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CFD Study on the Interaction between Water Sprays and Longitudinal Ventilation in Tunnel Fires

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Outline of the Presentation

1 – Introduction

2 – Methodology

3 – Experimental Work

4 – Numerical Set-Up

5 – List of Simulations

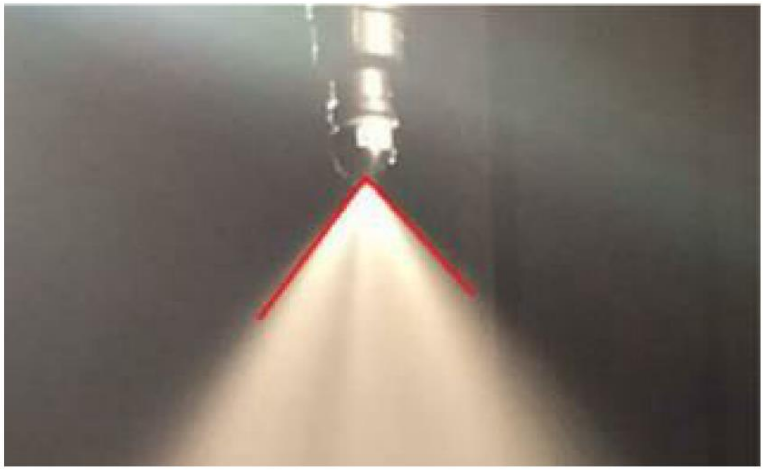
6 – Results & Discussion

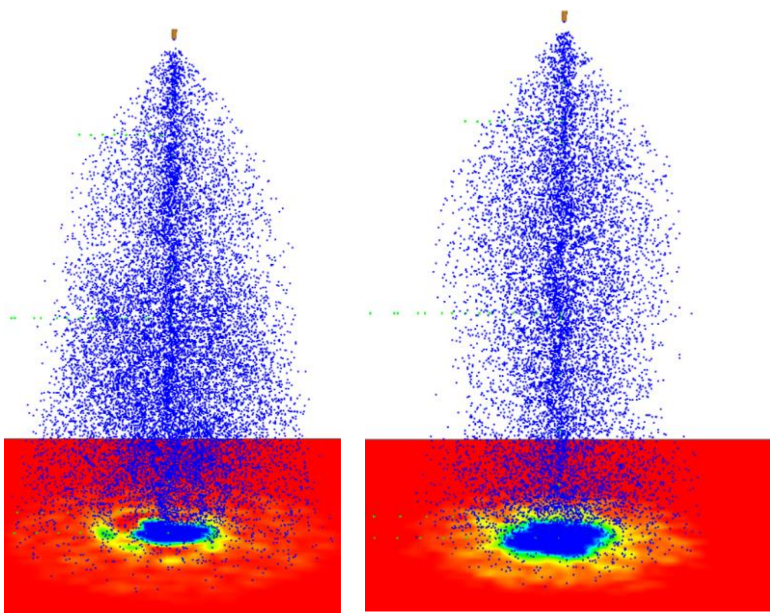
7 – Conclusions

Photo via Satra engineering company. www.satra.cz

1. Introduction

General & Scope





Objectives

General

To study the interaction of water spray and the backlayering in tunnel fires by means of CFD simulations, in order to investigate the effect of water spray on length and stratification of the backlayering.

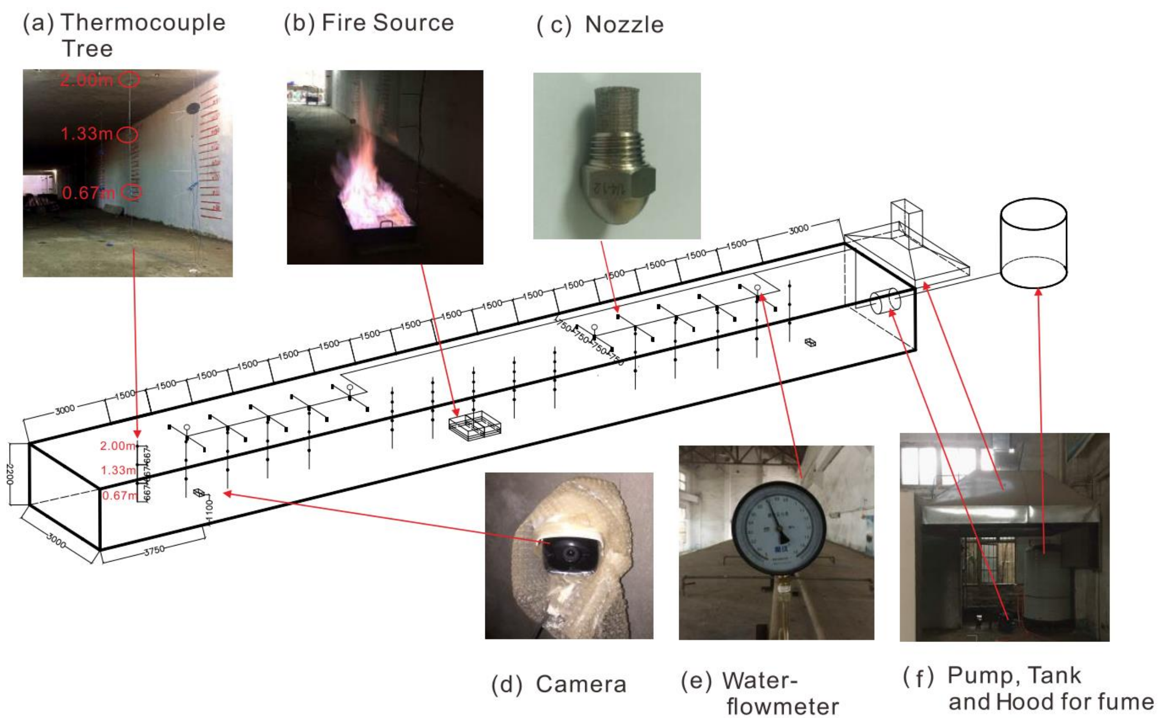
Specifics

- To assess CFD capabilities to predict experimental results that will be obtained in a medium-scale set-up.
- To analyse the effect of water spray on the length and thickness of the smoke back layer using a CFD package, namely the Fire Dynamics Simulator (FDS).

