14th International Water Mist Conference

THE USE OF AIR ATOMIZING NOZZLES TO PRODUCE SPRAYS WITH FINE DROPLETS

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INTRODUCTION

Break up mechanism for a sprinkler head:

Pressurized water column impinges on a solid deflector to form a spray of droplets

Water pressure is minimum 0.5 bar and maximum 12 bar

The orifice diameter is in the order of 13 mm

In the produced spray, droplet diameters are in the order of "milimeters"

INTRODUCTION

Break up mechanism for a watermist nozzle:

Water pressure is increased and orifice size is reduced.

For low pressure systems, water pressure is less than 12 bar

For medium pressure systems, water pressure is between 12 bar and 34 bar

For high pressure systems, water pressure is more than 34 bar

The orifice diameter is less than a milimeter

In the produced spray, droplet diameters are less than 1 mm

Classification in NFPA 750

Average droplet diameter

Class-1 → less than 200 μm

Class-2 → between 200 μm and 400 μm

Class-3 → between 400 μm and 1000 μm

INTRODUCTION

Break up mechanism for the proposed air atomizing nozzle design:

Pressurized air jets are used to breakup the pressurized water columns.

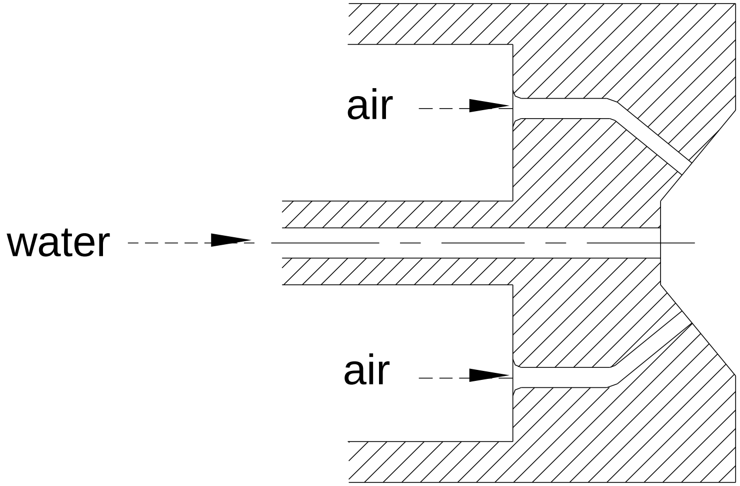
Water pressure is in the order of 1 bar

Air pressure is in the order of 2 bar

Water hole diamater is 3.5 mm

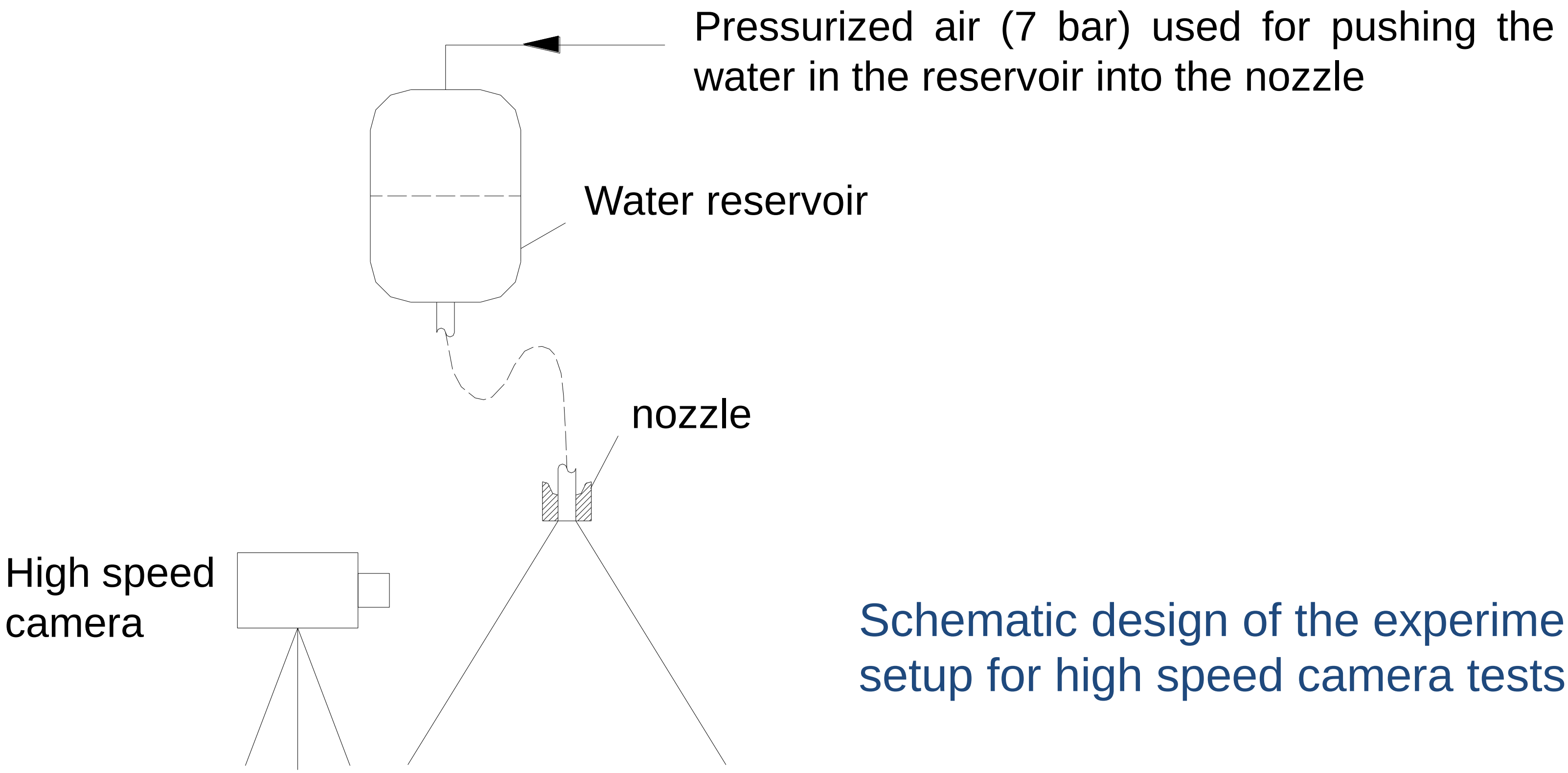
Each of the four air holes has a diamater of 1 mm

