

Numerical simulations of dense water mist sprays in cold conditions with an emphasis on multi-droplet aerodynamic interactions

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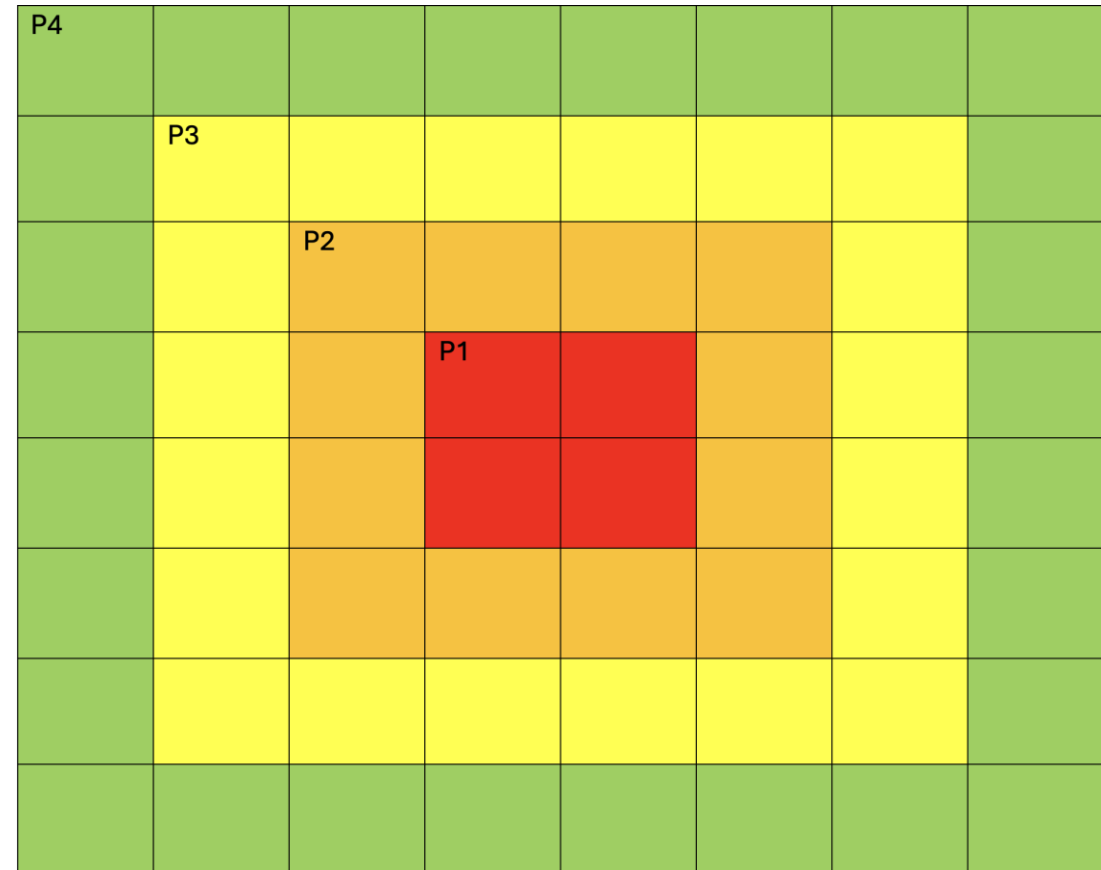
Acknowledgment

- Thanks to Prof. Tom De Mulder and Prof. Tarek Beji



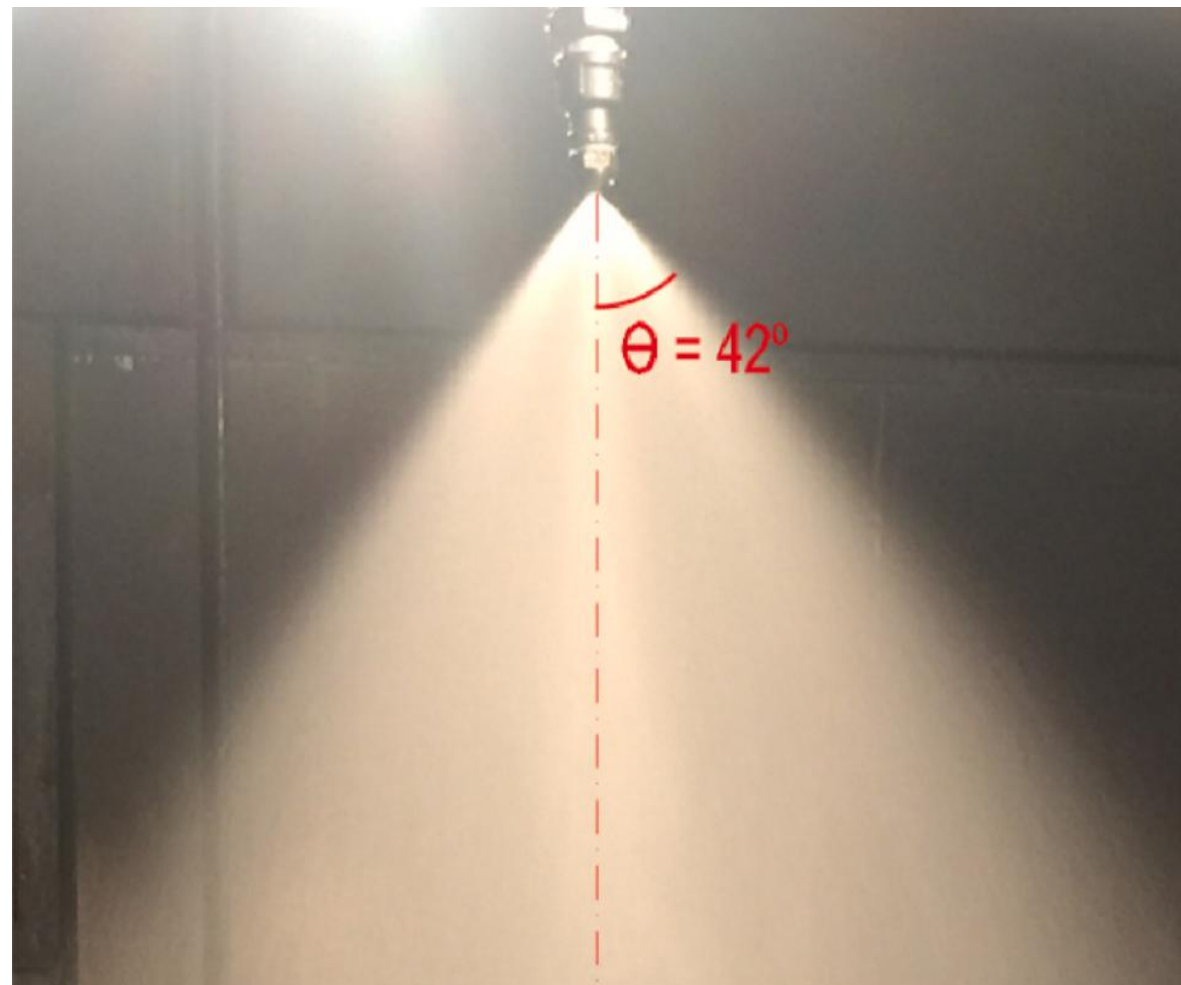
Terminology

- Averaged water flux: $\overline{q''} = \frac{V}{t * A}$
- Deviation: $\frac{\overline{q''}_{this\ study} - \overline{q''}_{experimental\ data}}{\overline{q''}_{experimental\ data}}$
- Near field, Mid-field and Far field Region



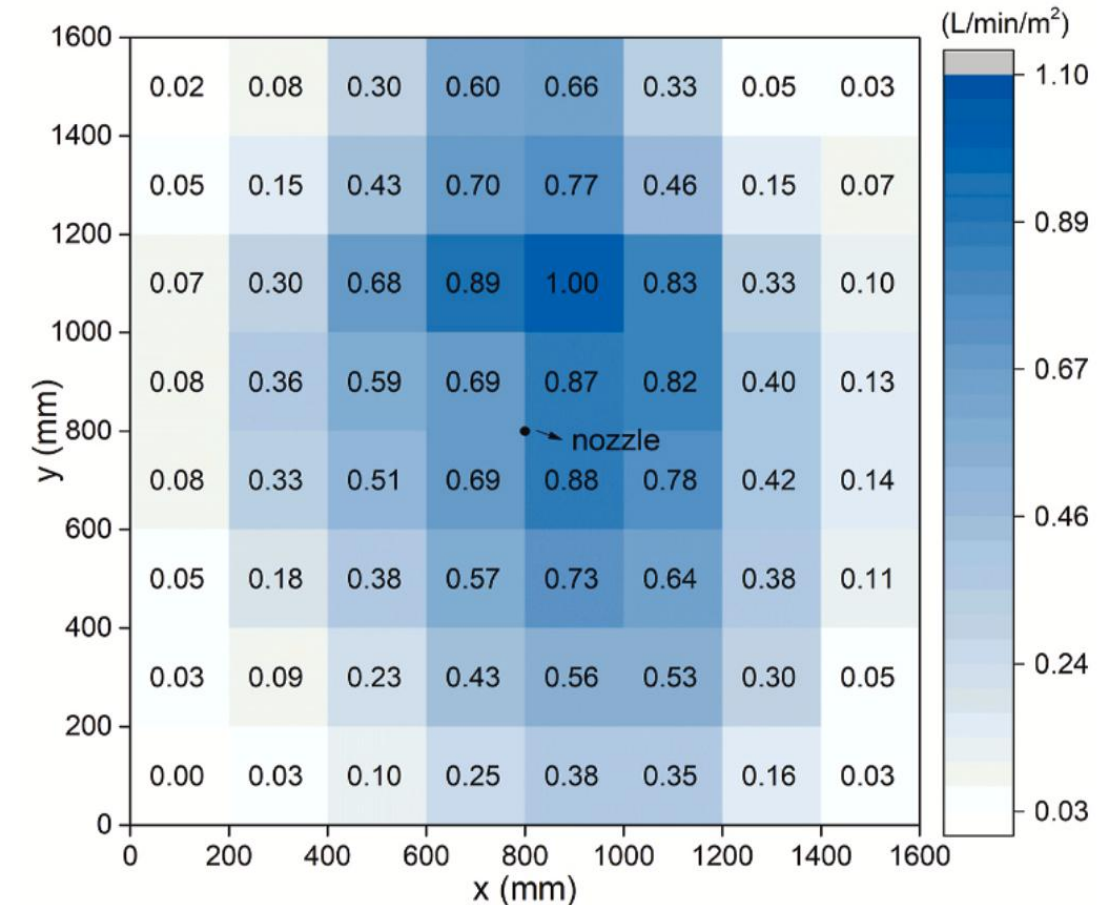
Low Pressure Water Mist Experimental Setup

- Nozzle Location
- Width of spray pattern
- Terminal velocity point
- Water droplets' diameter
- Water droplets' velocity
- Averaged water flux
- Spray angle



Low Pressure Water Mist Experimental Result

- Average water flux measured in the experiment carried out by Liu et al.

