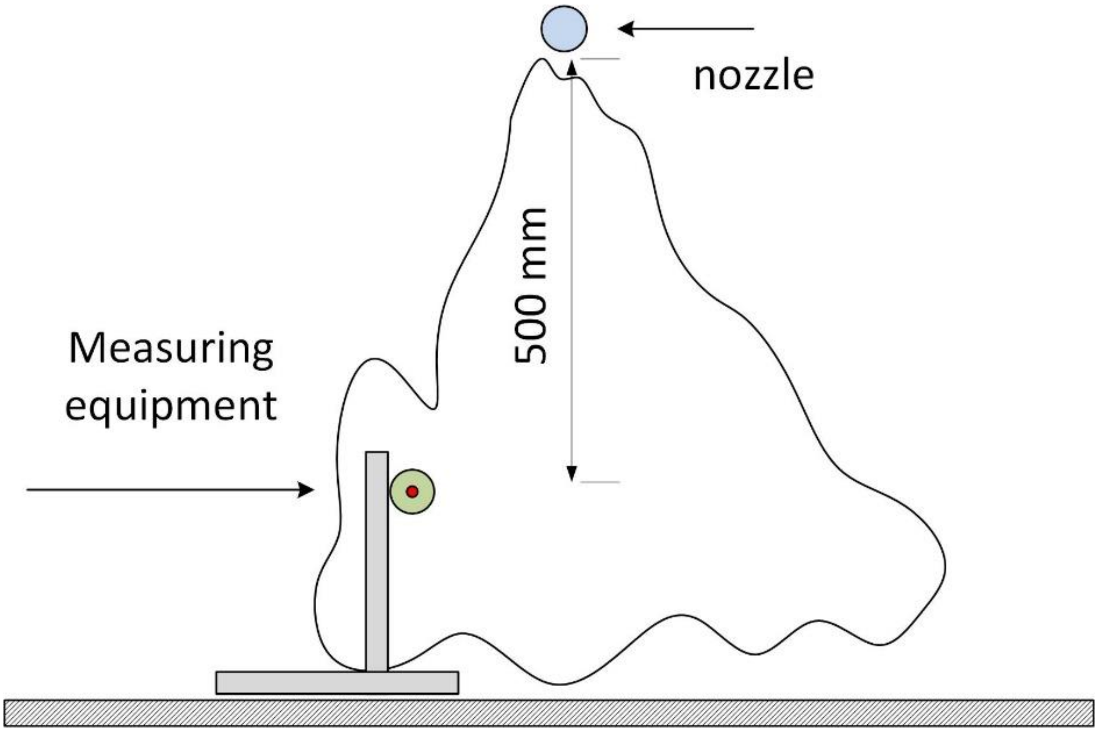
SAFETY AND TRANSPORT



Measurements of droplet size and velocity for three selected nozzles

Paul Otxoterena, Michael Försth

RISE Report 2024:25

Measurements of droplet size and velocity for three selected nozzles

Paul Otxoterena, Michael Försth

Abstract

Sprays produced by injecting water into quiescent air by three different types of nozzles were characterised by optical methods. The droplet velocities and droplet size distributions were assessed by the use of high speed shadowgraphs.

Key words: water spray, droplet size, velocity

RISE Research Institutes of Sweden
RISE Report 2024:25
ISBN 978-91-89896-73-4
Borås 2024

Table of Contents

Preface

The work is part of the project “Mechanisms and performance of different fixed fire fighting systems in tunnels” funded by Swedish Research Council FORMAS (2019-00521), which is gratefully acknowledged.

1 Introduction

To provide input data for numerical modelling of water sprays within the Formas project on fire suppression in tunnels, a series of water spray tests was conducted with the aid of optical methods. Three different nozzles were tested by injecting water into quiescent air. The objectives were to obtain the droplet size distributions of these three nozzles and provide useful data on droplet velocities.

2 Experimental set-up

The Shadowgraph method was used in the experiments. The experimental set-up was configured for allowing the characterisation of water sprays produced by the injection of water into quiescent air at injection pressures ranging between 0.39 and 11.5 bar. The experimental set-up consisted of a pressurised liquid source, an electrically driven reciprocating pump, a pressure regulator, a flow meter, a nozzle, a high speed camera and optics. The nozzles tested were Bete WL1, Lechler 502.448 and Bete MP156.