In the produced spray, droplet diameters are less than 1 mm



RESULTS OF A PREVIOUS STUDY

It will be useful to mention the results of previous experimental studies, (Balık, 2006 and Balık, 2010), conducted in the Von Karman Institute, Belgium (www.vki.ac.be).

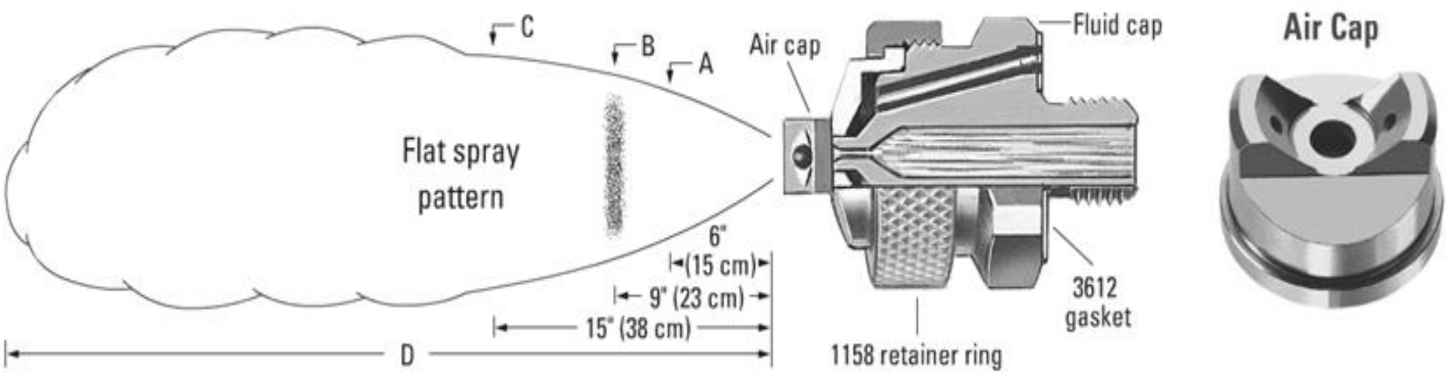


Schematic design of the experimental setup for high speed camera tests

RESULTS OF A PREVIOUS STUDY

The air atomizing nozzle (Spraying Systems Co.) used in the experiments

- The stainless steel nozzle is an external mixing type air atomizing nozzle, i.e. no mixing chamber is available.
- Two air jets are produced from the 45º inclined air holes.
- The diameter of the water side orifice is 1.50 mm while each of the air side orifices has a diamater of 1.35 mm.
- The produced spray is a **flat spray with a spray angle of 60º**