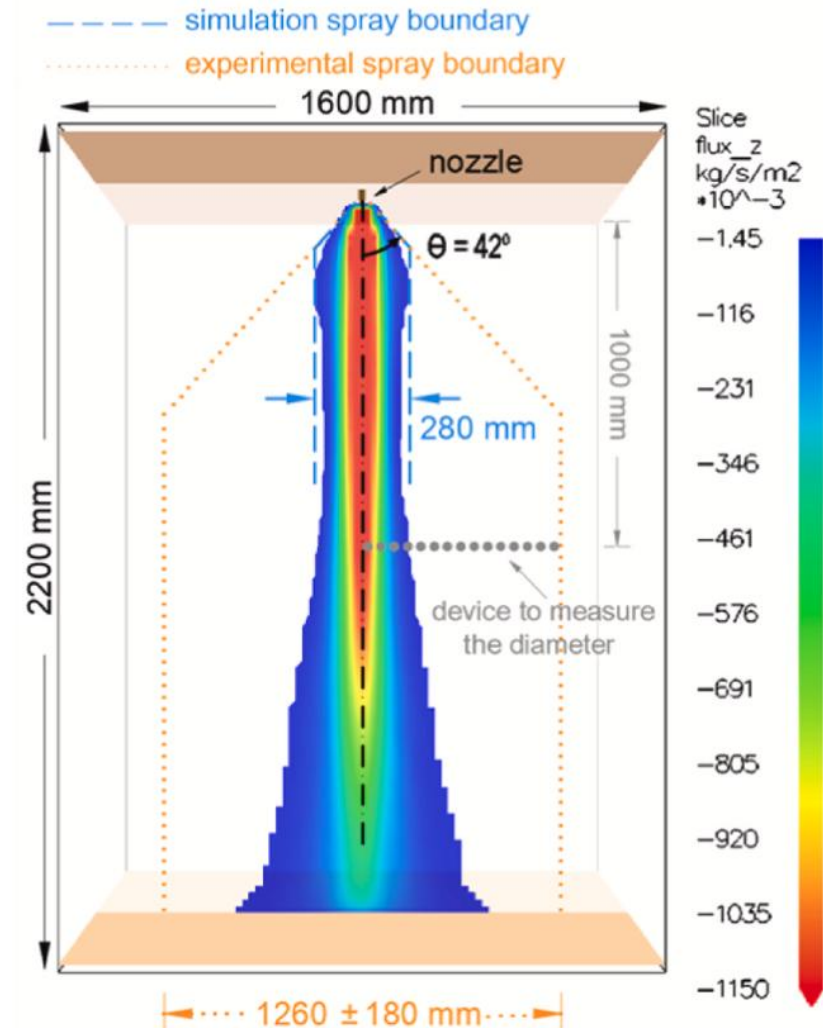


Input Parameters in FDS

Parameter	Symbol	Value	Unit
Simulation time	t_{sim}	10	s
Cell size	Δx	2	cm
Number of particles	N_p	200.000	1/s
Volume-median diameter of driplets	$D_{V,0.50}$	90	μm
Droplets minimum and maximum diameter	D_d	10 – 1.000	μm
Distribution width parameter	γ	6.4	-
Spray angle	θ	42	Degree
Initial velocity	$u_{d,0}$	20	m/s
Ambient gas initial velocity	$u_{g,0}$	0	m/s
Water flow	$\dot{q}$	1	LPM
Spray pattern shape (ON by default)	-	Gaussian	-
Auto drag reduction factor (ON by default)	-	-	-
Turbulence modelling approach (ON by default)	-	the modified Deardorff mode	-

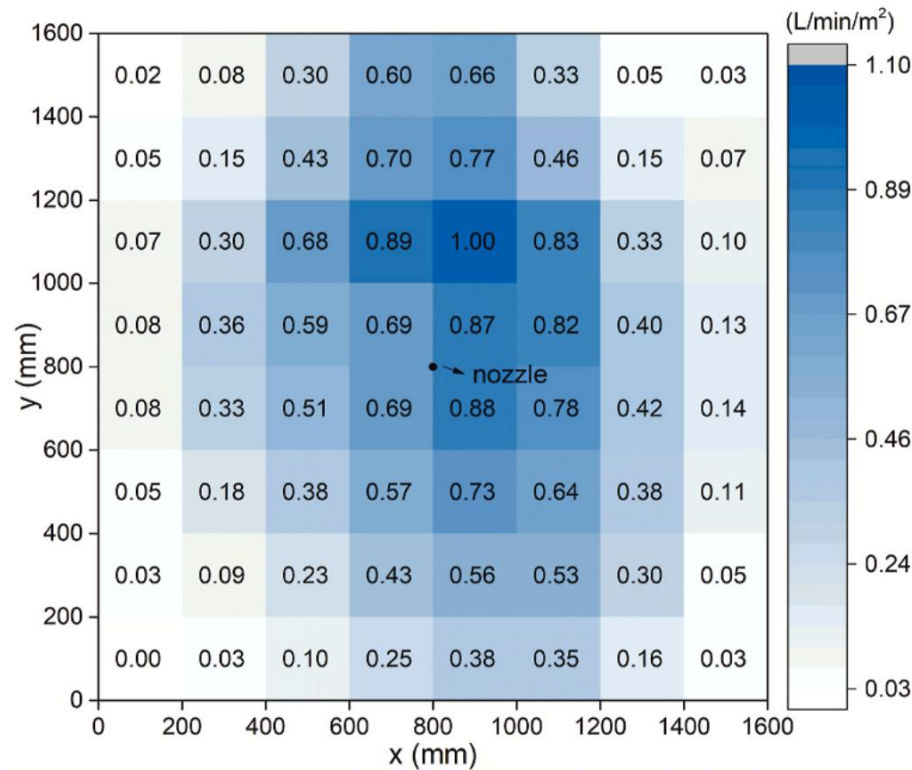
Low Pressure Water Mist Modelling Result

- A much narrower and dense water discharge was resulted by FDS.