Measurements were done 500 mm downstream the nozzle exit and at three radial positions: 0, 300 and 600 mm from the injection axis. A sketch of the measuring equipment in relation to the spray cloud is depicted in Figure 1. Figure 2 depicts the four radial locations where measurements were conducted, being a total of 9 locations inside the spray cloud.

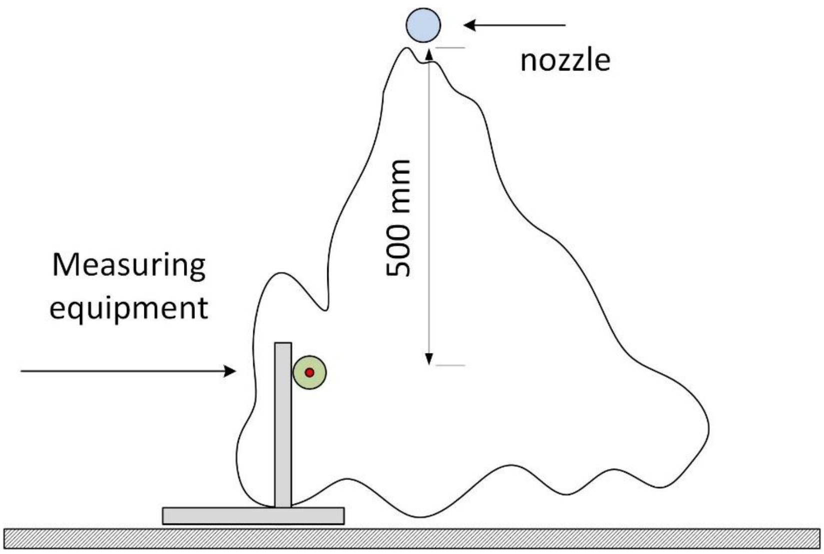


Figure 1. Sketch showing the placement of the experimental equipment in relation to the spray cloud.

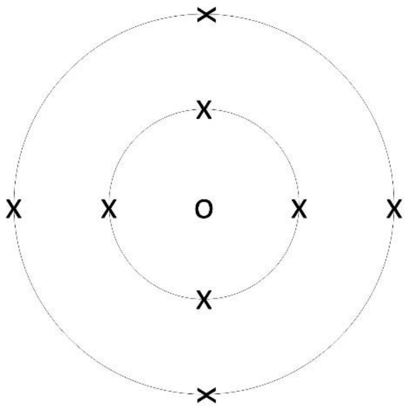


Figure 2. Measuring locations. The plane containing the measuring locations has its normal contained in the injection axis.

Droplet size distributions were measured by high speed shadowgraphs which were digitally post processed. A collimated light source through the aerosol was projected and the projected shadow was captured by a set of lenses on a monochromatic high speed CCD camera. The measuring volume was 19 x 11 mm with an opening of 20 mm in width. The shadowgraphs were captured at 10 kHz using a resolution of 2048 x 1152 pixel with a dynamic range of 12 bits.

3 Experimental procedure

The size and the position of the droplets were obtained by digitally processing the captured shadowgraphs. The processing procedure involved background subtraction, binarising the images, performing derivative edge detection and contour expansion before analysing the aspect ratio of the possible droplets. The projected surface of each of the validated droplet was then computed and their diameter was obtained. Drop velocity was computed by tracking the position of the droplets as function of time using particle tracking algorithms. Details of the employed methodology can be found elsewhere [1-3].

The system configuration used in this experimental set-up was adjusted to detect droplet sizes ranging between 10 and 3000 µm in non-optically dense sprays.

4 Results

4.1 Normalised droplet size distribution

The normalised droplet size distributions for the sprays produced by the tested nozzles at the studied conditions are presented in Figure 3 to Figure 7. For demonstrative purposes, data pertaining the entire spray produced by the Lechler nozzle is presented in Figure 4 while data measured exclusively at the central part of the spray produced by the same nozzle is depicted in Figure 5.