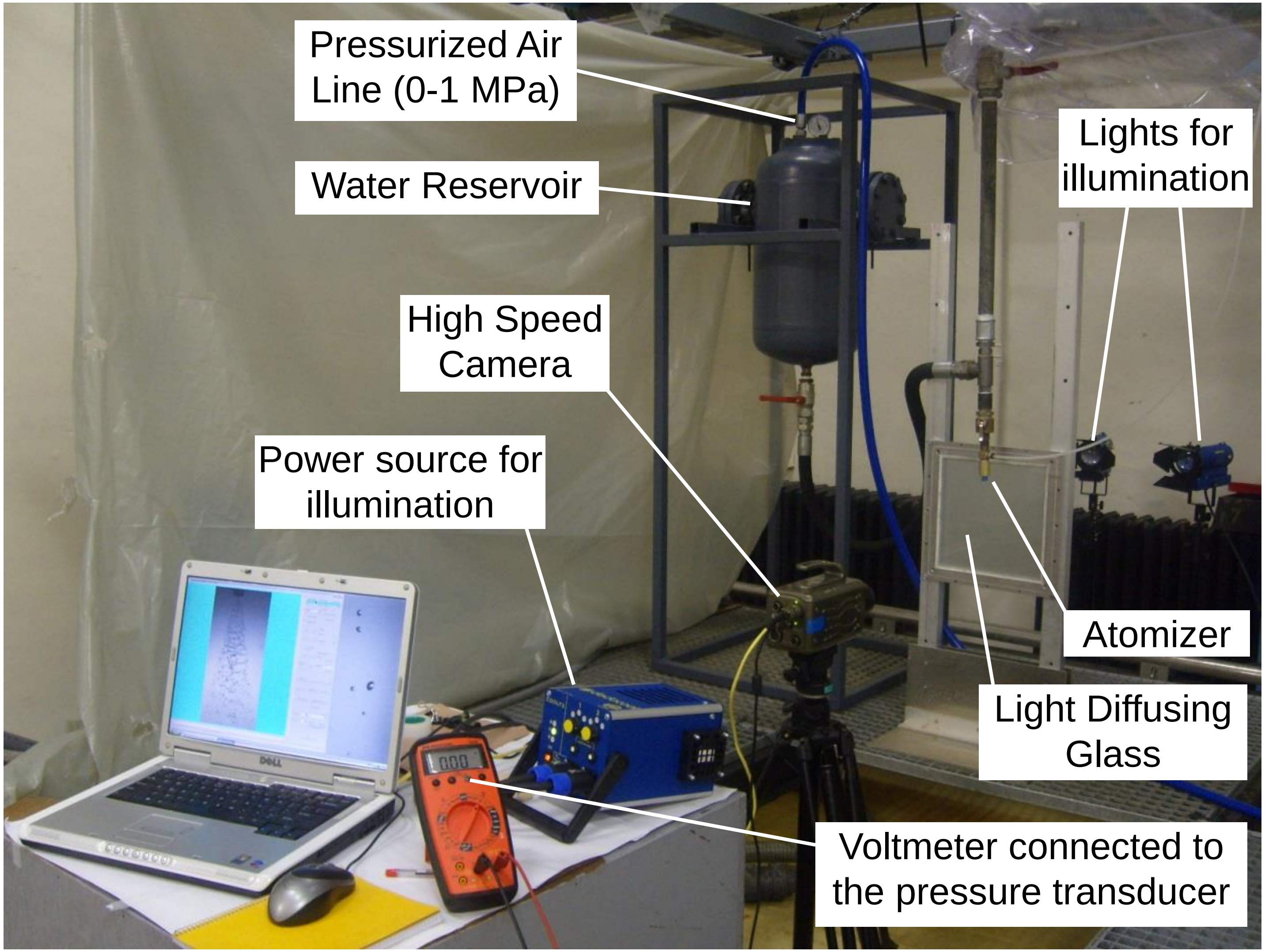


RESULTS OF A PREVIOUS STUDY

The experiments are performed by fixing the water flow rate at approximately $\dot{m}_w = 1.152$ l/min and altering the air flow rate to obtain various AIR-TO-LIQUID RATIO (w) values.

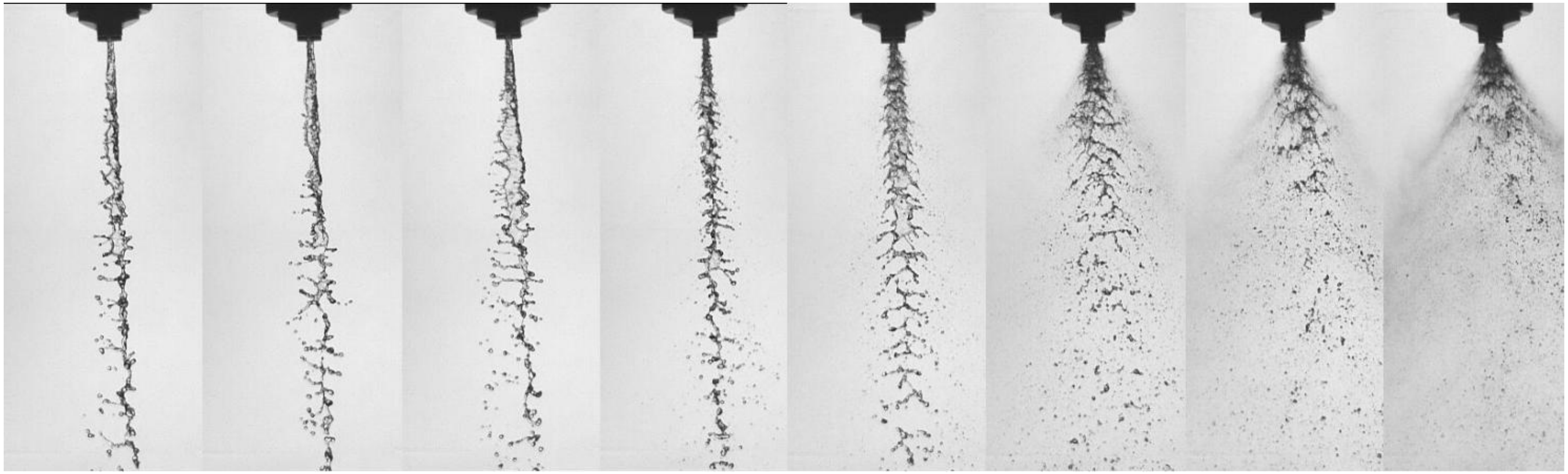
- The air-to-liquid ratio is defined as the ratio of the mass flow rates of air and water and it is commonly used in literature.
- The water pressure at the upstream of the nozzle is measured as 0.62 bar
- It has been more practical to use the reciprocal of air-to-liquid ratio (w^{-1}) to express the experimental conditions
- Measurements are performed for 8 different "w^{-1}" values ($6 < w^{-1} < 88$)
- The pressurized air source was 7 bar, but the pressure is reduced to obtain the given "w^{-1}" values.