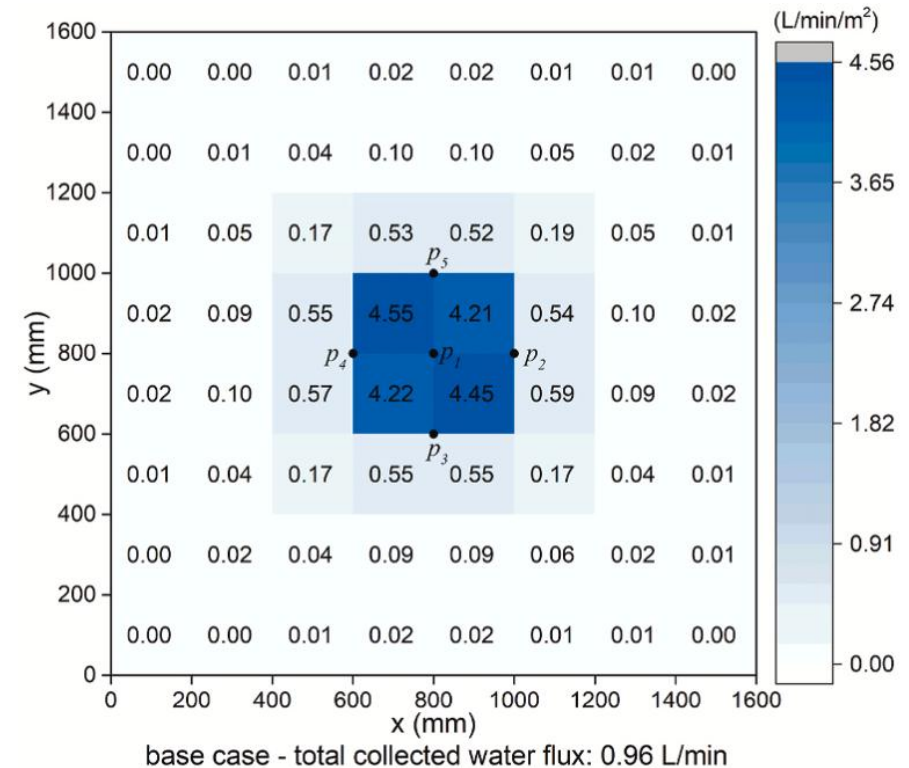


Low Pressure Water Mist Modelling Result

Experimental Result

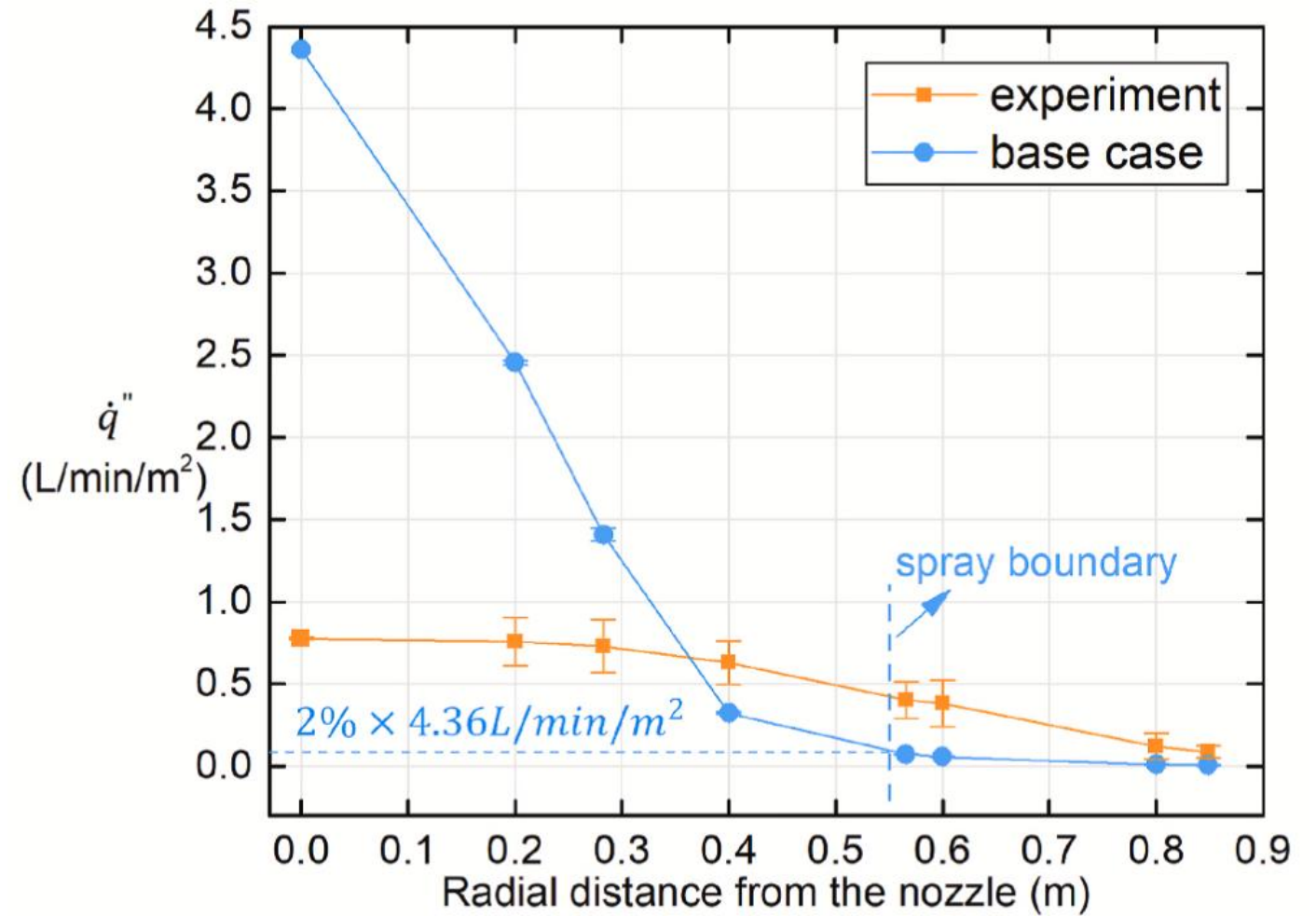


FDS Result



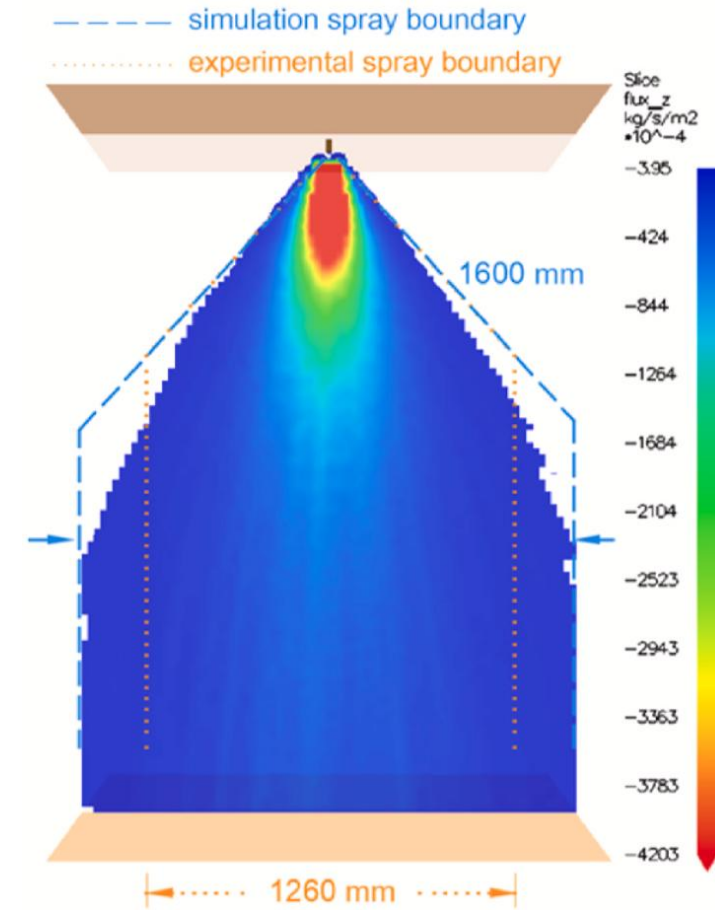
Averaged water flux of experimental and FDS model results in some spatial distances.

It should be noted that the lines are drawn for visual aid. It means that there is



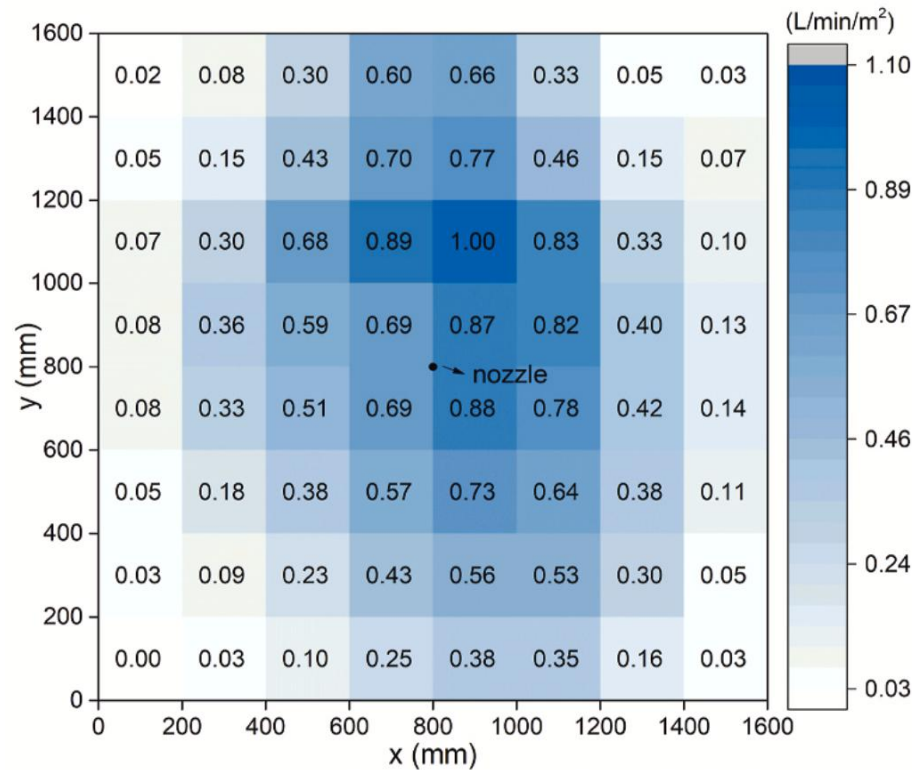
Low Pressure Water Mist Modelling Result

- Liu Best result by $C_d = 0.15$

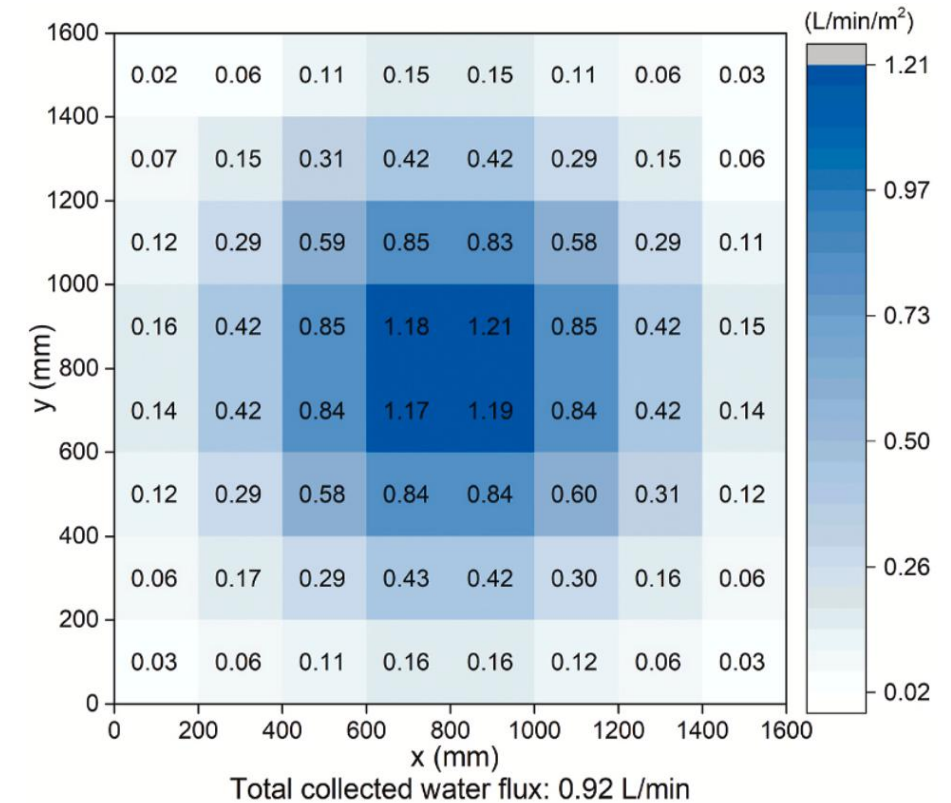


Low Pressure Water Mist Modelling Result

Experimental Result



FDS the Best Result by $C_d = 0.15$



Forces Applied on Single Droplet vs Multi droplet

Single Droplet

- $m_d \frac{d}{dt}(u_d) = m_d g - \frac{1}{2} \rho_g C_d \pi r_d^2 (u_d - u_g) |u_d - u_g|$
- $C_d = \begin{cases} \frac{24}{Re_d} & (Re_d \leq 1) \\ 24(0.85 Re_d^{-1} + 0.15 Re_d^{-0.313}) & (1 < Re_d \leq 1000) \\ 0.44 & (Re_d > 1000) \end{cases}$