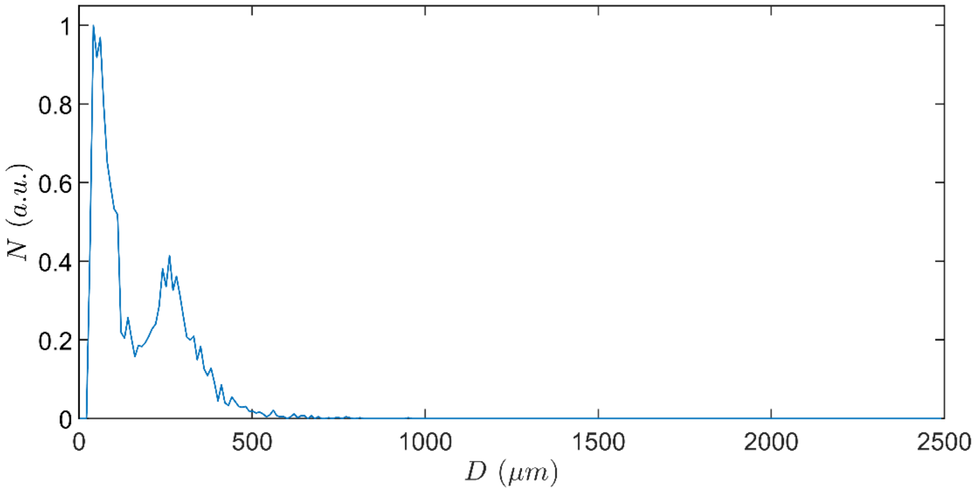


Figure 3. Normalised droplet size distributions for sprays produced by Bete WL1 and measured at an injection pressure of 5.4 bar.

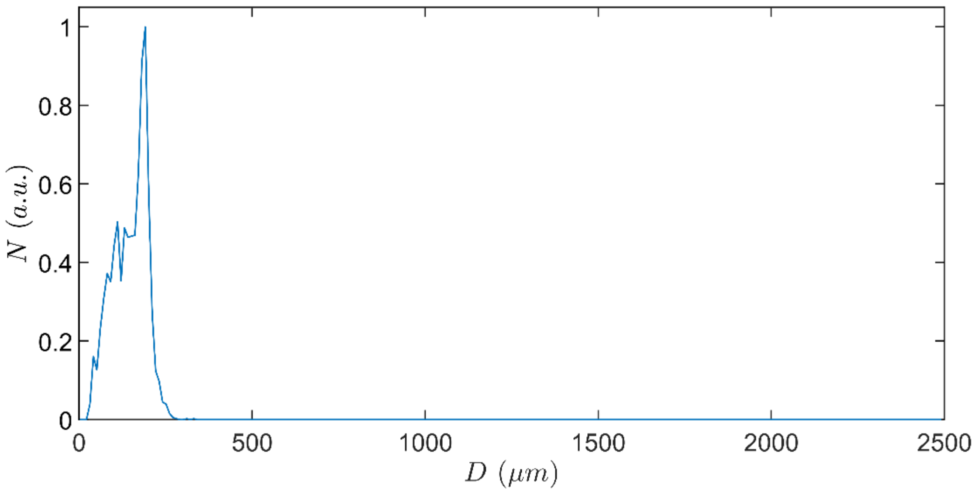


Figure 4. Normalised droplet size distributions for sprays produced by Lechler and measured at an injection pressure of 11.5 bar.