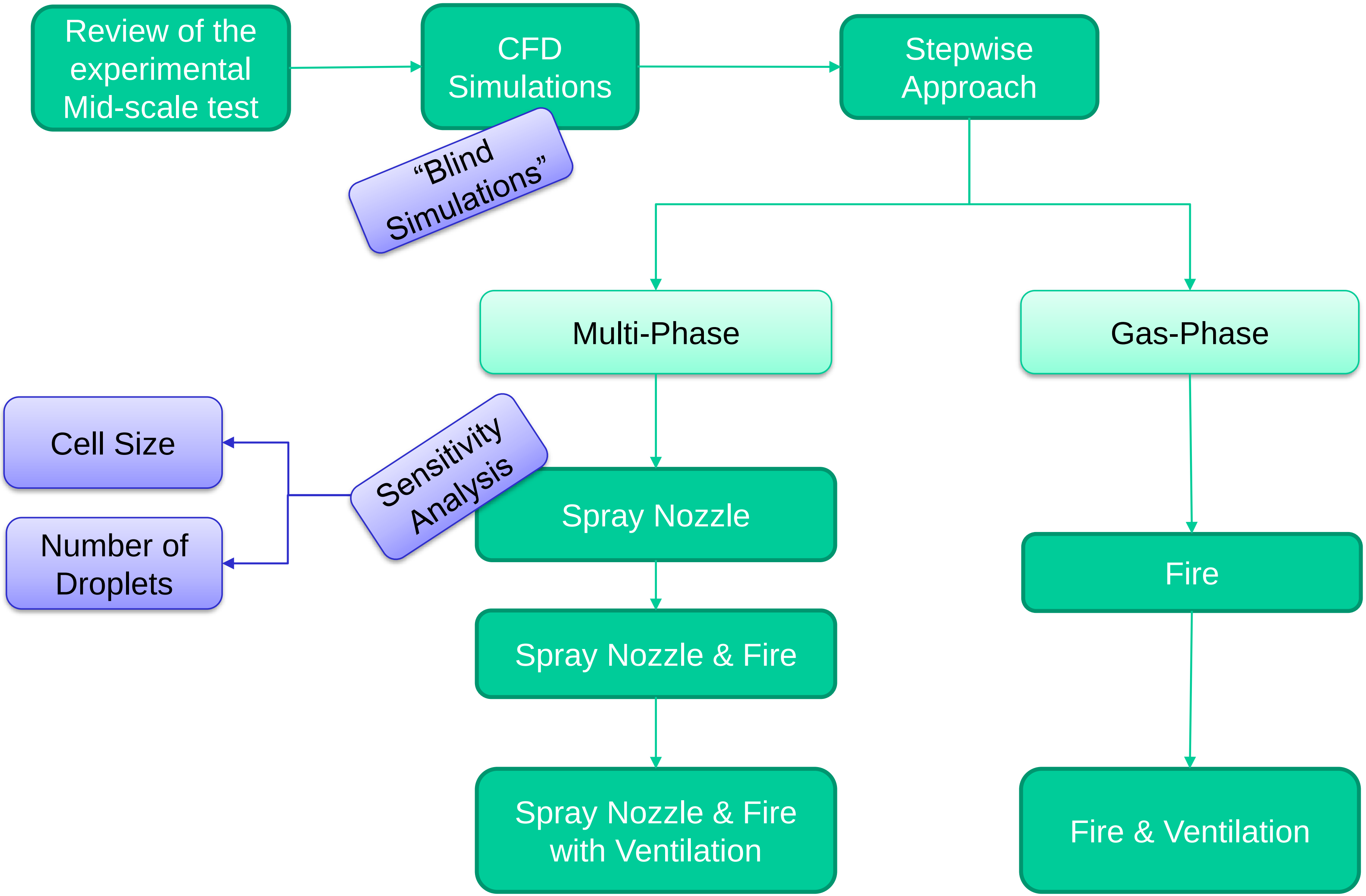
1. Introduction

Summary

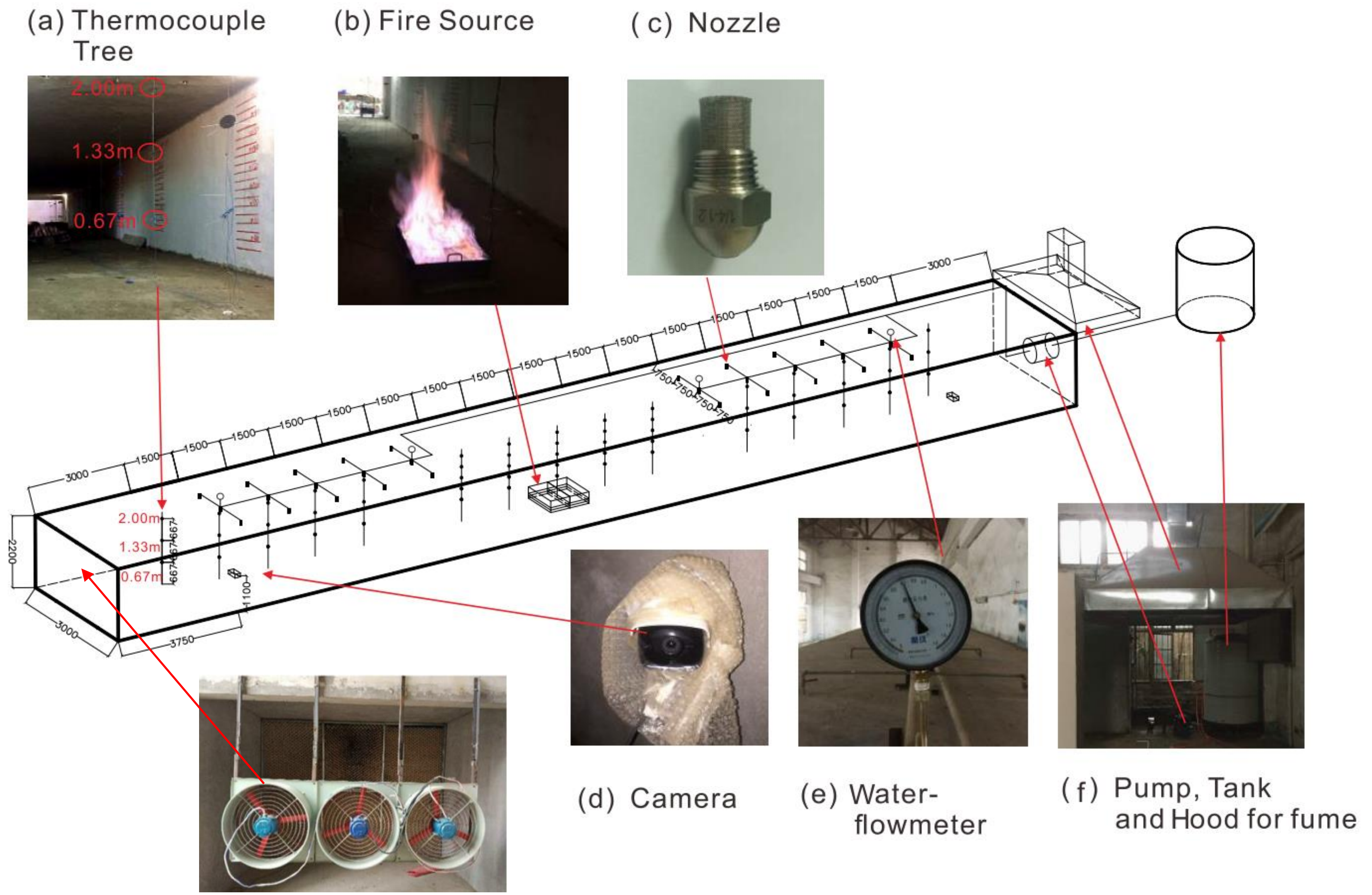
- A tunnel fire will be modelled.
- The tunnel is equipped with longitudinal ventilation & spray nozzles system.
- The main three scenarios will correspond to three different pressure in the spray system (0.5, 0.7 & 0.9 MPa) operating when the longitudinal ventilation is working.
- Extra scenarios has been modelled in order to asses a sensitivity analysis and obtain data for comparison.



2. Methodology



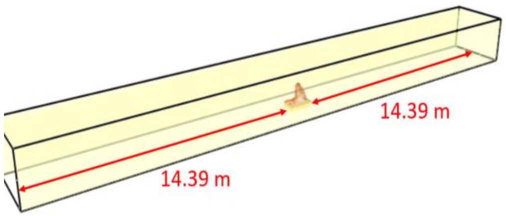
3. Experimental Work

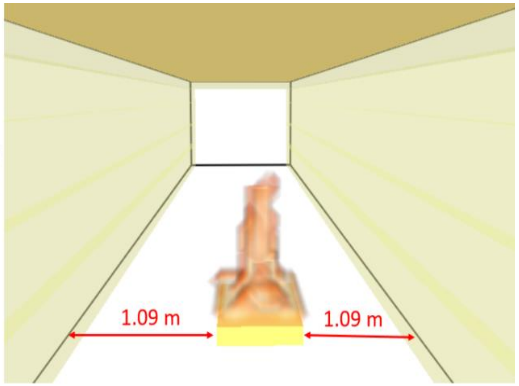


Photos via Wuhan University of China

3. Experimental Work

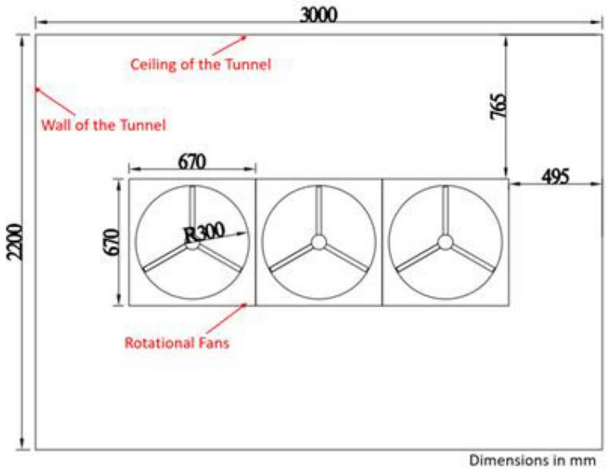
Fire





HRRPUA	Area	Nº of Pan	HRR
kJ/(m2*s)	m2	Unit	kW
384.1	0.5	2	384.1

Ventilation System in the Tunnel



The mean velocity measured in the cross section of the tunnel should be **1.368** m/s

Flow Rate	9500	m3/h
Rotational Speed	1450	rpm
Voltage	380	Volt
Motor Power	370	Watt