Multi Droplets

- $m_d \frac{d}{dt}(u_d) = m_d g - \frac{1}{2} \rho_g C_d \pi r_d^2 (u_d - u_g) |u_d - u_g|$
- $\frac{L}{D} = \left(\frac{\pi}{6\alpha}\right)^{\frac{1}{3}}$
- $C_d = C_{d,0} \frac{F}{F_0}$
- $\frac{F}{F_0} = W \left[1 + \frac{Re}{16} \frac{1}{\left(\frac{L}{D} - \frac{1}{2}\right)^2} e^{\left(-\frac{Re}{16} \frac{1}{\left(\frac{L}{D} - \frac{1}{2}\right)}\right)} \right]$
- $W = 1 - \frac{C_{d,0}}{2} \left[1 - e^{\left(-\frac{Re}{16} \frac{1}{\left(\frac{L}{D} - \frac{1}{2}\right)}\right)} \right]$

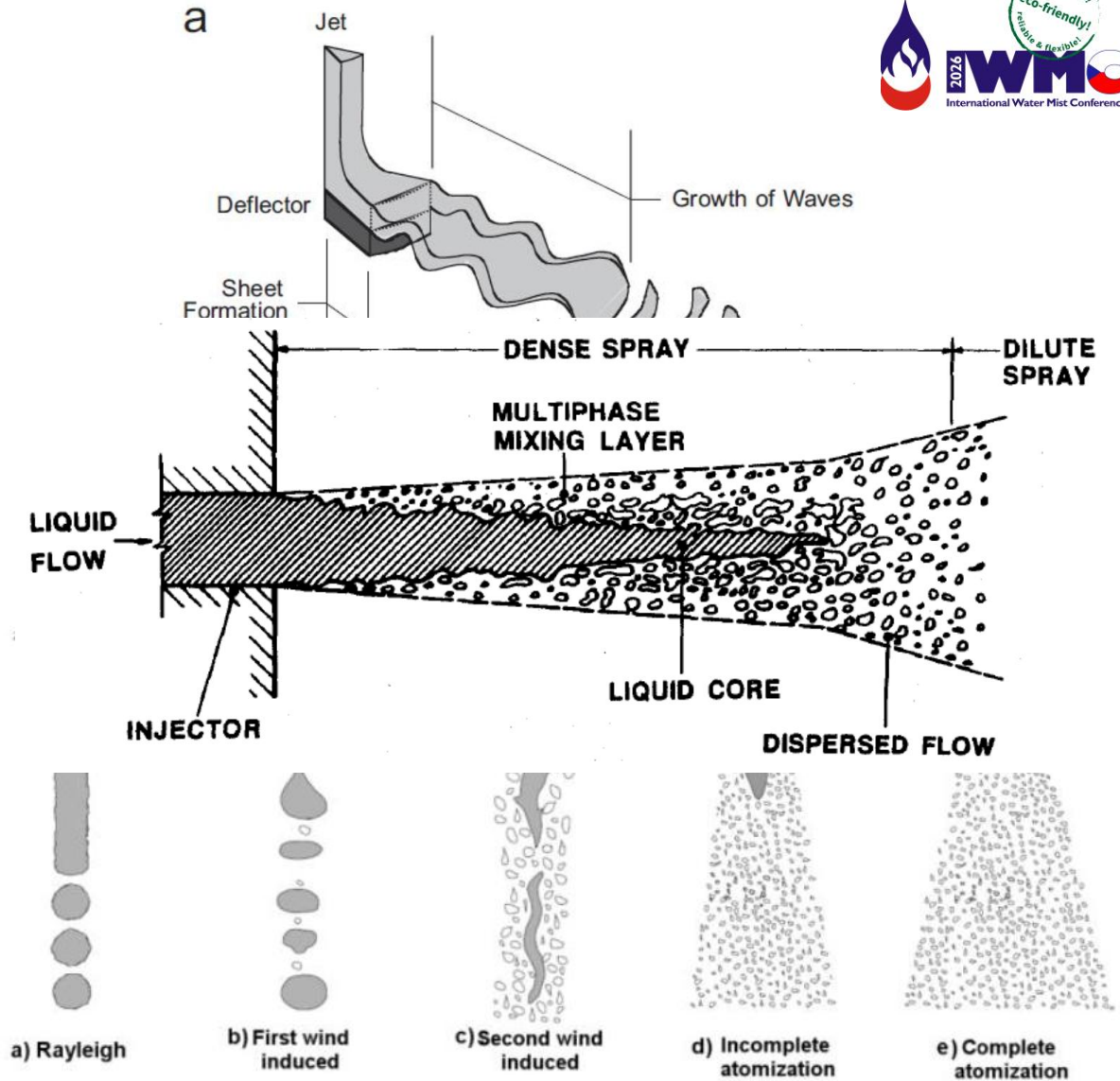
Primary Break-up method

- This method incorporates both the breakup length (B_l) and the drag reduction factor ($C_{d,red}$) into the FDS input file, with the objective of enhancing the accuracy of spray dynamics representation.
- The drag coefficient in this case will be equated as:

$$C_{d-breakup} = C_{d,red} \times C_d$$

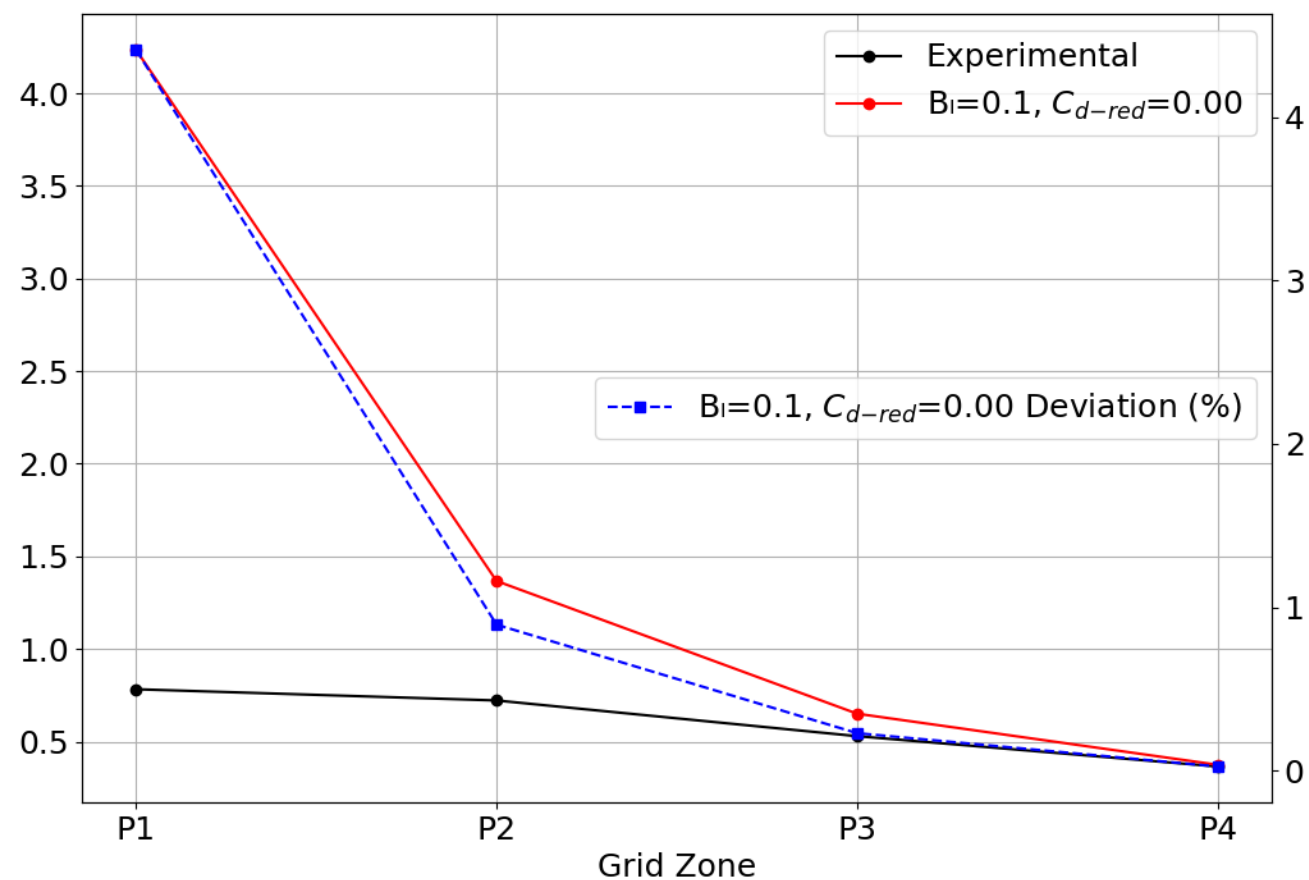
Where $C_{d-breakup}$ is the drag coefficient in the B_l , $C_{d,red}$ shows the drag reduction factor, and C_d represents the actual drag coefficient.

- As noted in FDS User's Manual, B_l and $C_{d,red}$ are empirical and require calibration specific to each experimental setup to ensure reliable modelling outcomes.



