	1007÷1012	979÷985	1309÷1315	1304÷1309	1271÷1276
C	1892÷1902	2378÷2389	2327÷2337	2347÷2358	2616÷2627	2565÷2575

Water mist contains very small drops, whose majority has a diameter smaller than 1 000 mm, i.e. 1 mm [6, 8, 14]. More specifically, it constitutes water spray whose diameters by volume in a group of 90% or 99% (depending on a given source) have to be smaller than 1 000 mm [1, 9]. Table 1 presents volume ranges of drops generated by the tested water mist extinguishers. Drops generated with extinguishers A and C do not create water mist. In two out of three applications of extinguisher B were founded which were within the required range ($D_{v0.9}$ < 1 000 µm). Taking into account the maximum measurement error of DSA, which amounts to 35mm for the selected range, it may be assumed that extinguisher B generates water mist.

Due to varied sizes of drops in the extinguishing stream, mean diameters are used to determine characteristics of a given group. They are determined in terms of their count, diameter, surface or volume of particles. They enable the analysis of various physical phenomena connected with drop movement as well as heat and mass exchange [13].

Table 2 presents results of testing mean diameters of drops in spray generated by water mist extinguishers. Descriptive statistics include arithmetic means and coefficients of variation. The following values were taken into account: D_n – arithmetic diameter mean, D_s – mean surface diameter, D_v – mean diameter by volume, D_a – weighted mean of diameter by volume of drops (Sauter). Mathematical dependencies of the values are presented in Table 3.

Arithmetic means of drop diameters generated by water mist extinguishers differ significantly. The lowest values of arithmetic means were generated by extinguisher B, whereas the biggest ones by C. Water mist extinguishers A and C generated particles with bigger mean diameter than B by 35% and 56%, respectively (D_n), 34% and 66% (D_s), 32% and 75% (D_v) as well as 29% and 96% (D_a). It needs to be noted that arithmetic means obtained for extinguisher B had the lowest variability. Despite a similar construction of the atomizer, intake tube and aeration tube of extinguishers A and B, the size of the generated drops differed significantly.

Table 2.
Results of testing mean diameters of drops. Source: own study

Water Mist Extinguisher	D_n	D_s	D_v	D_a
A	441.80 (12.76)	517.07 (12,97)	579.93 (12.90)	728.87 (11.72)
B	326.43 (3.83)	385.53 (4,21)	437.70 (4.28)	564.03 (4.45)
C	508.30 (6.06)	639.70 (9,75)	766.50 (12.60)	1102.73 (18.47)

Table 3.
Mathematical dependencies of mean diameters of drops. Where: Δn – share of drops with a D diameter. Source: [11, 12]

Mean diameter	Symbol	Formula
Arithmetic	D_n	$D_n = \frac{\sum D_{\Delta n}}{\sum_{\Delta n}}$
Surface	D_s	$D_s = \sqrt{\frac{\sum D^2 \Delta n}{\sum_{\Delta n}}}$
Volume	D_v	$D_v = \sqrt[3]{\frac{\sum D^3 \Delta n}{\sum_{\Delta n}}}$
Sauter	D_a	$D_a = \frac{\sum D^3 \Delta n}{\sum D^2 \Delta n}$

In order to perform a detailed analysis of the liquid flow (for the entire group), quantitative and volumetric distribution of drops is determined. Figure 4 presents representative distribution functions of density for probable sizes of drops, depending on their count. Figure 5 presents representative curves for total volumetric share of particles in the extinguishing flow.

The smallest slope, and at the same time lowest dispersion of measures, can be found in drops generated by water mist extinguisher B. With particle diameter of 500 mm, distribution for drops generated by extinguishers A and C was similar. After that, there is also a change in the relation between the drop diameter and the quantitative share to the detriment of extinguisher C.