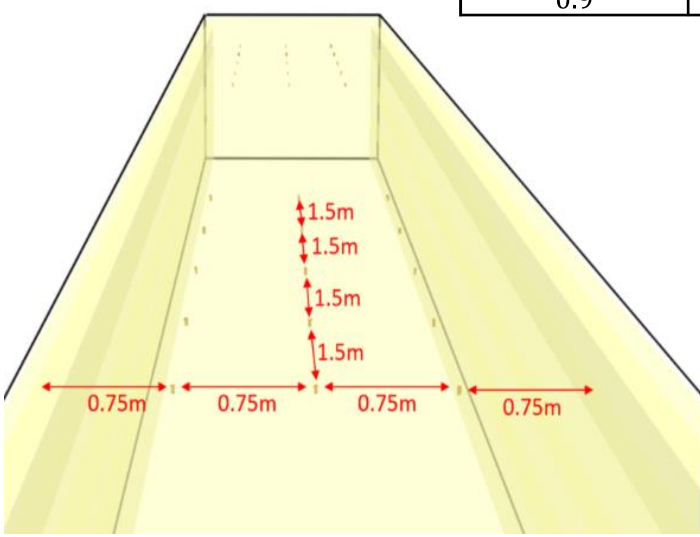
Density	Heat Conductivity	Specific Heat
kg/m3	W/(m*K)	kJ/(kg*K)
1900	1.1	1.05

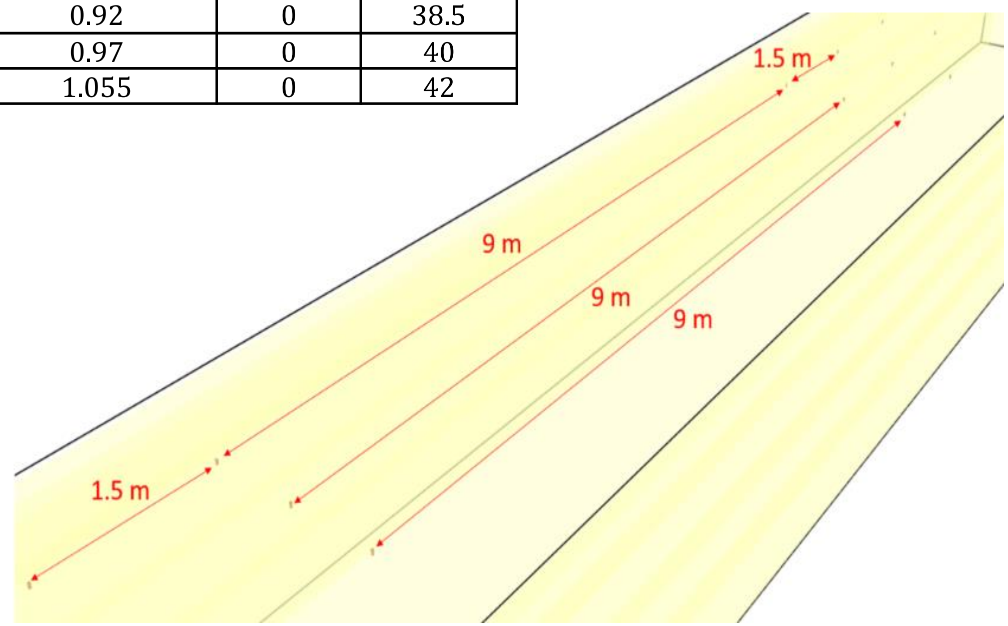
3. Experimental Work

Water Spray

Water Pressure	Water Flow Rate		Discharge Coefficient	Nozzle Orifice Diameter	Nozzle Orifice Area	Initial Velocity	Dv 50
Mpa	l/min	m3/min	lpm/Mpa^0.5	mm	m2	m/s	µm
0.5	0.92	0.00092	0.411	1.2	1.13094E-06	13.558	137
0.7	0.97	0.00097	0.366	1.2	1.13094E-06	14.295	120
0.9	1.055	0.001055	0.351	1.2	1.13094E-06	15.548	112

Water Pressure	Water Flow Rate	Angle of Spray	
Mpa	l/min	θ min (º)	θ max (º)
0.5	0.92	0	38.5
0.7	0.97	0	40
0.9	1.055	0	42





4. Numerical Set-Up

Mesh

Expression used $\frac{D*}{\delta x}$ where D* is a characteristic fire diameter and δx is the nominal size of a mesh cell.

$$D^* = \left(\frac{Q}{\rho\, C\, T \sqrt{g}}\right)^{\frac{2}{5}}$$

D*/δx value ranges between 4 and 16.

Adjustment

HRR (kW)	D*	Coarse Mesh		Fine Mesh		Refined Mesh	
		x (mm)	D*/δx	x (mm)	D*/δx	x (mm)	D*/δx
384.1	0.655	0.082	8	0.055	12	0.041	16

Coarse Mesh				
x (m)	Nº Cell X	Nº Cell Y	Nº Cell Z	Total Cell
0.075	40	40	32	51200

Fine Mesh				
x (m)	Nº Cell X	Nº Cell Y	Nº Cell Z	Total Cell
0.05	60	60	48	172800

Refined Mesh				
x (m)	Nº Cell X	Nº Cell Y	Nº Cell Z	Total Cell
0.04	75	75	60	337500

4. Numerical Set-Up

Mesh

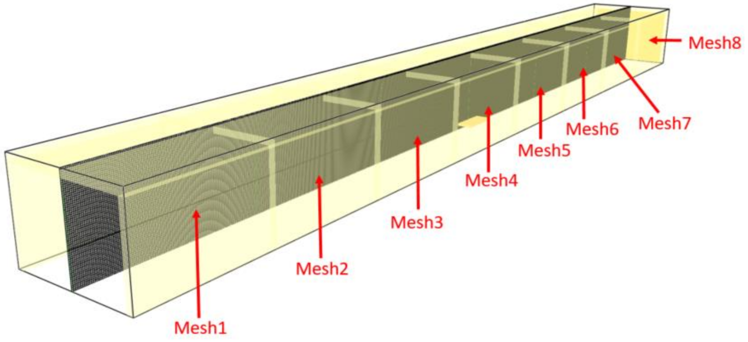
The **re-fined** mesh is selected – with **466875** cells per core (HPC)

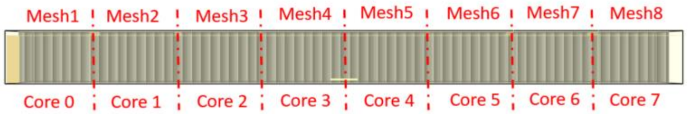
Cell Size (m)	X Axe Length (m)	Y Axe Length (m)	Z Axe Length (m)	Total
0.04	30	3.32	2.4	3735000

For the simulations of **spray nozzles and fire with ventilation**, the mesh cell size has been **decreased** from the **re-fined mesh** to the **fine mesh** (Max time HPC 72 Hrs)

Cell Size (m)	X Axe Length (m)	Y Axe Length (m)	Z Axe Length (m)	Total
0.05	30	3.32	2.4	1912320

The **re-fined** mesh is selected – with **239040** cells per core (HPC)





5. List of Simulations

Main Simulations

Re-Fined Mesh → rows 1–2; Fine Mesh → 1C1, 2C1, 3C1

Simulation Tag	Stage	Fire	Ventilation	Spray Nozzle	
				Activated	Pressure (MPa)
-	Single-Phase	Yes	No	No	-
-		Yes	Yes	No	-
1C1	Multi-Phase	Yes	Yes	Yes	0,5
2C1		Yes	Yes	Yes	0,7
3C1		Yes	Yes	Yes	0,9

Sensitivity Analysis – Cell Size

Re-Fined Mesh

Simulation Tag	Fire	Ventilation	Spray Nozzle		Mesh
			Activated	Pressure (MPa)	
1A	No	No	Yes	0,5	Coarse
2A			Yes	0,7	
3A			Yes	0,9	
1B	No	No	Yes	0,5	Fine
2B			Yes	0,7	
3B			Yes	0,9	
1C	No	No	Yes	0,5	Re-Fined
2C			Yes	0,7	
3C			Yes	0,9	