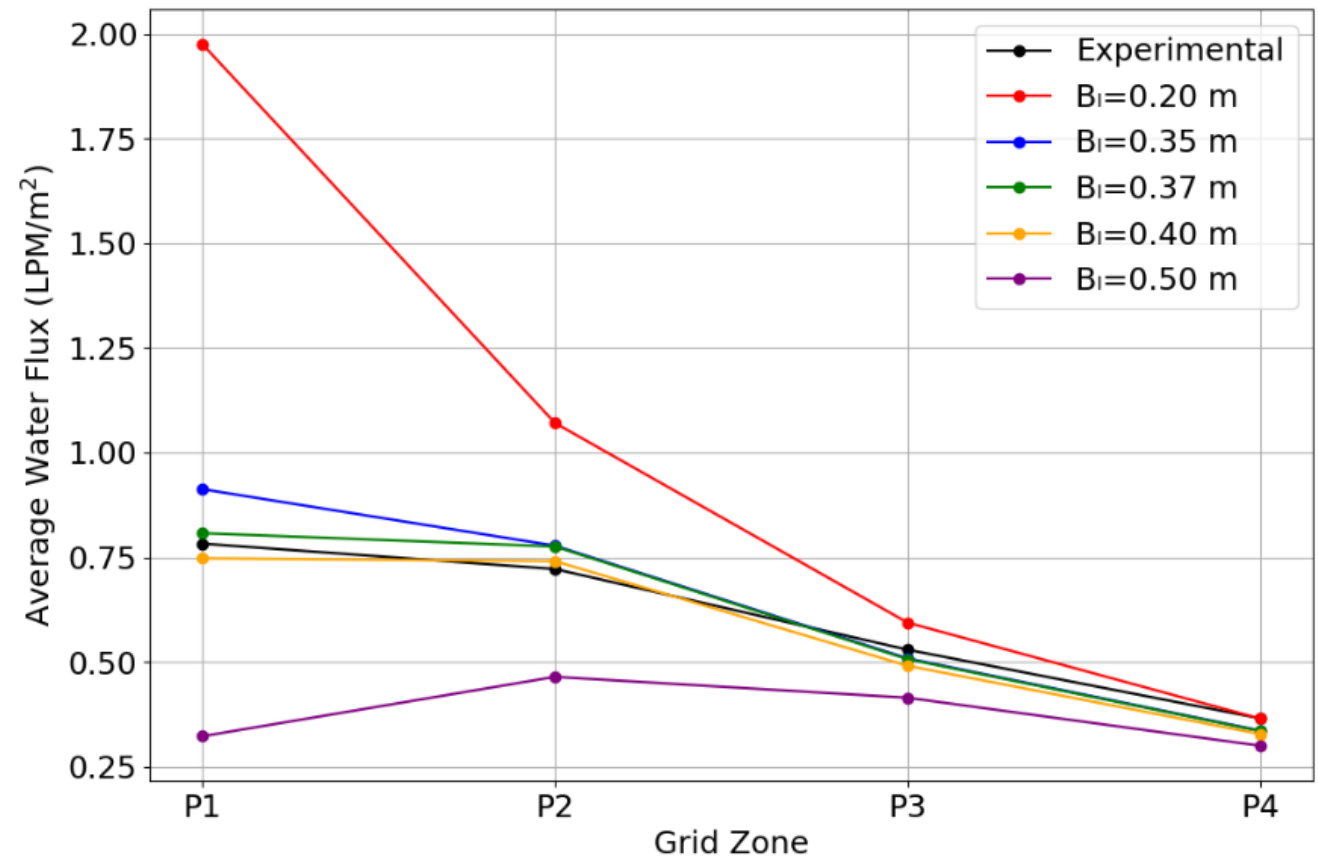
Modelling Results based on Primary Break-up Method

$B_l = 0.1 \text{ m}$, $C_{d-red}=0.00$



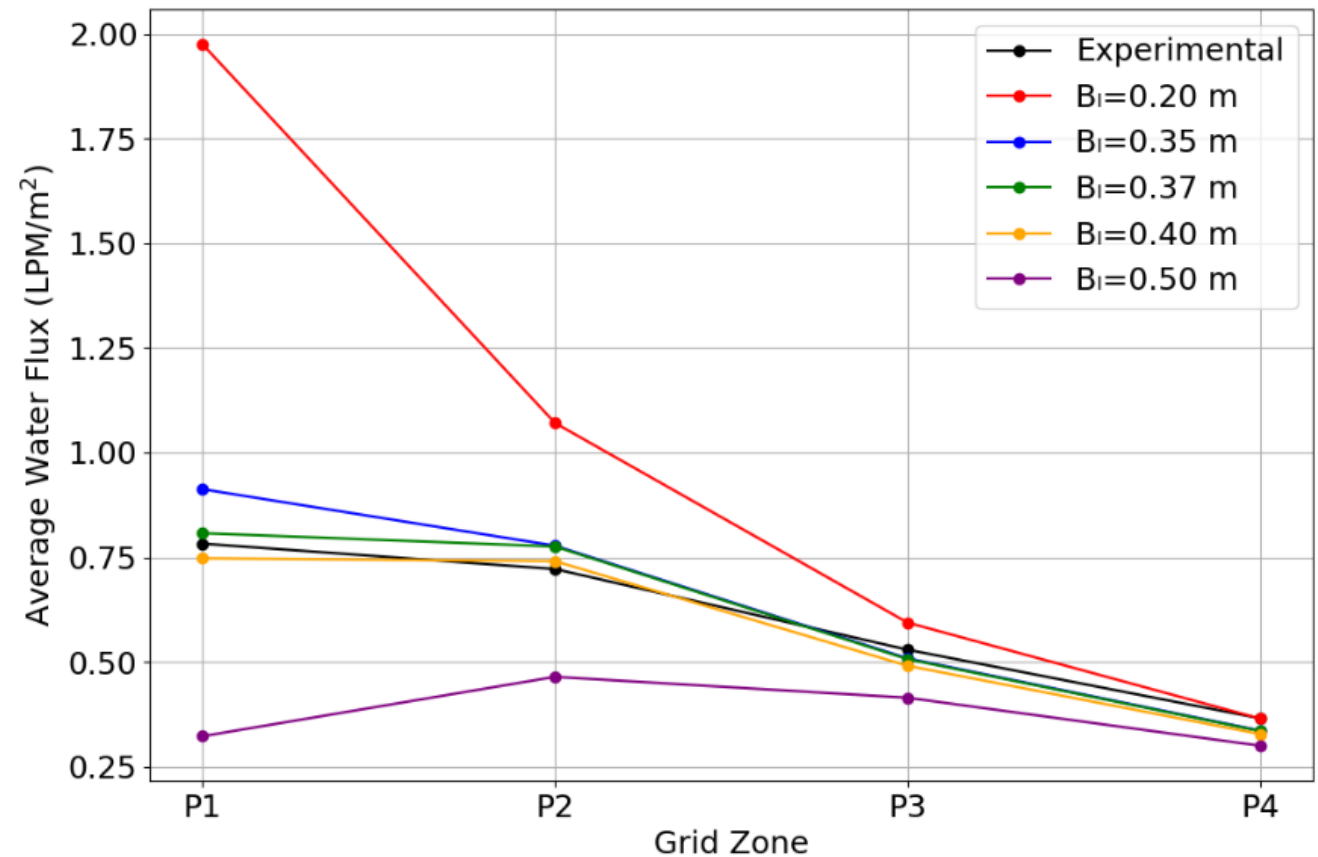
Modelling Results based on Primary Break-up Method

$B_l = 0.2 \text{ m to } 0.5 \text{ m}$, $C_{d\text{-red}} = 0.00$



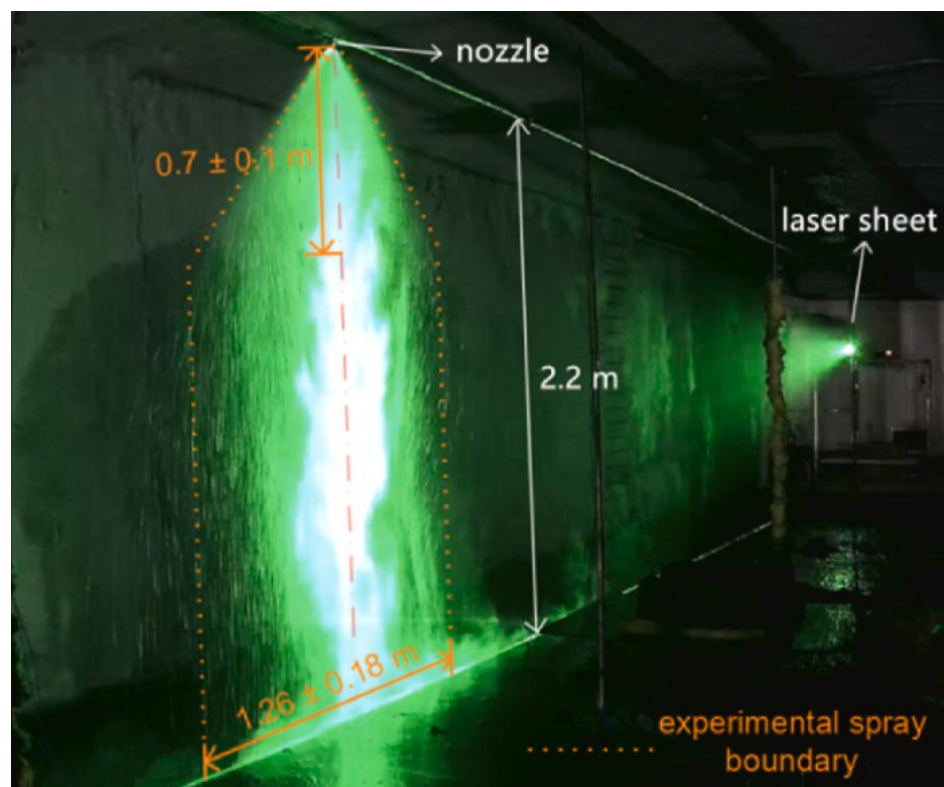
Modelling Results based on Primary Break-up Method