EXPERIMENTAL SETUP
FOR HIGH SPEED CAMERA TESTS

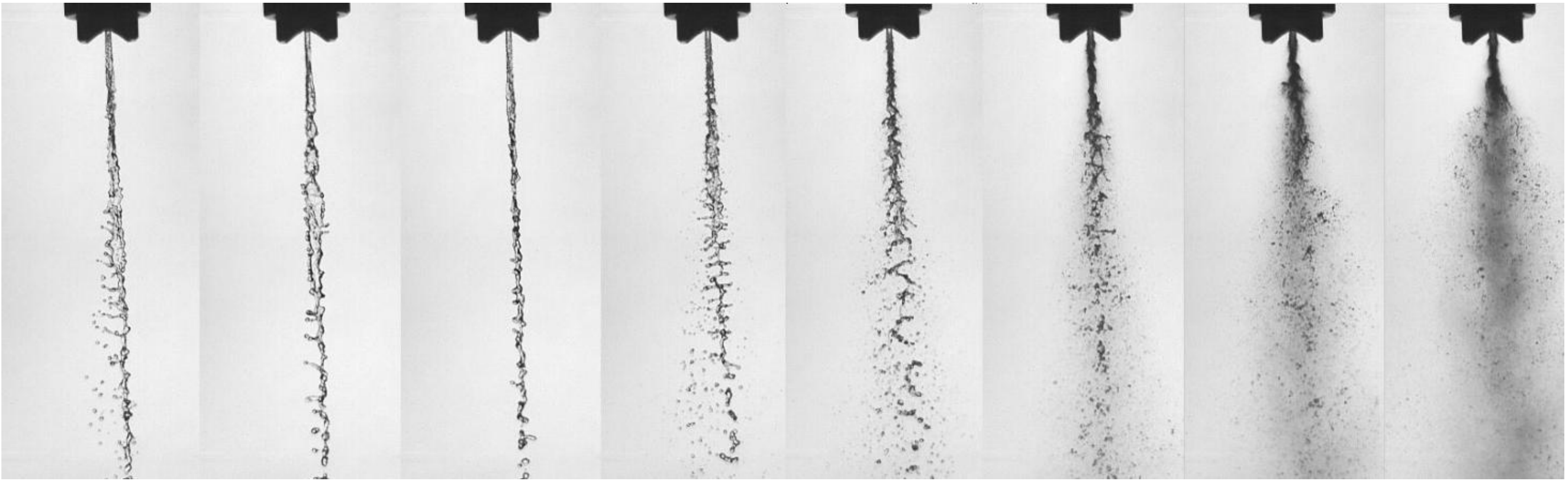


HIGH SPEED CAMERA IMAGES

(Water flow rate is fixed as $\dot{m}_w = 1.15$ l/min)



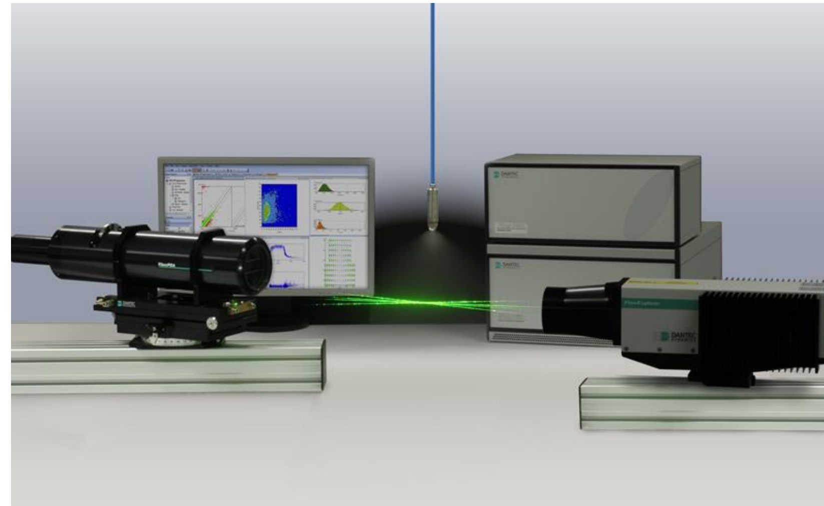
(only water) ($w^{-1} \approx 88$) ($w^{-1} \approx 43$) ($w^{-1} \approx 24$) ($w^{-1} \approx 15$) ($w^{-1} \approx 10$) ($w^{-1} \approx 8$) ($w^{-1} \approx 6$)