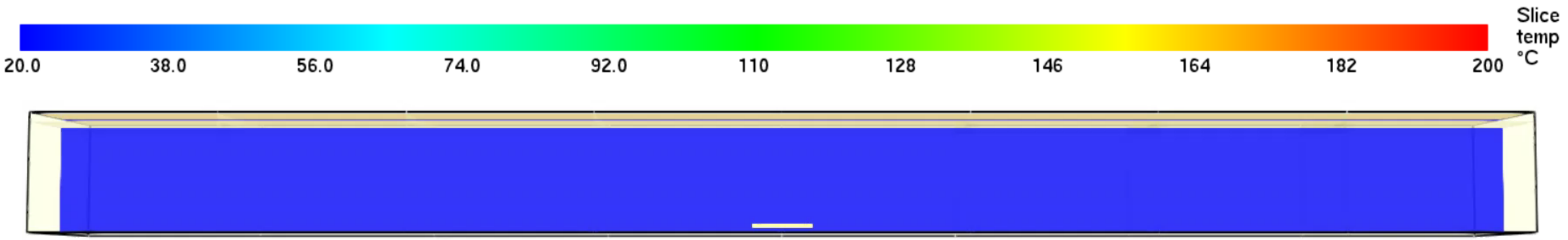
Sensitivity Analysis N° Droplets

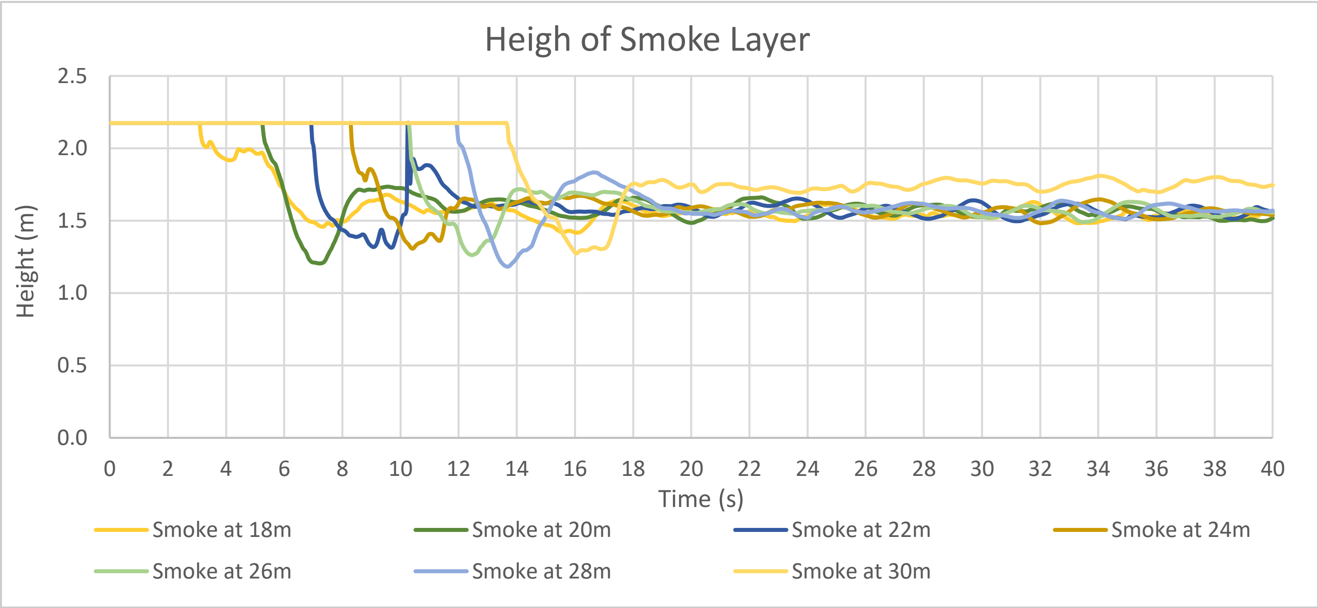
Re-Fined Mesh

Simulation Tag	Fire	Ventilation	Spray Nozzle		Mesh	N° Droplets
			Activated	Pressure (MPa)		
3C-0	No	No	Yes	0,9	Re-Fined	5000
3C-05						10000
3C-06						20000
3C-07						30000
3C-08						40000
3C-09						50000
3C-1						100000
3C-2						150000
3C-3						200000