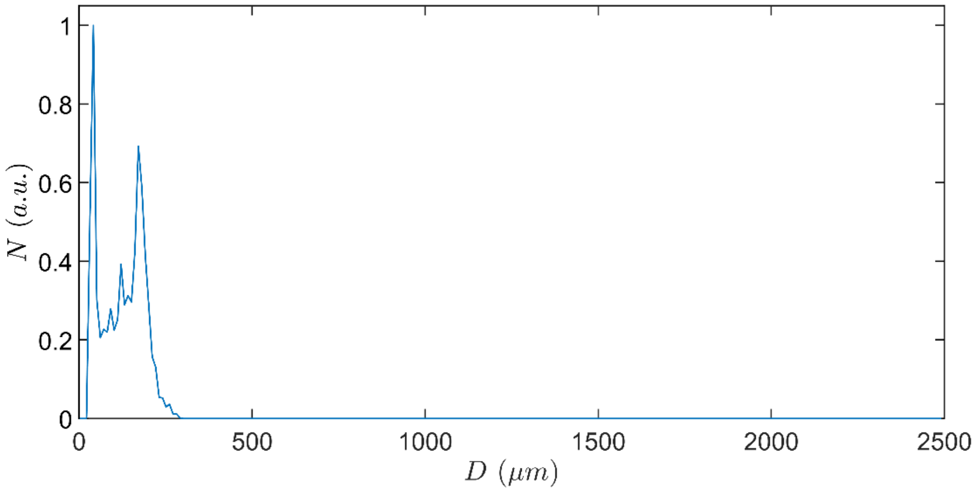


Figure 5. Normalised droplet size distributions for ***exclusively the central part*** *of the spray produced by Lechler and measured at an injection pressure of 11.5 bar.*

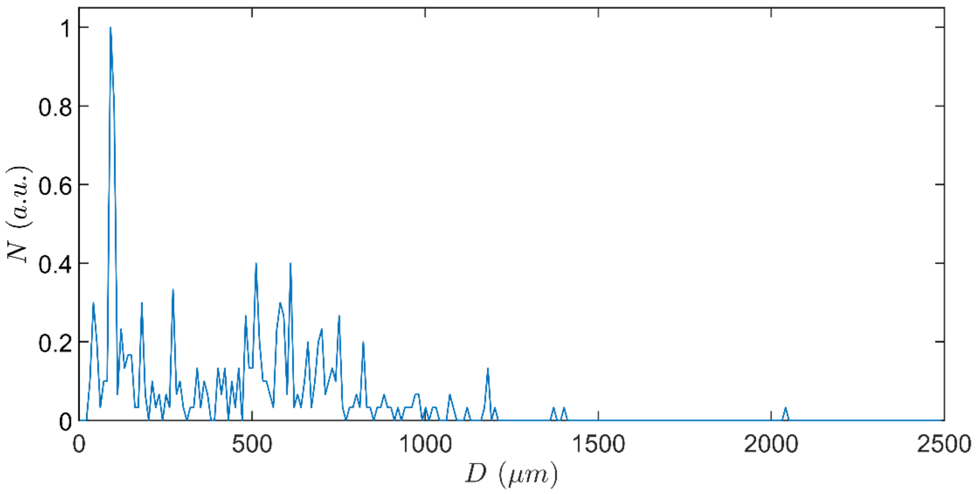


Figure 6. Normalised droplet size distributions for the sprays produced by MP156 and measured at an injection pressure of 0.39 bar.

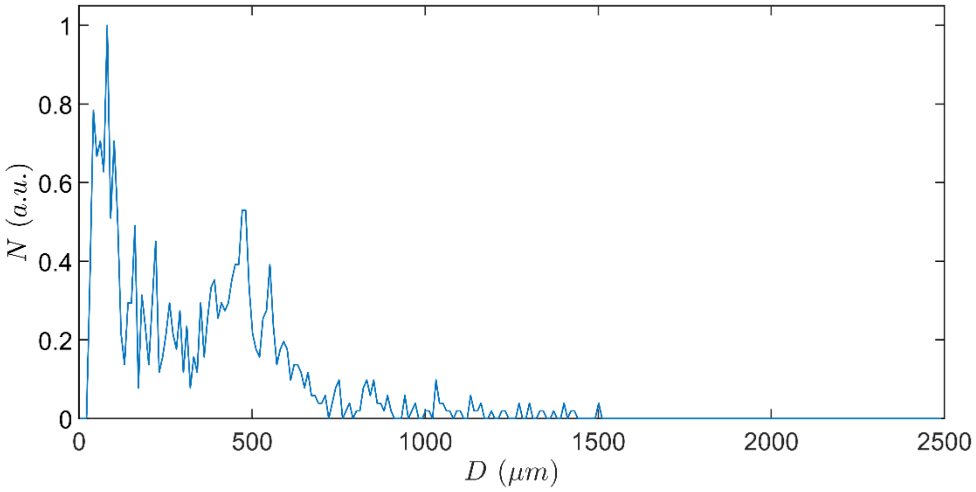


Figure 7. Normalised droplet size distributions for the sprays produced by MP156 and measured at an injection pressure of 0.82 bar.