$B_l = 0.2 \text{ m to } 0.5 \text{ m}$, $C_{d-red}=0.00$

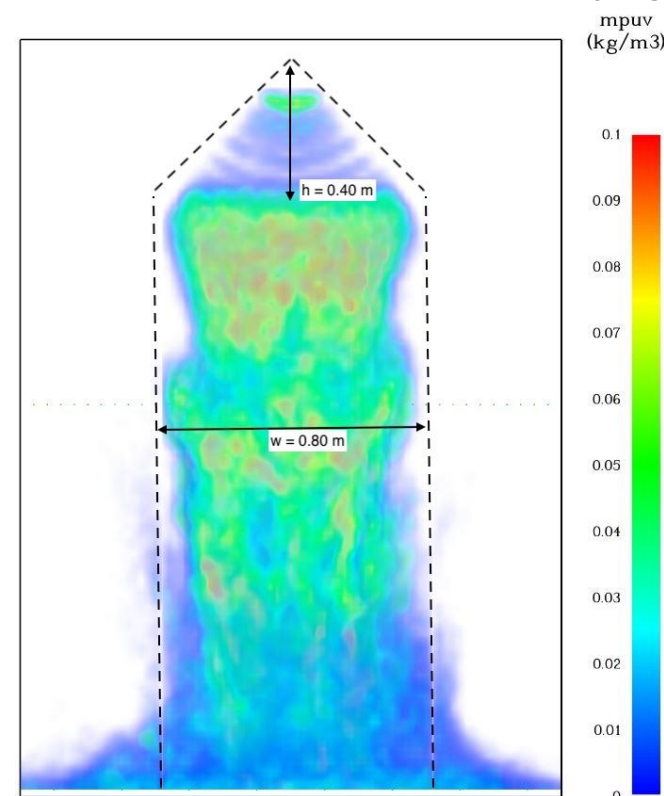


Modelling Results based on Primary Break-up Method

Experimental Result

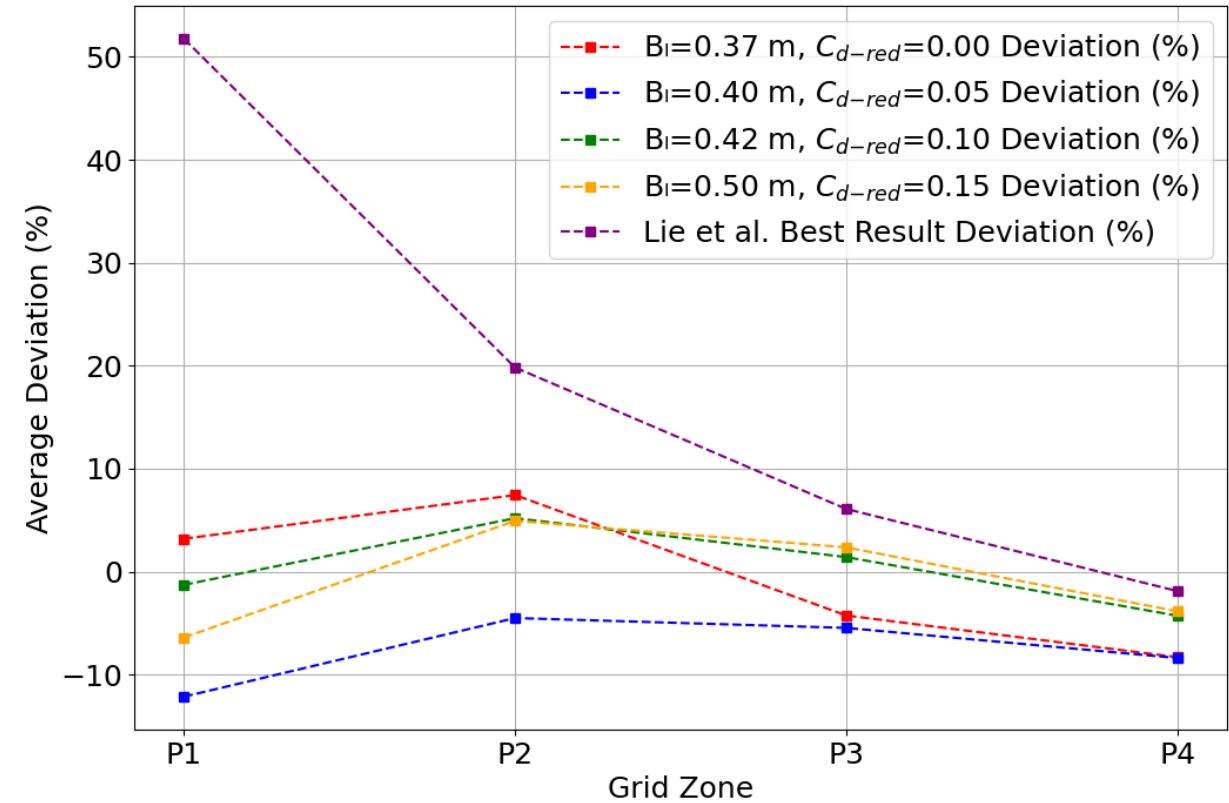
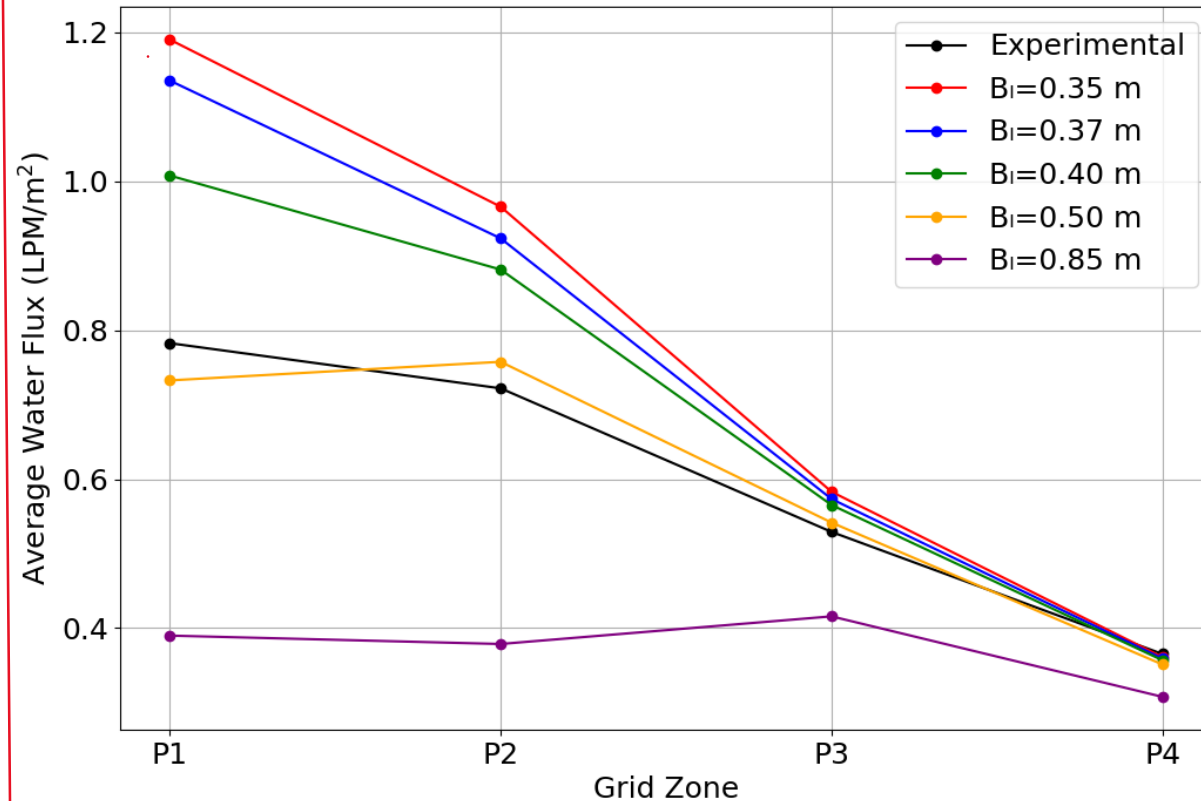


FDS Result $B_l = 0.4$ m and $C_{d-red} = 0.0$



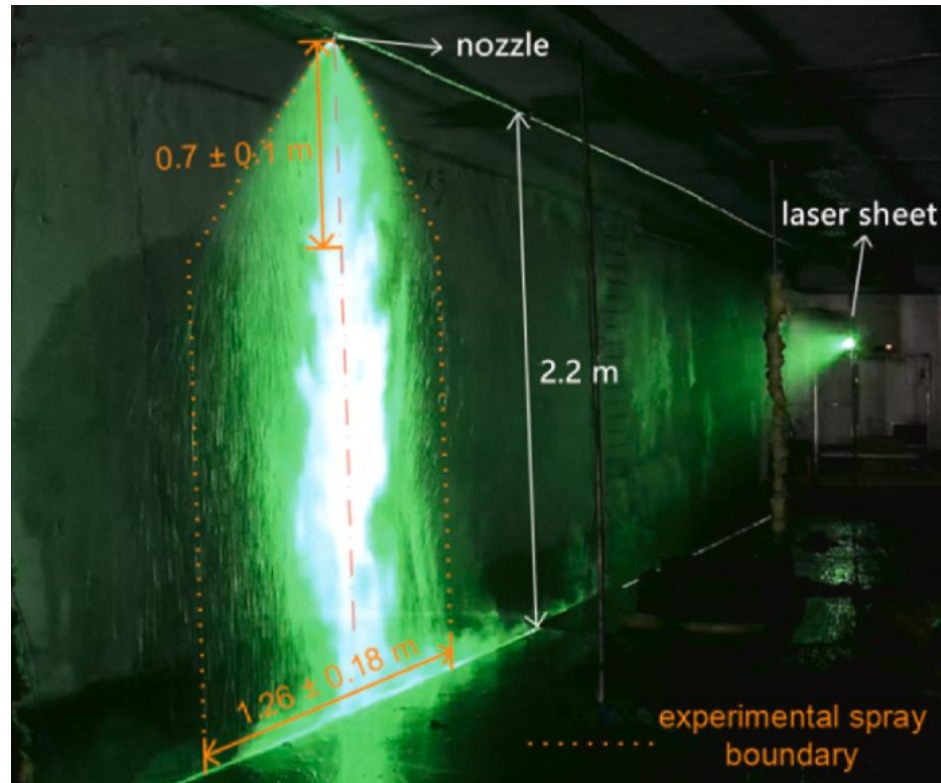
Modelling Results based on Primary Break-up Method