6. Results & Discussion

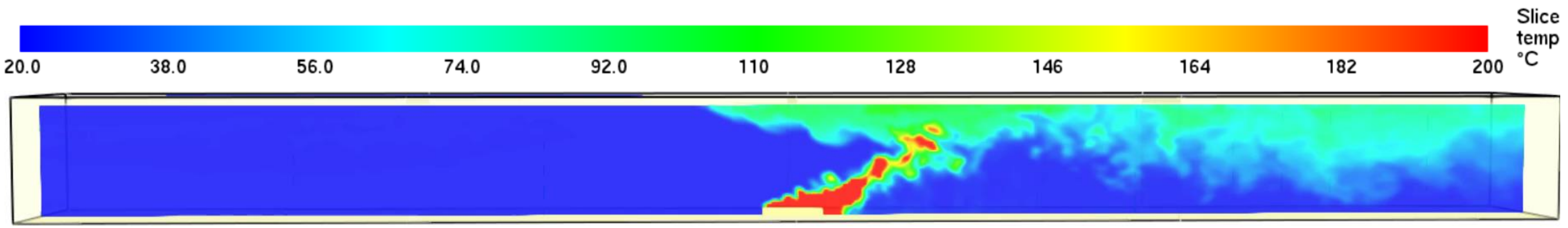
Fire

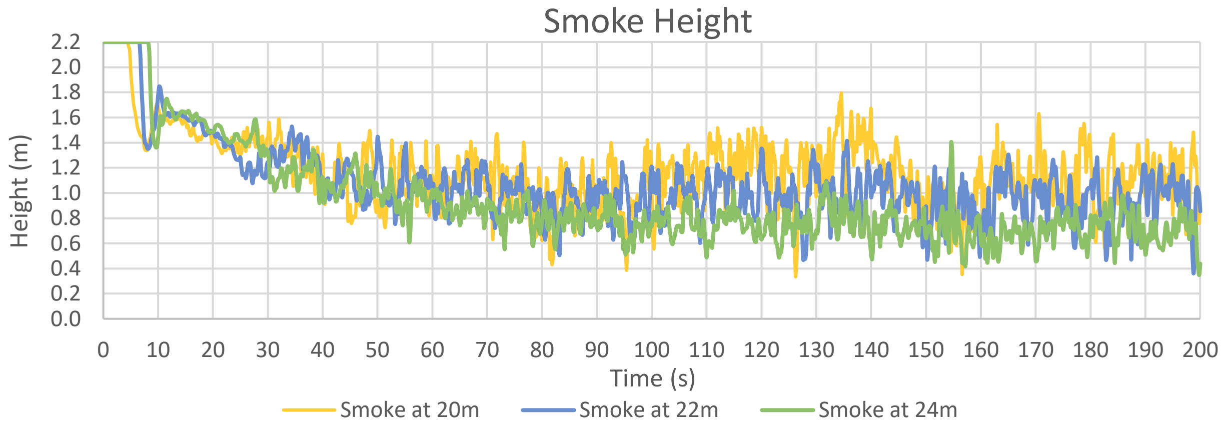


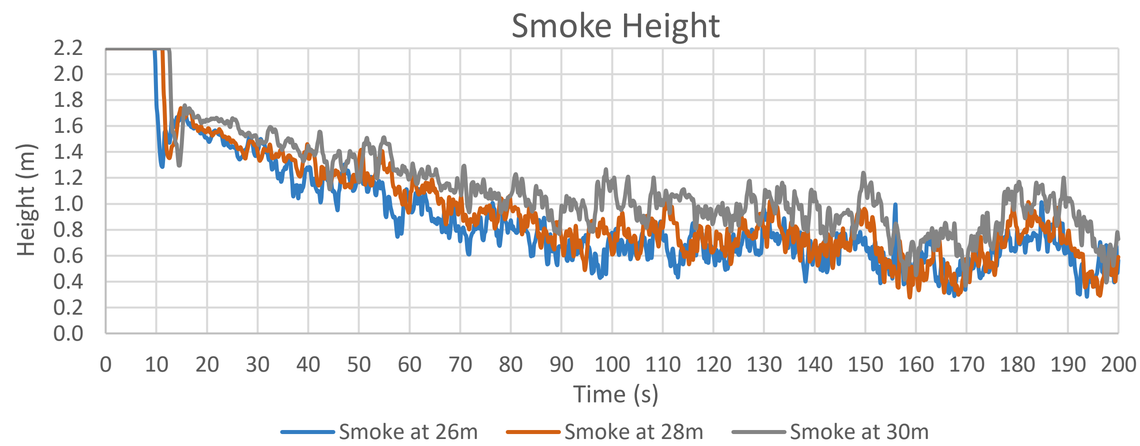


6. Results & Discussion

Fire & Ventilation



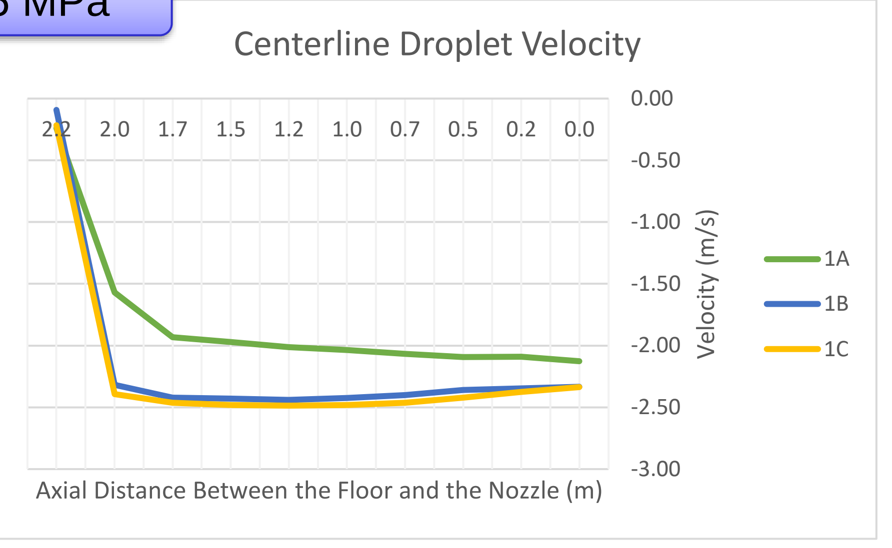




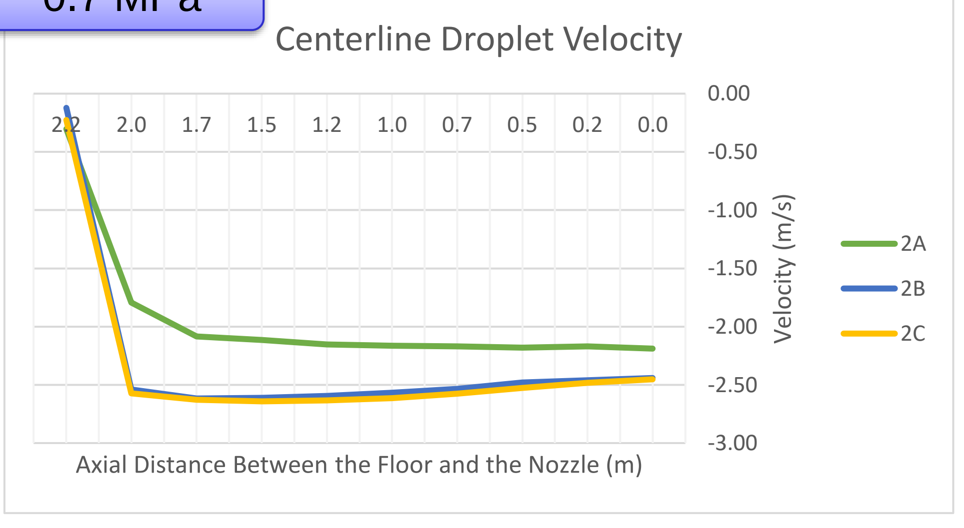
6. Results & Discussion

Multiphase – S. Analysis

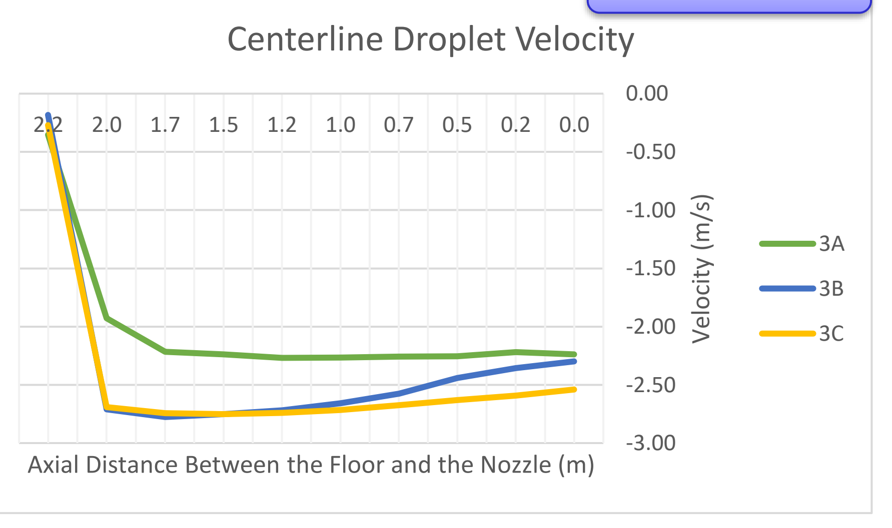