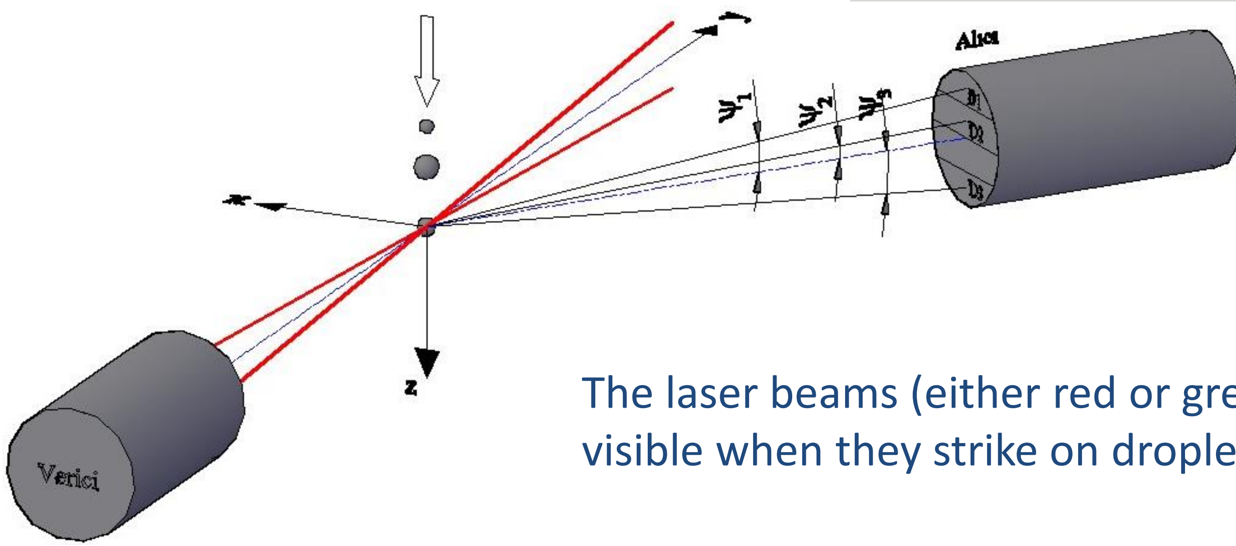


DROPLET SIZE AND VELOCITY MEASUREMENT SYSTEM

The measurement system is known by several names in the market:

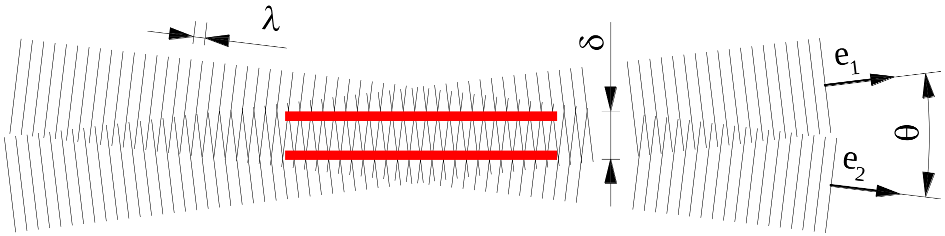
- Phase Doppler Analyzer (PDA)
- Phase Doppler Particle Anaylzer (PDPA)
- Phase Doppler Interferometer(PDI)





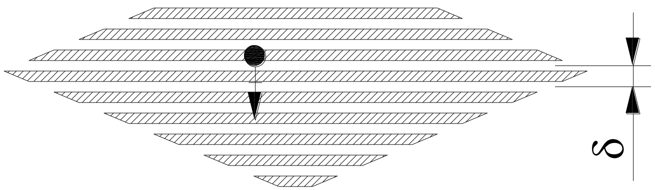
The laser beams (either red or green lights) become visible when they strike on droplets

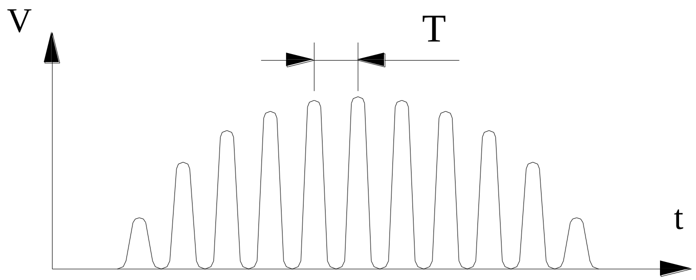
PRINCIPLE OF VELOCITY MEASUREMENT (DOPPLER FREQUENCY)



- The distance between the fringe lines (δ) is used as a very accurate ruler to measure the distance. This distance can be calculated from the wavelength (λ) of the laser light and the alignment angle (θ) of the beams.