$B_l = 0.35 \text{ m to } 0.8 \text{ m}$, $C_{d-red}=0.15$

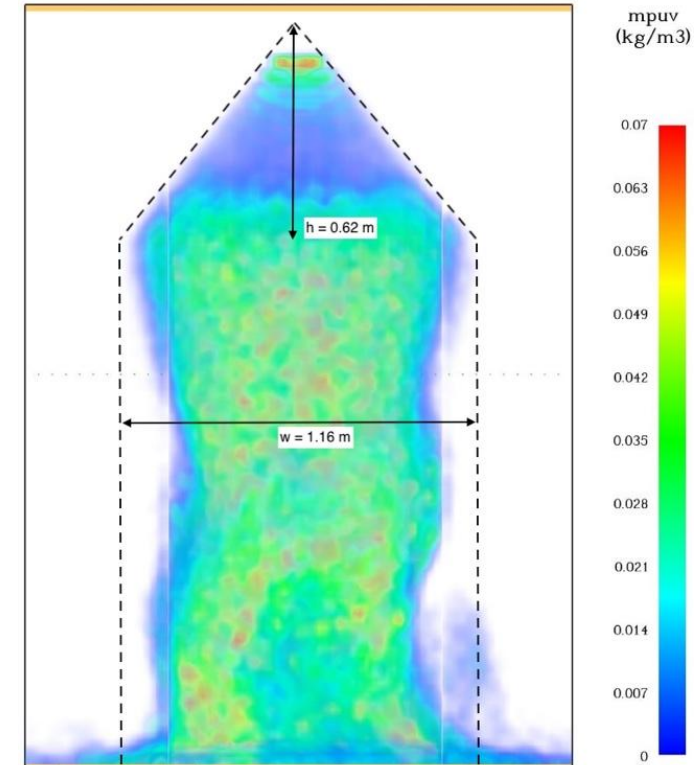


Modelling Results based on Primary Break-up Method

Experimental Result

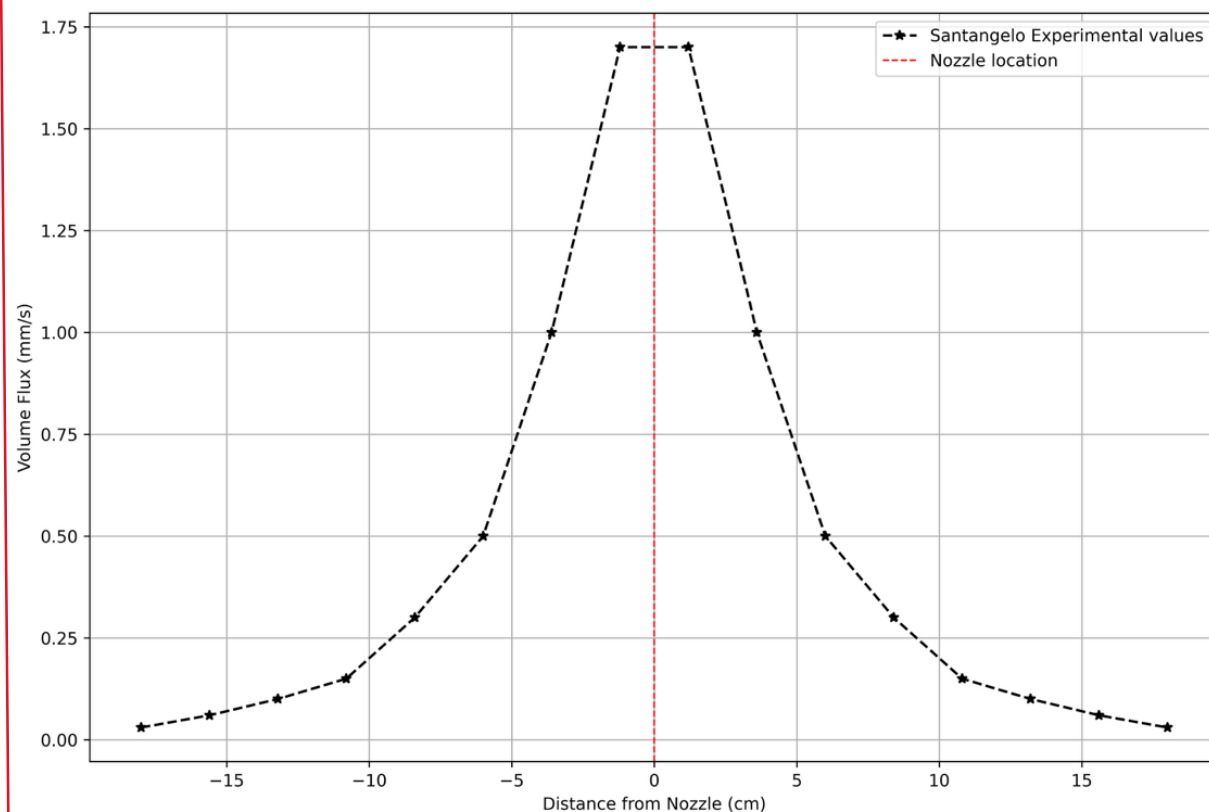


FDS Result $B_l = 0.5$ m and $C_{d-red} = 0.15$

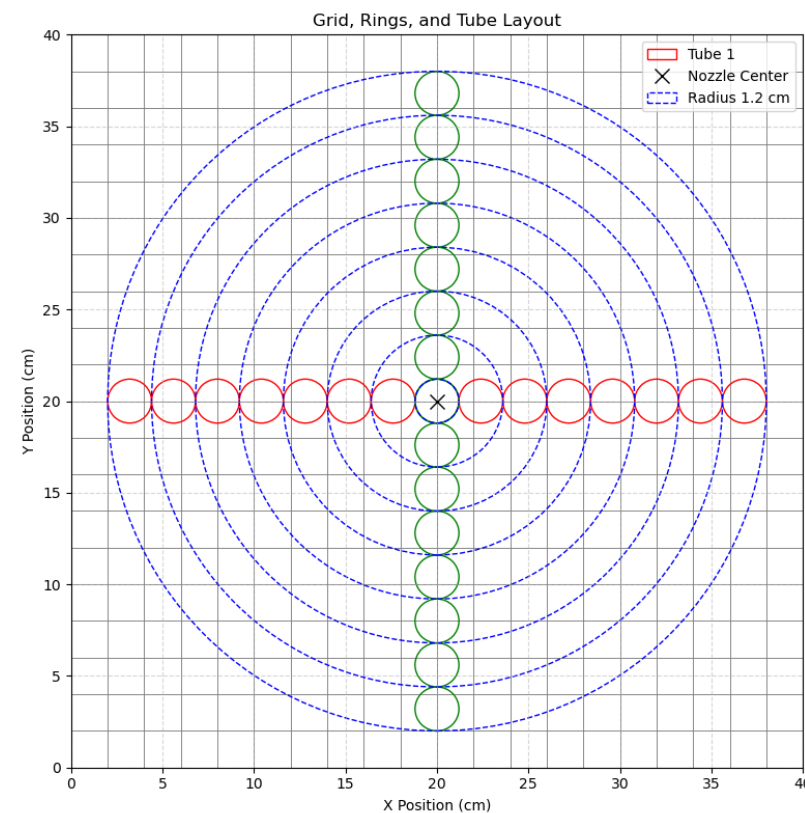


High Pressure Water Mist Experimental Setup

Experimental Result By Santangelo



Measuring Tubes Locations

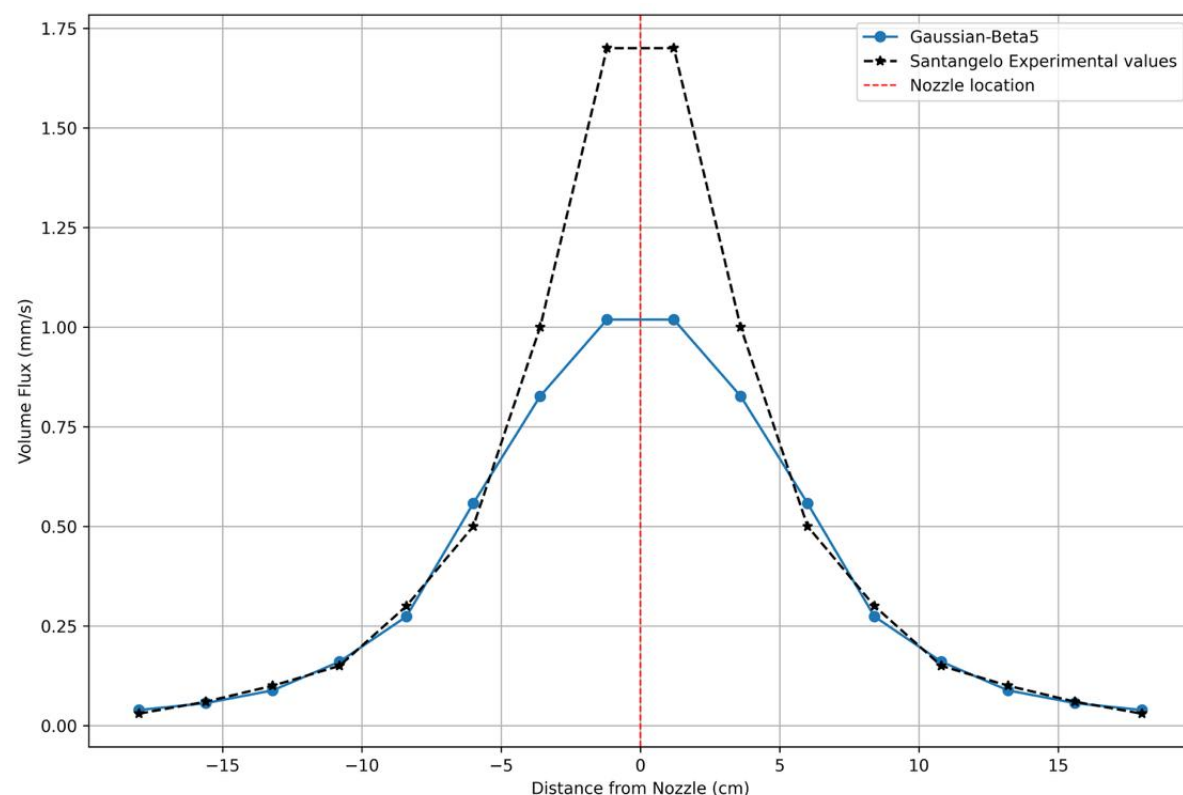


Input Parameters in FDS

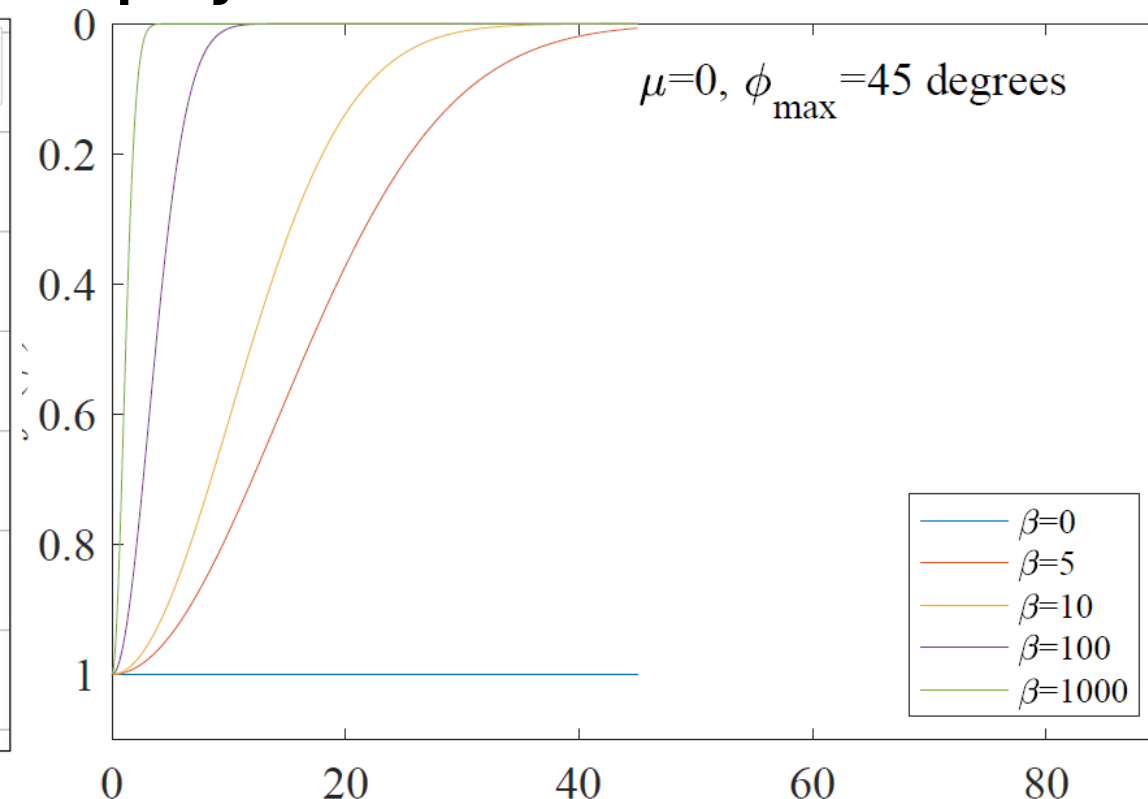
Parameter	Symbol	Value	Unit
Simulation time	t_{sim}	5	s
Cell size	Δx	2	cm
Number of particles	N_p	200.000	1/s
Volume-median diameter of droplets	$D_{V,0.50}$	94	μm
Droplets minimum and maximum diameter	D_d	10 – 1.000	μm
Distribution width parameter	γ	2.3	-
Spray angle	θ	30	Degree