4.2 Cumulative density functions

The cumulative density functions on droplet volume for the tested nozzles at the studied conditions are presented in Figure 8Figure 12. For demonstrative purposes, data pertaining the entire spray produced by the Lechler nozzle is presented in Figure 9 while data measured exclusively at the central part of the spray produced by the same nozzle is depicted in Figure 10.

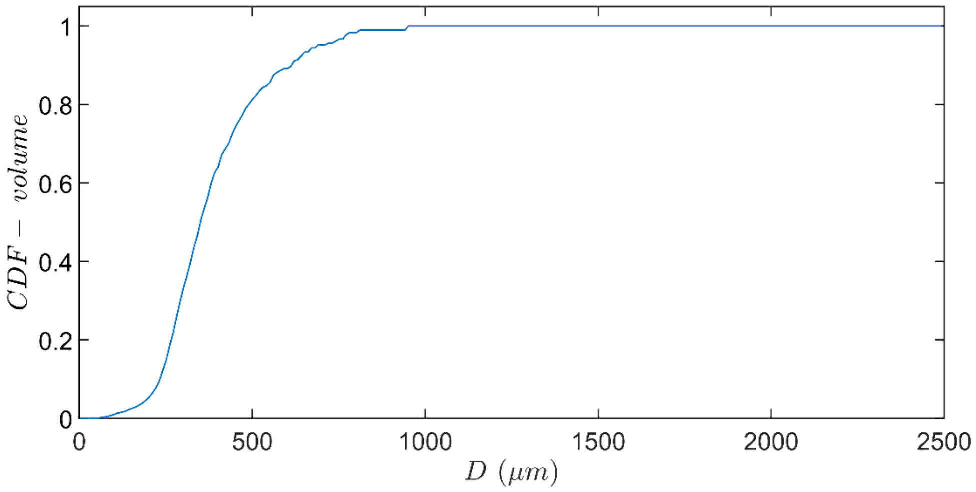


Figure 8. Cumulative density function on droplet volume for the sprays produced by Bete WL1 and measured at an injection pressure of 5.4 bar.

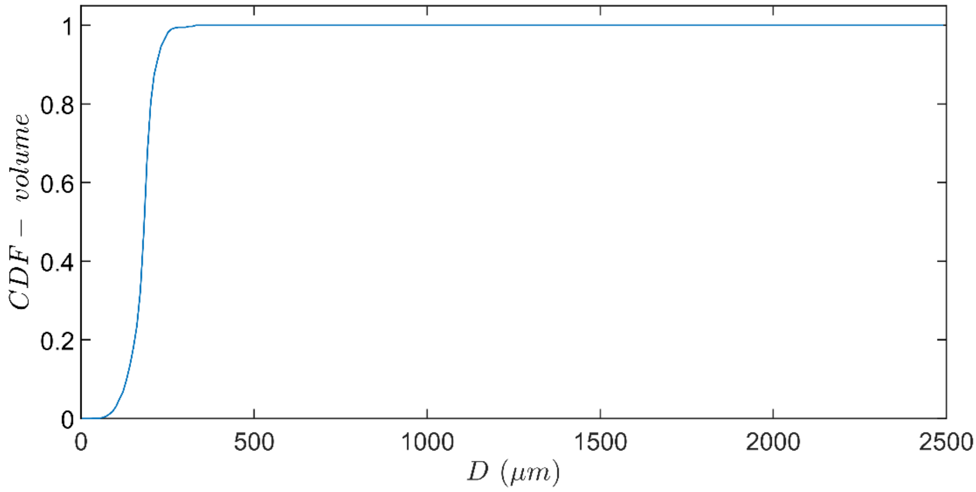


Figure 9. Cumulative density function on droplet volume for the sprays produced by Lechler and measured at an injection pressure of 11.5 bar.