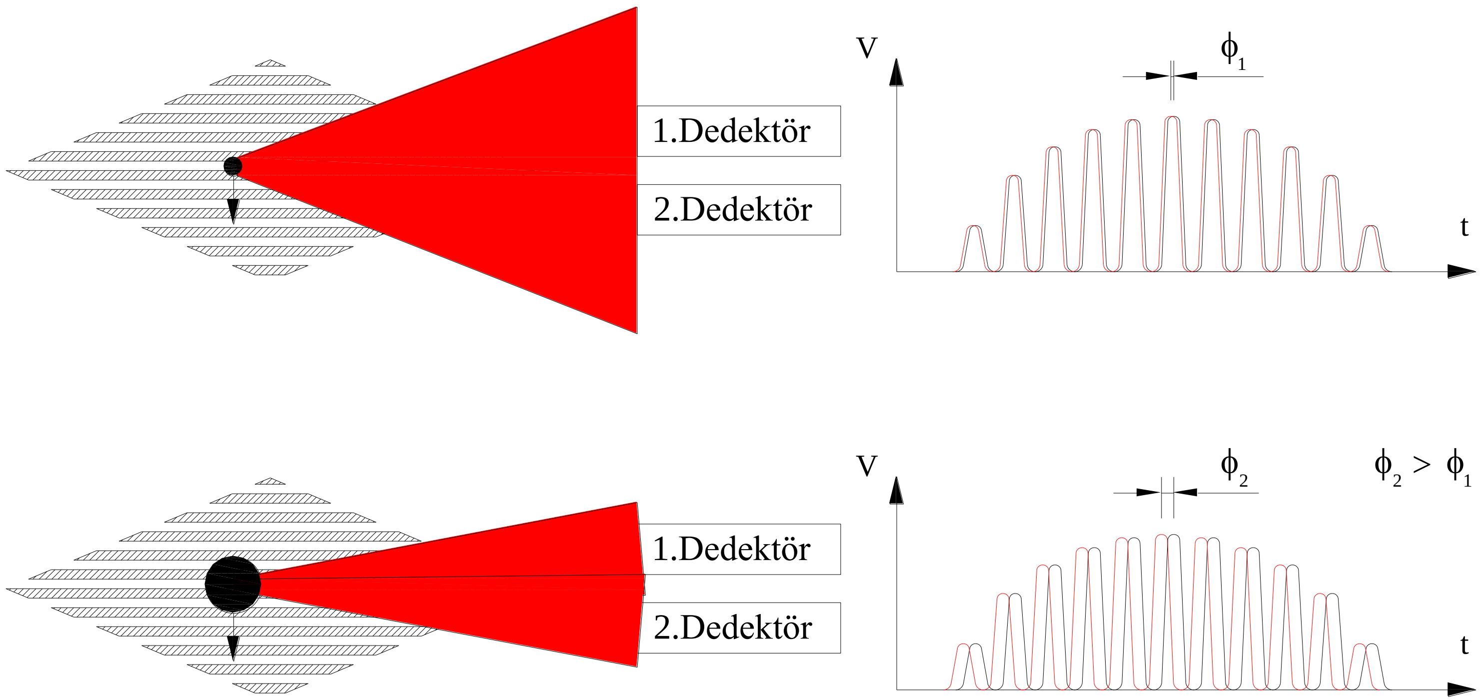
- The droplets produce a signal on the receiver when it passes through each fringe line and the time difference (Δt) between two successive signals is recorded by the data acquisition system.





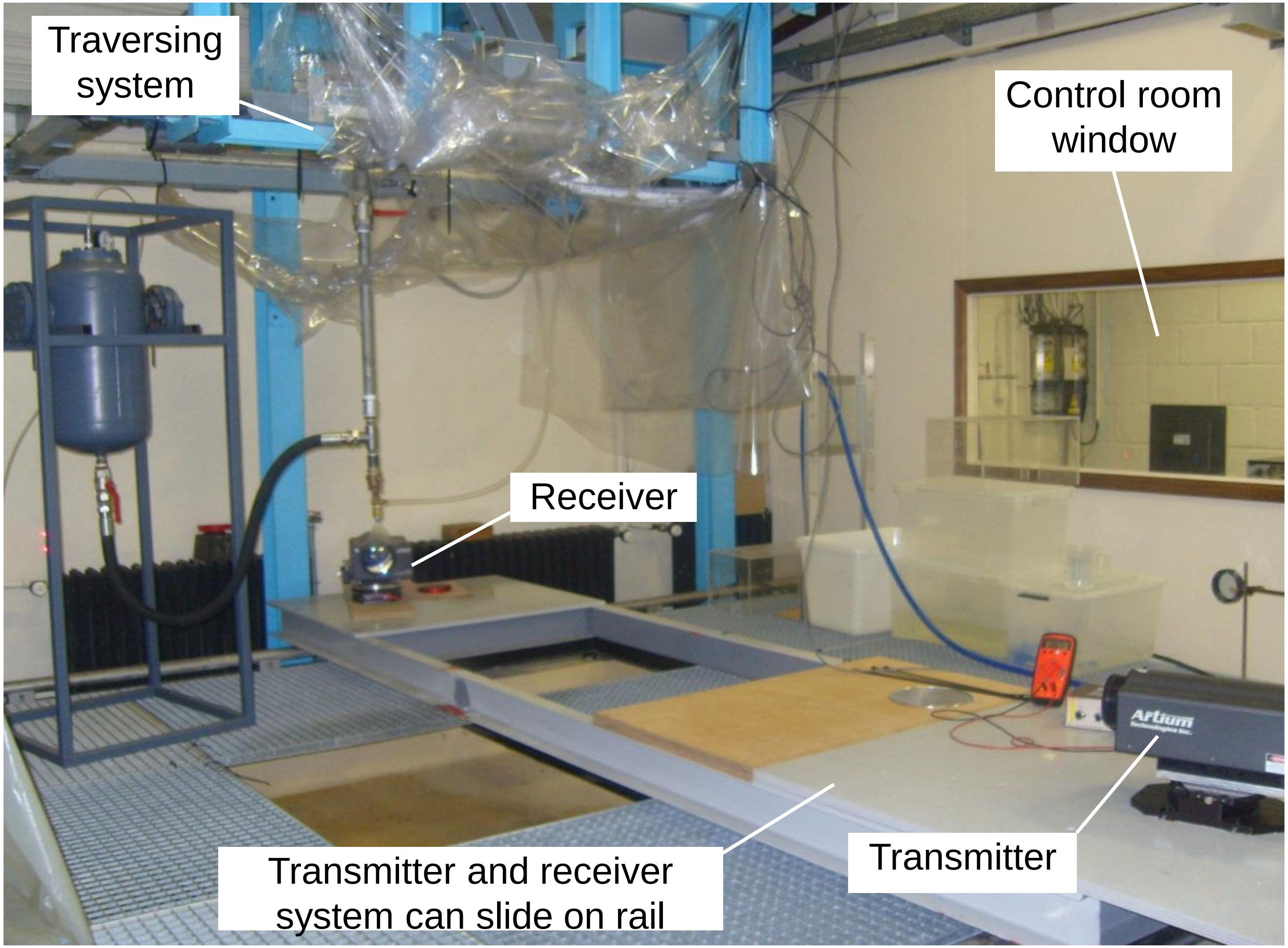
- Finally, the velocity of the droplet can be calculated as → $V = \delta / \Delta t$