Initial velocity	$u_{d,0}$	109.55	m/s
Ambient gas initial velocity	$u_{g,0}$	0	m/s
Water flow	$\dot{q}$	1.47	LPM
Spray pattern shape (ON by default)	-	Gaussian	-
Spray pattern beta	-	Default (5)	-
Nozzle offset	-	10	mm

High Pressure Water Mist Modelling Result

FDS Base Model

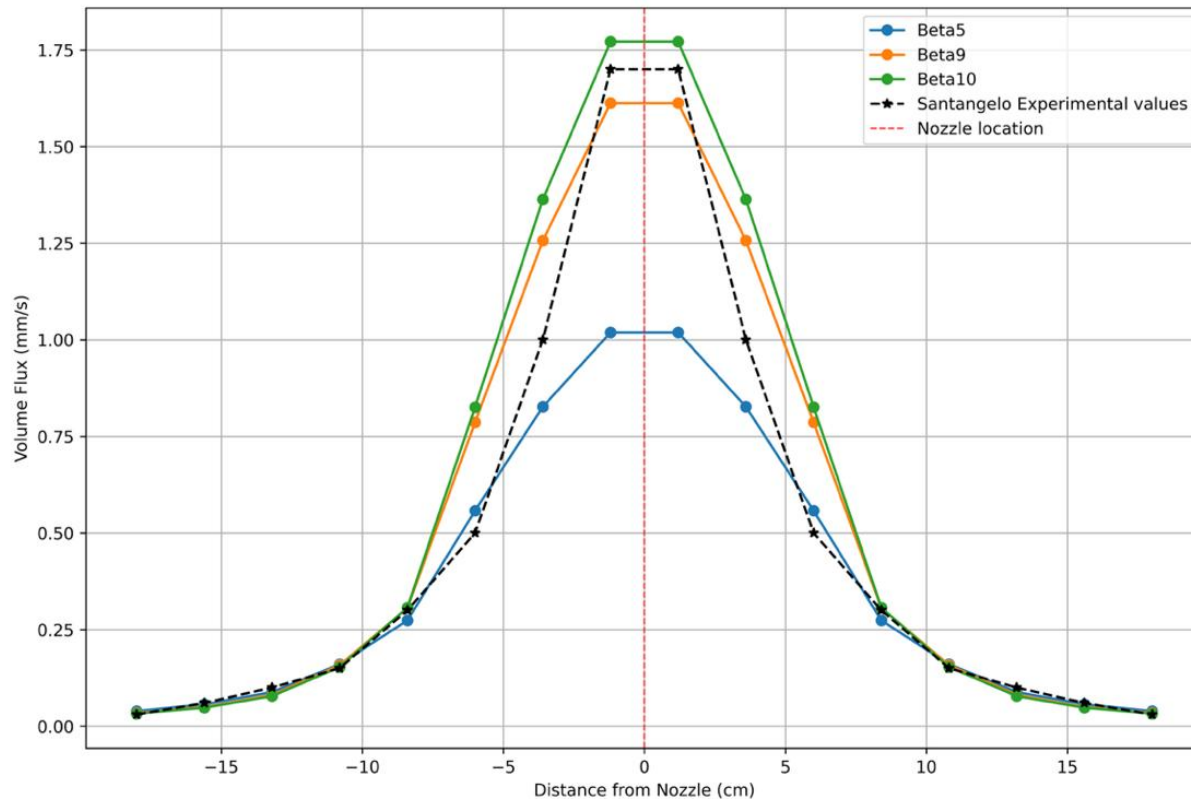


Spray Pattern Beta

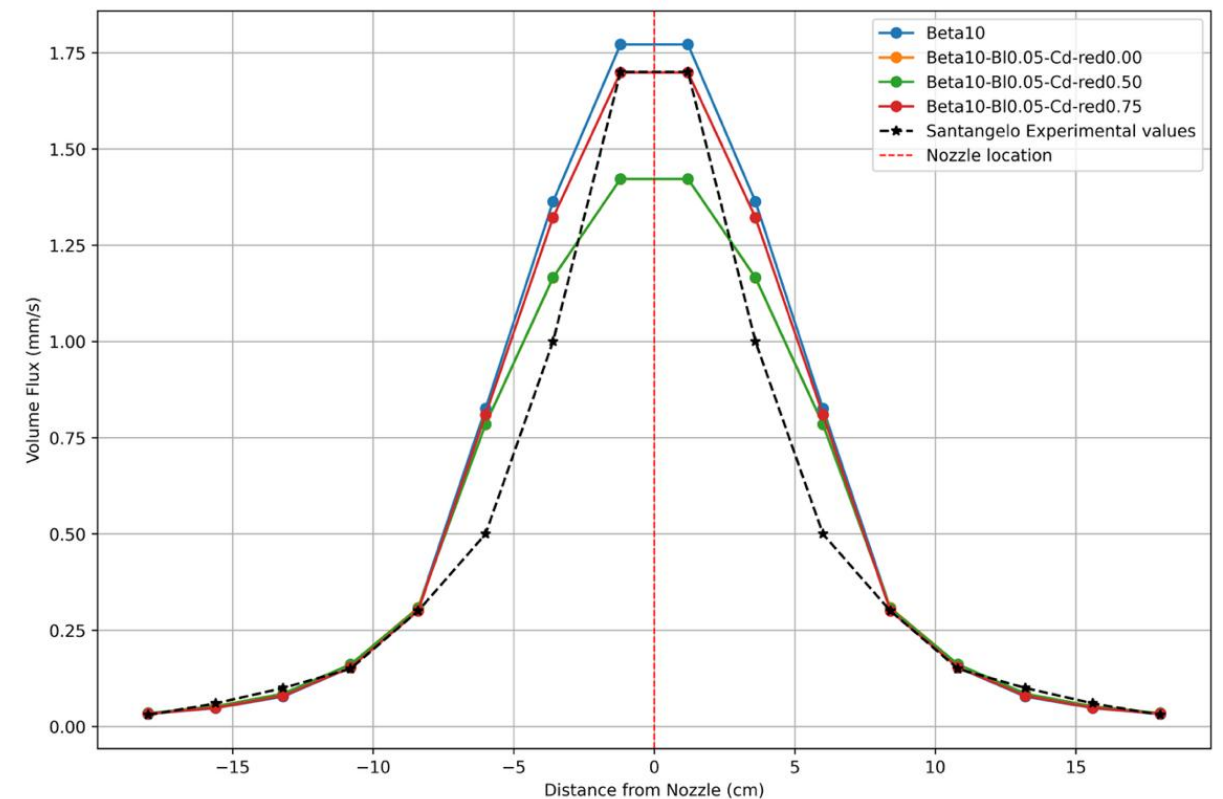


High Pressure Water Mist Modelling Result

FDS Model Based on Different Betas



FDS Model Based on Primary Break-up



Takeaway

- It should be noted that the default values in FDS are not accurate in Water Mist Nozzle Discharge Modelling for both low and high pressure systems.
- There is no universal numbers that can be used as fixed C_d , B_l , and C_{d-red} values.

Thank you!

Happy to answer any
questions in Q/A
Session