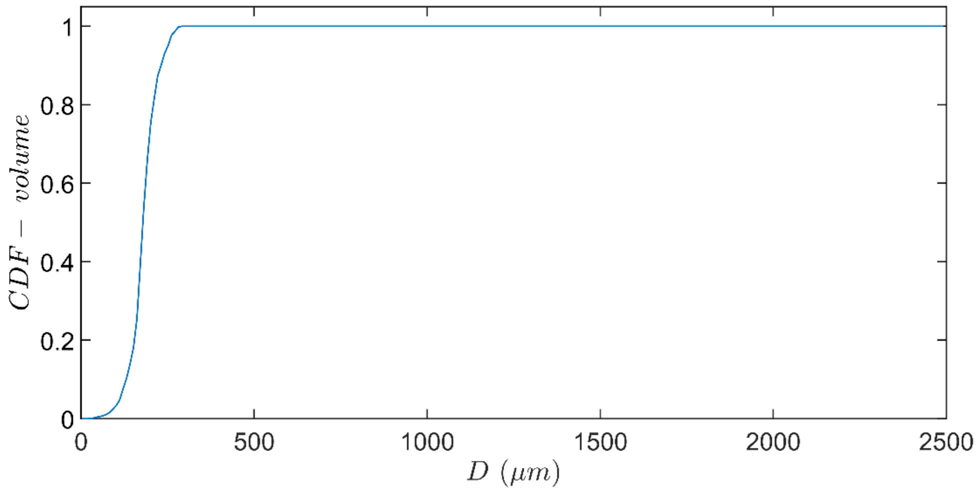


Figure 10. Cumulative density function on droplet volume for ***exclusively the central part*** *of the spray produced by Lechler and measured at an injection pressure of 11.5 bar.*

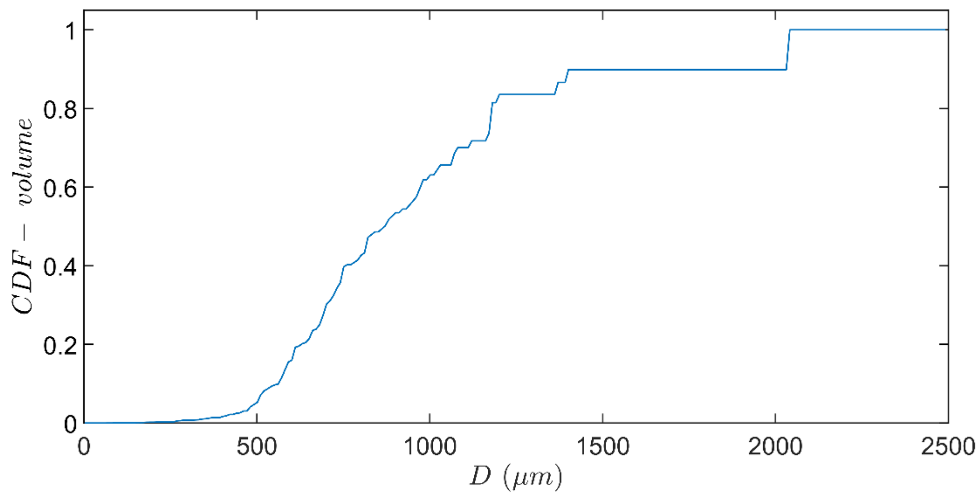


Figure 11. Cumulative density function on droplet volume for the sprays produced by MP156 and measured at an injection pressure of 0.39 bar.