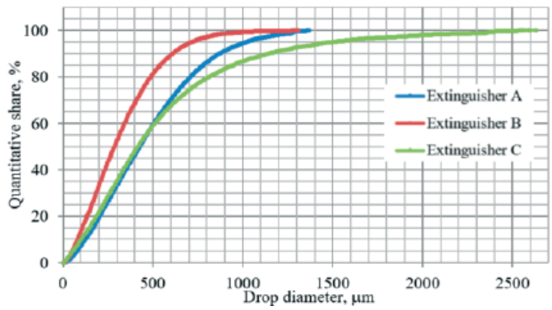

Figure 4.
Representative curves for total quantitative share of drops
Source: own study

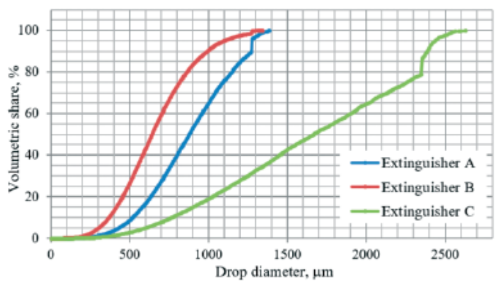

Figure 5.
Representative curves for total volumetric share of drops
Source: own study

Curves for total volumetric share of drops differ from curves for quantitative share. It is noticeable that the extinguishing flow generated by water mist extinguisher A and C is not qualified as water mist ($D_{v0.9}$ > 1 000 mm). The smallest slope can be seen on the curve obtained from the dispersion of particles generated by water mist extinguisher B. However, it should be noticed that with a volumetric share of approx. 70% there is a logarithmic curve slope. It affects the dispersion of values of medium particles. Taking into account the slope and the shape of curves, it is concluded that the dispersion of drop diameters is lowest for extinguisher A. However, the biggest dispersion of drop diameter based on their volume can be found in the stream generated by extinguisher C.

In order to determine the quality of spraying, apart from analyzing the dispersion of drops, it is also possible to use another two parameters: uniformity of spraying (J) and level of spraying (D_{xy}). The uniformity of spraying parameter determines the dispersion of drop diameters. The higher the value, the more uniform the spraying. The level of spraying is often determined on the basis of the weighted mean of diameter by volume (Sauter). The higher the value, the lower the level of spraying. Table 4 presents test results of spraying quality.

Table 4.
Results of the analysis of extinguishing medium dispersion
Source: own study

Water Mist Extinguisher	J	D_{xy} (µm)
A	1.16	728.87
B	1.03	564.03
C	0.86	1102.73

Parameters results for spraying quality of the extinguishing medium confirm the previous analysis. The highest uniformity of spraying can be found in the stream generated by water mist extinguisher A, the smallest – C. The values obtained for extinguishers B and C are lower by 11% and 26% than the values of the spraying uniformity parameter obtained for extinguisher A. The highest level of spraying was obtained with extinguisher B, the lowest – C. The differences in the results were significant. The parameters obtained for extinguishers A and C were higher by 29% and 96% than those obtained for extinguisher B.

4. CONCLUSION

Water mist is defined as water spray, whose $D_{v0,9}$ amounts to less than 1 000 µm at the minimum operating pressure. The tests have shown that two out of three tested extinguishers do not generate water mist with standard parameters at a distance of 170 cm. The extinguishers chosen for the tests are of the same type, have the same construction of the control valve and the same volume of the extinguishing medium. Two of the tested extinguishers have the same spraying nozzles. The extinguishers have differently constructed size of the tanks and length of the discharge hose. The smallest mean diameters of drops were generated by extinguisher B, whereas the biggest ones by extinguisher C. Despite the same construction of the spraying nozzle, drops generated by extinguishers A and B significantly differed in size. The slope of the curve representing the quantitative share of drops of up to 500 µm is similar to extinguishers A and C, the quantitative share of drops amounts to 60% for both extinguishers, whereas for extinguisher B it is approx. 80%. The curves representing the volumetric share of drops differ significantly. The flow of extinguishers A and C is not classified as water mist. At the range of 1 000 µm, the volumetric share of extinguisher A is approx. 65% and extinguisher C – 20%. However, it amounts to 90% for extinguisher B, which means that it generates water mist. The highest uniformity of spraying can be found in the stream of extinguisher A, the lowest – C. The smallest Sauter diameter mean was found in extinguisher

B and amounted to 564.03 µm, which shows that it had the biggest level of spraying among all samples.

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