0.5 MPa



0.7 MPa



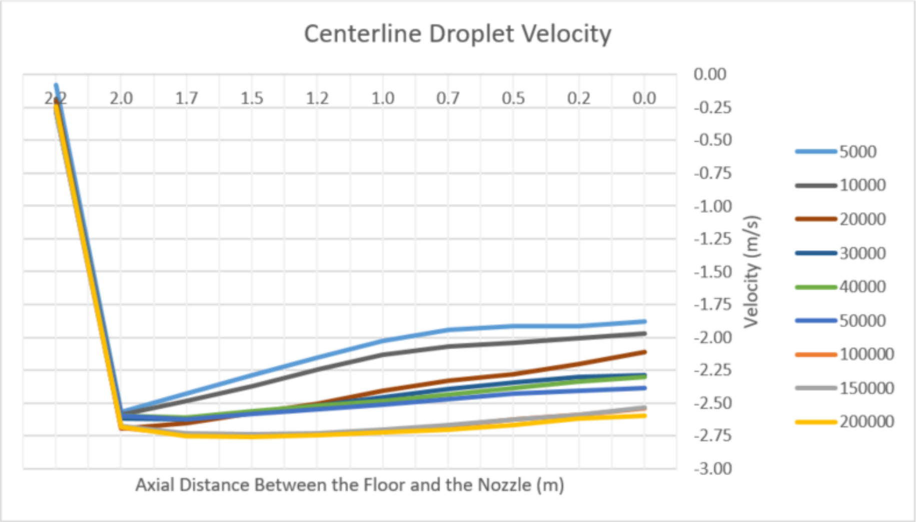
0.9 MPa

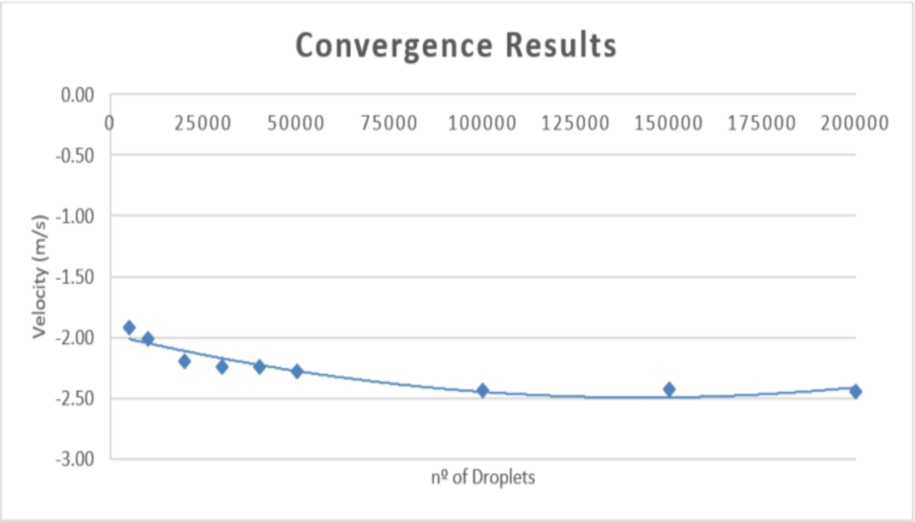


6. Results & Discussion

Multiphase – S. Analysis

Centreline Velocity @ 0.9 MPa



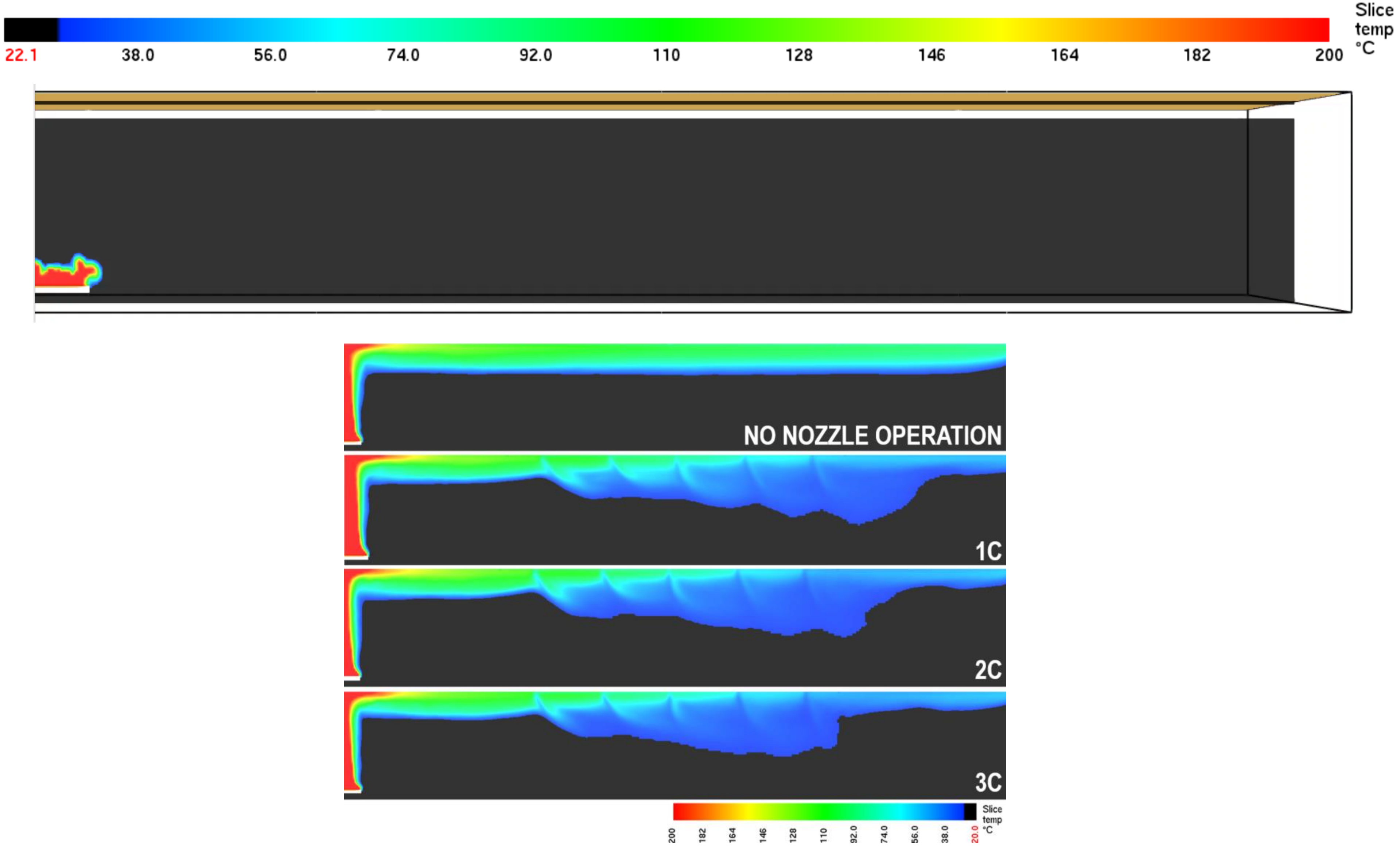


Results

Nº of Droplets	5000	10000	20000	30000	40000	50000	100000	150000	200000
% of Variation	21.7	18	10.3	8.56	8.24	6.85	0.67	0.9	-