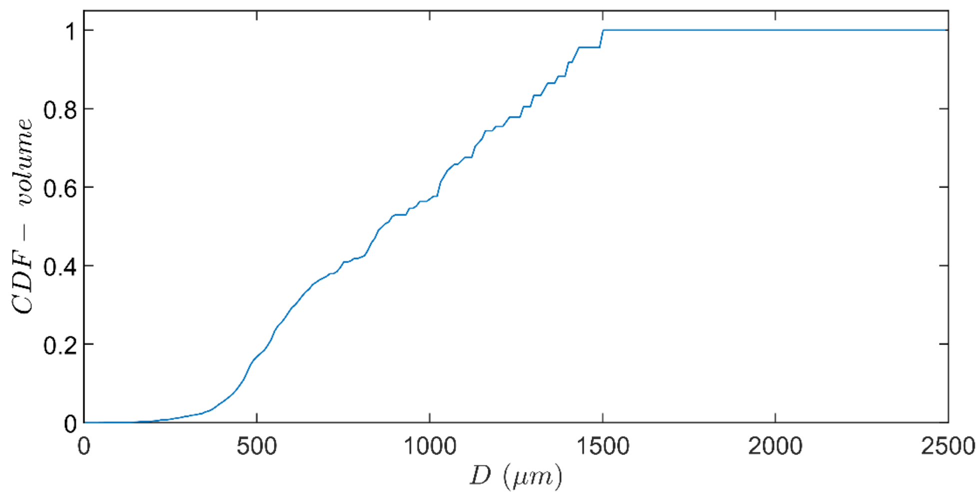


Figure 12. Cumulative density function on droplet volume for the sprays produced by MP156 and measured at an injection pressure of 0.82 bar.

4.3 Averaged velocity

Results about averaged velocity, v_μ, standard deviation, v_σ, and measured limits for the studied nozzles at the tested conditions are presented in Table 1.

Table 1. Averaged velocity (v_μ), standard deviation (v_σ) and measured velocity limits for the studied nozzles at the measured conditions.

	Bete WL1	*Lechler*	*Lechler **-centre***	*MP 156*	*MP 156*
p (bar)	*5.4*	*11.5*	*11.5*	*0.39*	*0.82*
v_μ *(m/s)*	*3.56*	*0.56*	*1.19*	*2.54*	*2.58*
v_σ *(m/s)*	*2.77*	*0.32*	*0.65*	*1.30*	*1.19*
min (v) (m/s)	*0.37*	*0.40*	*0.56*	*0.19*	*0.59*
max (v) (m/s)	*9.37*	*1.53*	*2.44*	*4.40*	*4.38*

5 Discussion

Results regarding droplet size show that, as expected, increasing the injection pressure leads to a reduction in droplet size. Droplet size distributions show that the tested nozzles produce sprays where the vast majority of droplets have sizes below 1000 µm. However, the nozzles identified as MP156 produced sprays with a not neglectable amount of droplets between 1000 and 1500 µm in diameter. The computed CDFs on volume (also known as CVF) for MP156 at both operating pressures, reach unity at sizes as large as 1500 and 2000 µm at the lower and higher injection pressures, respectively. Results pertaining droplet velocity show large variations within each of the sprays for all the tested nozzles.

References

[1] Canny J. A computational approach to edge detection. IEEE Transactions on Pattern Analysis and Machine Intelligence 8:679–698, (1986).
[2]Luc Biasiori-Poulanges and Hazem El-Rabii, "High-magnification shadowgraphy for the study of drop breakup in a high-speed gas flow," Opt. Lett. 44, 5884-5887, (2019).
[3] Otxoterena Af Drake P., Willstrand O., Andersson A., and Biswanger H., Physical characteristics of splash and spray clouds produced by heavy vehicles (trucks and lorries) driven on wet asphalt, J. Wind, Eng. And Ind. Aero., 217, (2021).

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,200 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

I internationell samverkan med akademi, näringsliv och offentlig sektor bidrar vi till ett konkurrenskraftigt näringsliv och ett hållbart samhälle. RISE 2 200 medarbetare driver och stöder alla typer av innovationsprocesser. Vi erbjuder ett 100-tal test- och demonstrationsmiljöer för framtidssäkra produkter, tekniker och tjänster. RISE Research Institutes of Sweden ägs av svenska staten.

RISE Research Institutes of Sweden
Box 857, 501 15 BORÅS
Telefon: 010-516 50 00
E-post: info@ri.se, Internet: www.sp.se / www.ri.se

Safety and Transport –
Fire and Safety
RISE Report 2024:25
ISBN 978-91-89896-73-4