PRINCIPLE OF VELOCITY MEASUREMENT (PHASE DIFFERENCE)



- The small and large particles produce different phase differences on multiple photodetectors, which are located on the receiver.
- The droplet diameter is calculated from the phase difference information.

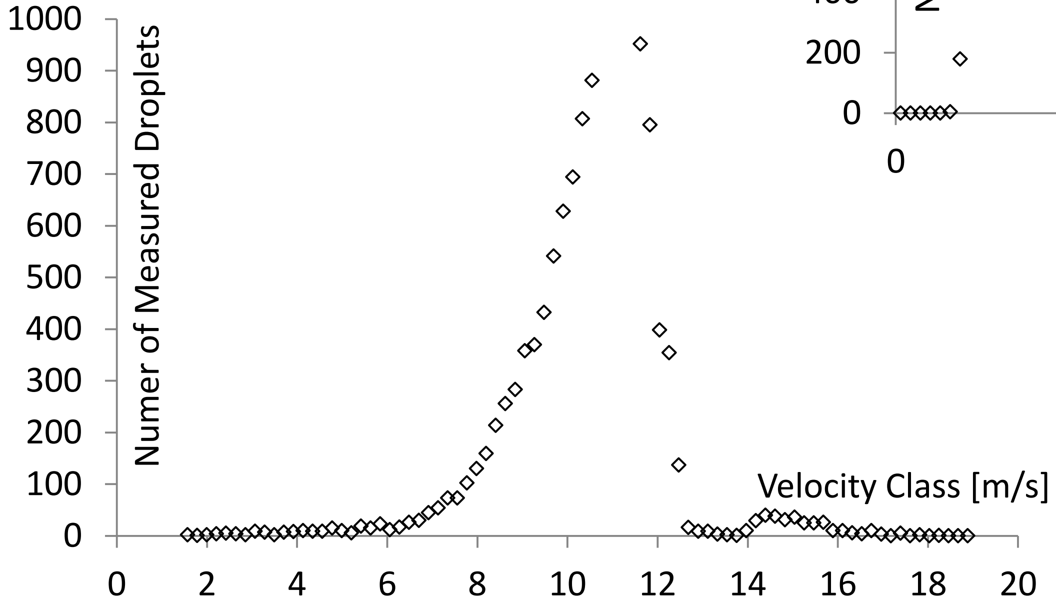
EXPERIMENTAL SETUP
FOR PHASE DOPPLER SYSTEM TESTS

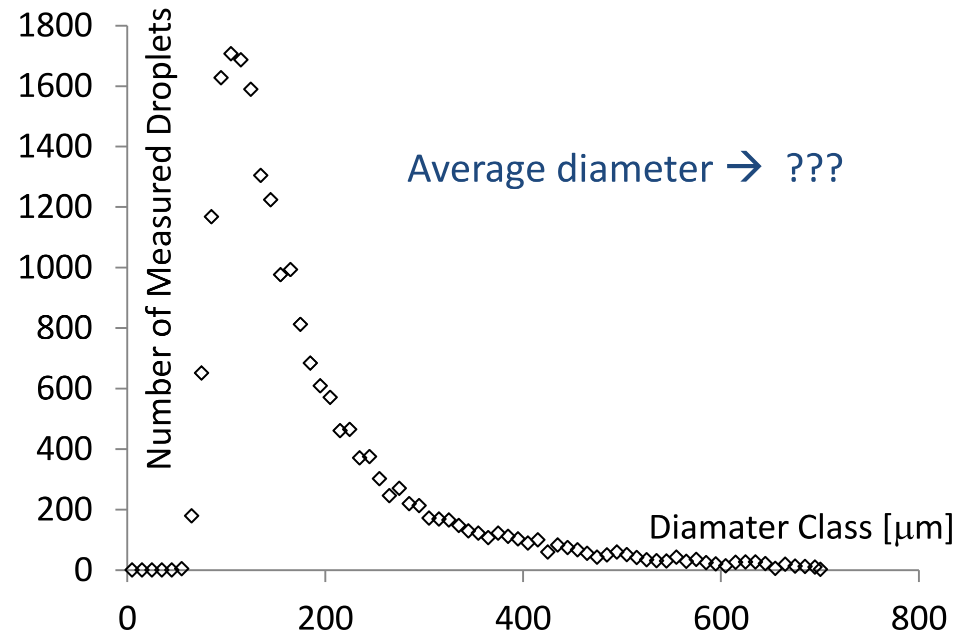


DROPLET SIZE AND VELOCITY DISTRIBUTIONS

Joint velocity and size distribution of droplets passing through the center of the spray at a point $\boldsymbol{x = 150\, d_0}$ downstream of the atomizer

Average velocity ≈ 11 m/s





Average diameter → ???