6. Results & Discussion

Spray Nozzle & Fire



6. Results & Discussion

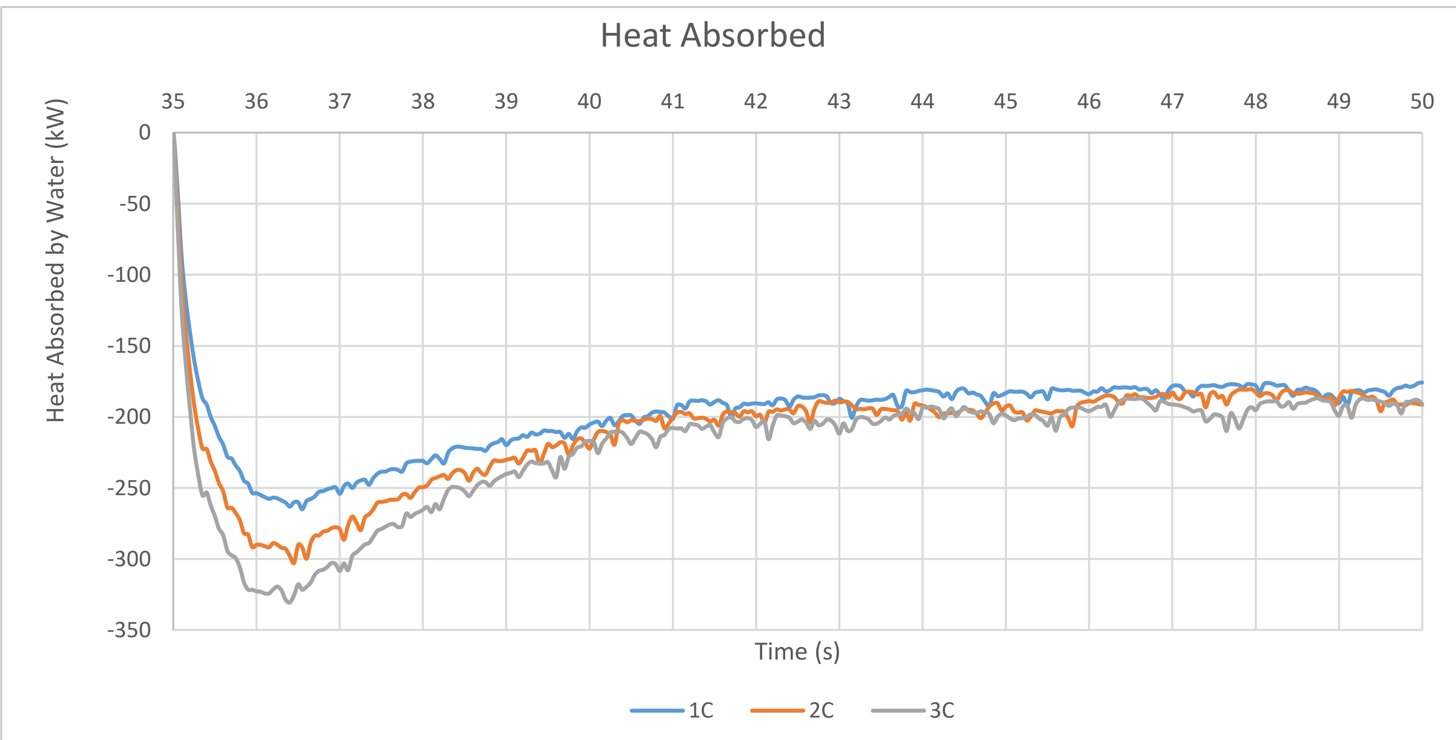
Spray Nozzle & Fire

0.5 MPa

0.7 MPa

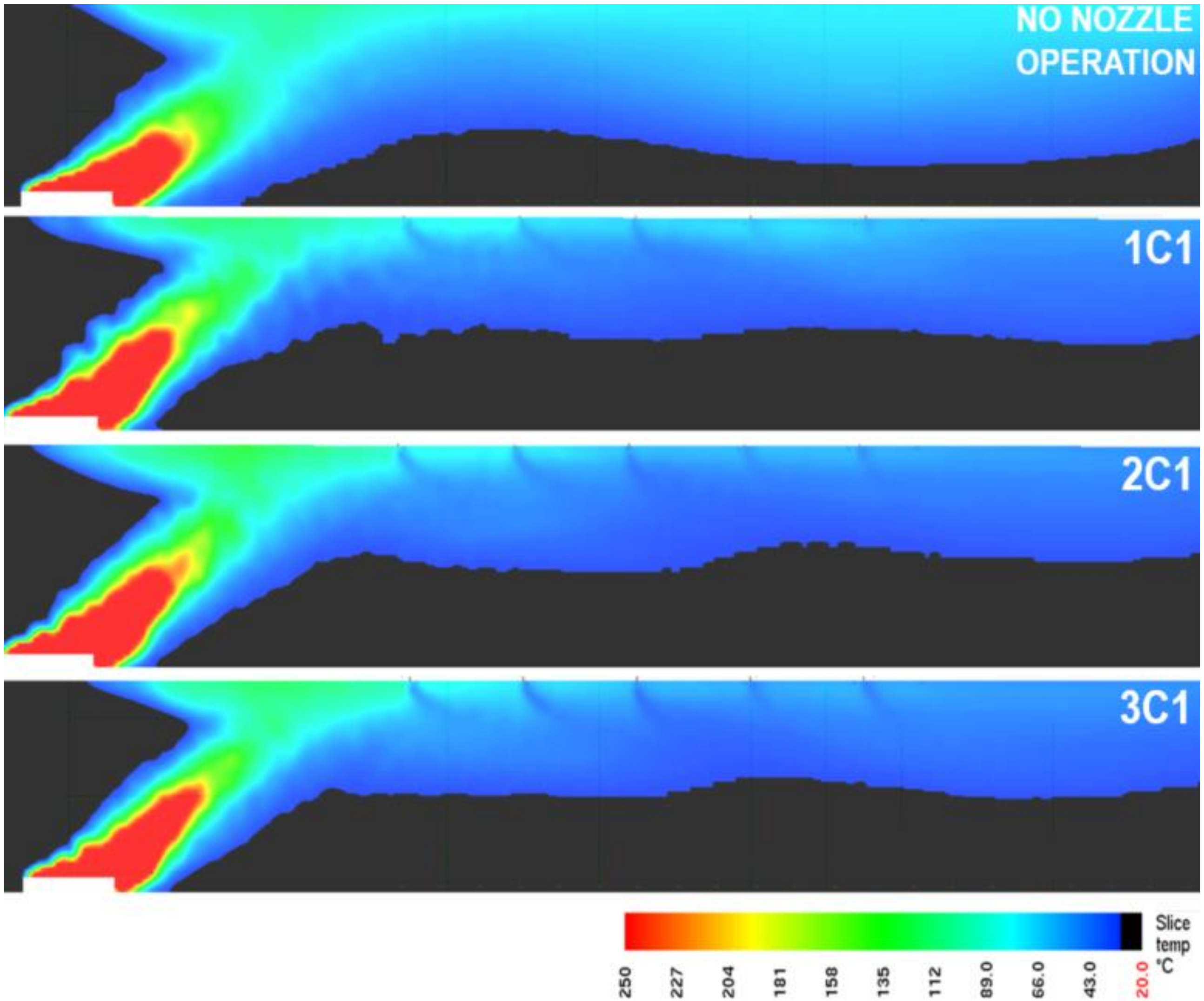
0.9 MPa

Label	Pressure	Flow	Heat Absorbed
1C	55.55%	87.20%	89.60%
2C	77.70%	91.94%	95.24%
3C	100%	100%	100%



6. Results & Discussion

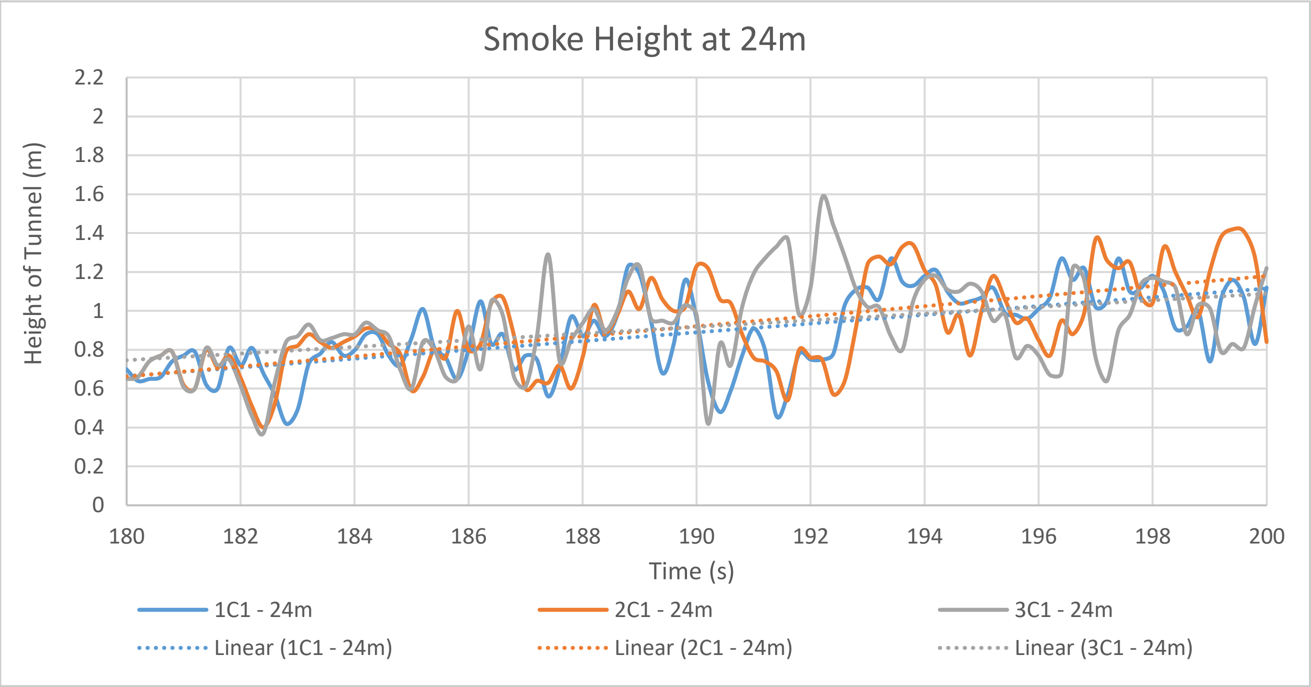
Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

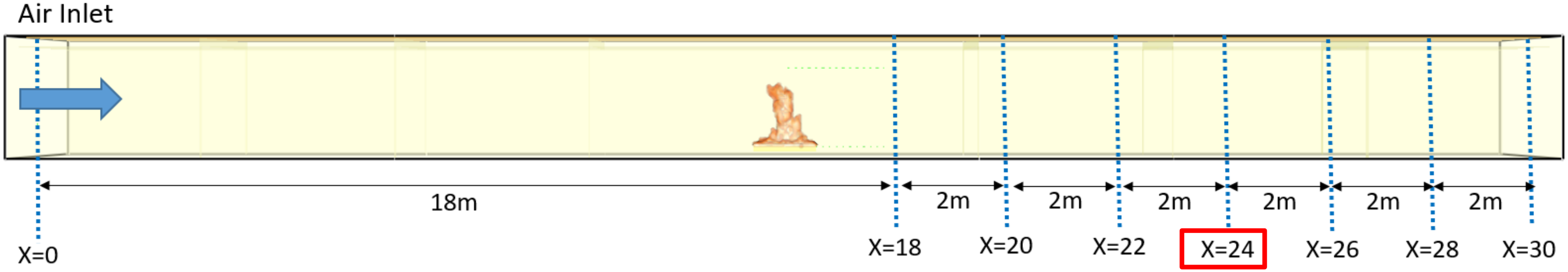


6. Results & Discussion

Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

The nozzle configuration 2C1 and 3C1 have the best performance regarding with the increase of the average free smoke height, which one correspond to an average of 0.5m.