Sauter Mean Diameter (SMD)

$$D_{32} = \frac{\int_0^\infty D^3 f_0(D)\,dD}{\int_0^\infty D^2 f_0(D)\,dD} = \frac{\sum N_i D_i^{\,3}}{\sum N_i D_i^{\,2}}$$

EMPIRICAL RELATION FOR OBTAINING DROPLET DIAMETERS

Elkotb et.al. (1982) proposed the below empirical relation to obtain Sauter Mean Diameter (SMD) of the droplets for an external mixing type air atomizing nozzle:

$$\mathrm{SMD} = 51\, d_0 Re^{-0.39} We^{-0.18} \left(\frac{\dot{m}_L}{\dot{m}_A}\right)^{0.29}$$

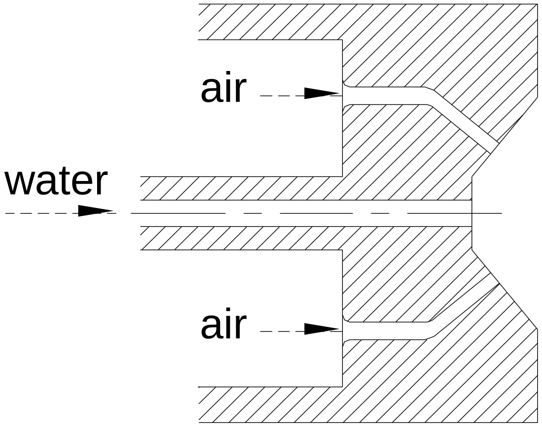
In this empirical relation, Re and We are the dimensionless Reynolds number and Weber number. And $\frac{\dot{m}_L}{\dot{m}_A}$ is known as the "AIR TO LIQUID RATIO".

$$Re = \frac{\rho_L U_R d_0}{\mu_L} = \frac{U_R d_0}{\nu_L} \qquad We = \frac{\rho_L U_R^2 d_0}{\sigma}$$

ρ_L = density of the liquid
μ_L = dynamic viscosity of the liquid
ν_L = kinematic viscosity of the liquid
σ = surface tension

THE PROPOSED DESIGN

- Water hole diamater is 3.5 mm
- Each of the four air holes has a diamater of 1 mm
- The velocity of the water jet at the outlet of the orifice is taken as 30 m/s
- The air jets are assumed to be introduced with a maximum achievable velocity of approximately 330 m/s
- The relative velocity between the air jet and the water jet is calculated by taking the horizontal component of the air jet as 230 m/s
- The flow rate of the water is then calculated as approximately 17 l/min.
- Assuming the K-factor as $K = 20\ l/(min \cdot \sqrt{bar})$, the calculated water flow-rate can be obtained by a water pressure of not more than 1 bar.



THE PROPOSED DESIGN

- Total air flow-rate from 4 holes is obtained as 0.0012 kg/s, which corresponds to a flow rate of approximately 0.1 air change per hour, i.e. negligibly small!

- The ratio of the mass flow rates of water and air (AIR TO LIQUID RATIO) is obtained as $\dot{m}_{water}/\dot{m}_{air} = 231$
- The thermodynamic properties of air and water are used to calculate the Reynolds number (approximately Re = 800,000) and the Weber number (approximately We = 2,600,000)

- Using the below empirical relation, Sauter Mean Diameter is calculated as approximately 300 μm for this nozzle.

$$\mathrm{SMD} = 51\, d_0 Re^{-0.39} We^{-0.18} \left(\frac{\dot{m}_L}{\dot{m}_A}\right)^{0.29}$$

RESULTS

- In the proposed nozzle design, a spray with an average droplet diamater (SMD) of 300 μm can be obtained by using moderate pressure values at both air and water sides.

- Water pressure is calculated as 1 bar by assuming $K = 20\ l/(min \cdot \sqrt{bar})$.

- The amount of air introduced into the origin of fire is calculated to be negligibly small, i.e. approximately 0.1 air changes per hour, so that there shouldn't be a concern about fire growth due to the air coming from the nozzle.

- The water pressure in the proposed system is in the same order with that in sprinkler systems. Since the exposed pressure value is reduced, both the system components and the piping can be made of less expensive materials. It is thought that this will have a great contribution in terms of a cost effective design over the conventional watermist nozzles for producing fine sprays.

RESULTS

- The diamater of the water hole in the proposed air atomizing nozzle is smaller than that in a typical sprinkler nozzle but it is still considerably larger than that of a typical water mist nozzle. Therefore, the proposed nozzle design will have an advantage for preventing the clogging problem comparing to typical water mist nozzles. It is open to discussion if conventional sprinkler pipes can be used in the proposed design by simply adding strainers. Further exprimental studies are required to make conclusions on this issue.

- The addition of an air compressor and an air pipe to the system is the disadvantage of the system using the nozzle in the proposed design.

- The idea seems promising but further studies are required to prove its effectiveness in the area of fire suppression industry.