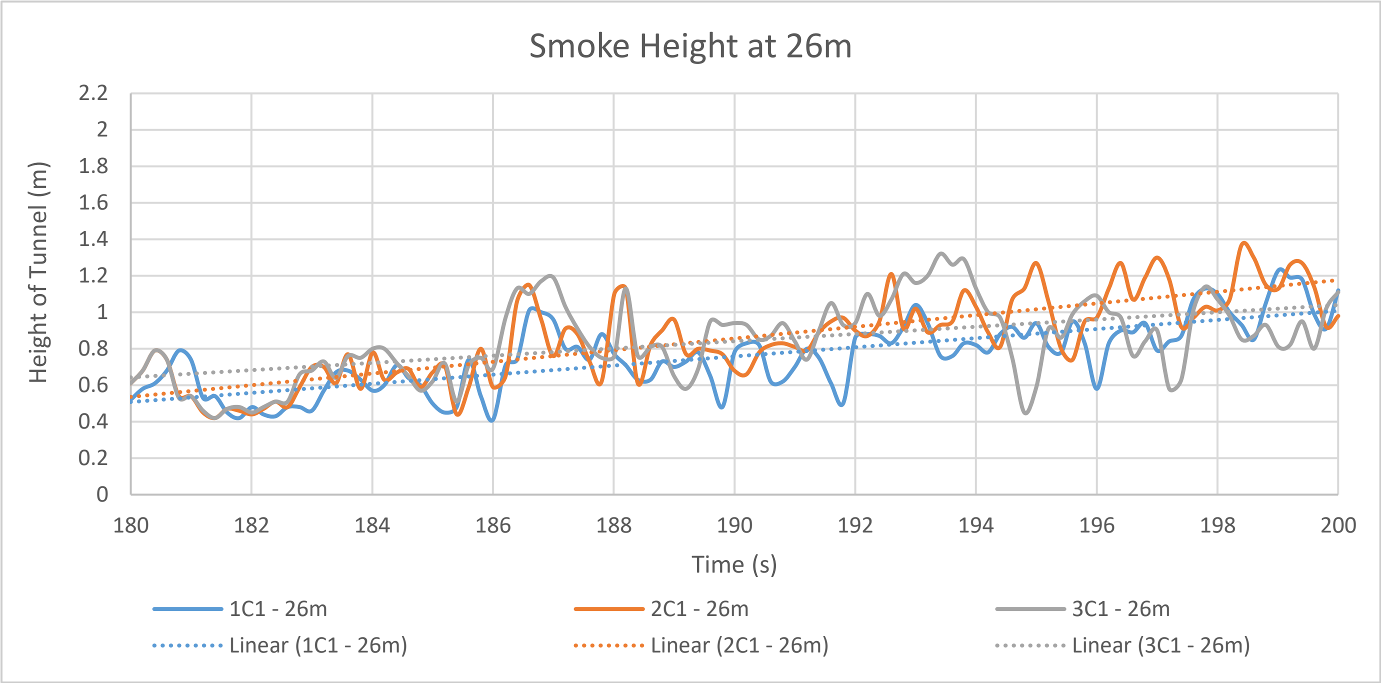


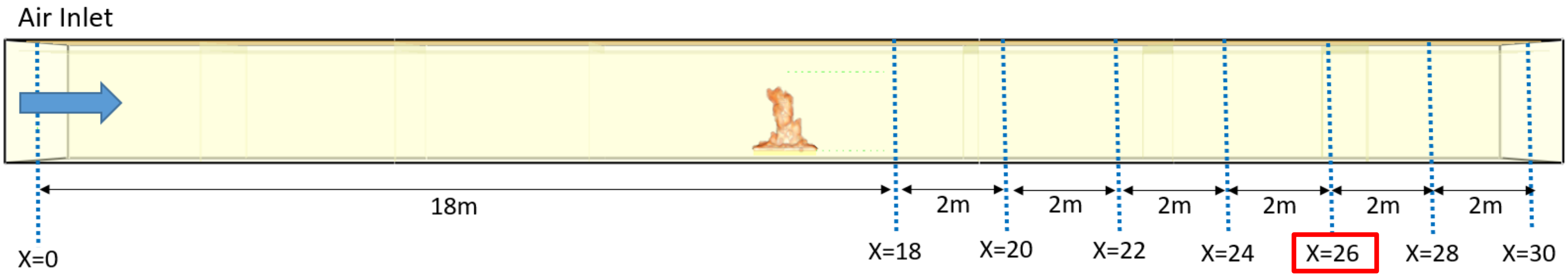


6. Results & Discussion

Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

The nozzle configuration 2C1 and 3C1 have the best performance regarding with the increase of the average free smoke height, which one correspond to an average of 0.6m.

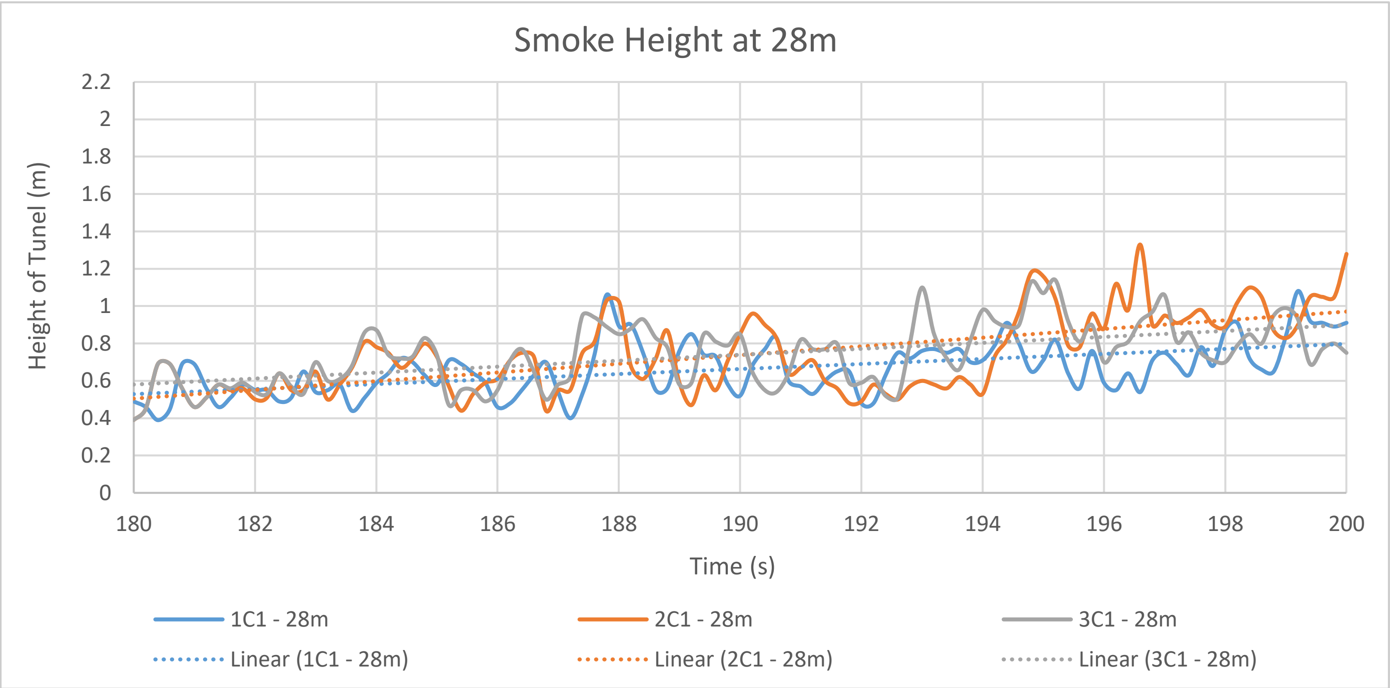


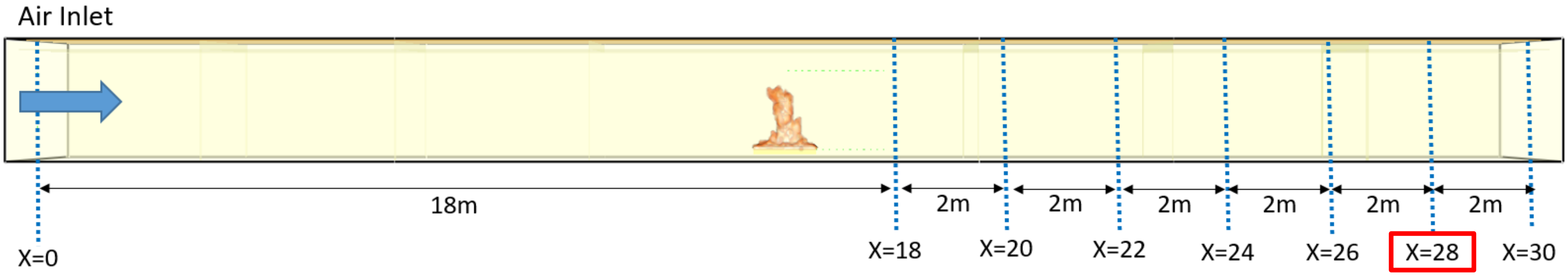


6. Results & Discussion

Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

The nozzle configuration 2C1 and 3C1 have the best performance regarding with the increase of the average free smoke height, which one correspond to an average of 0.4m.

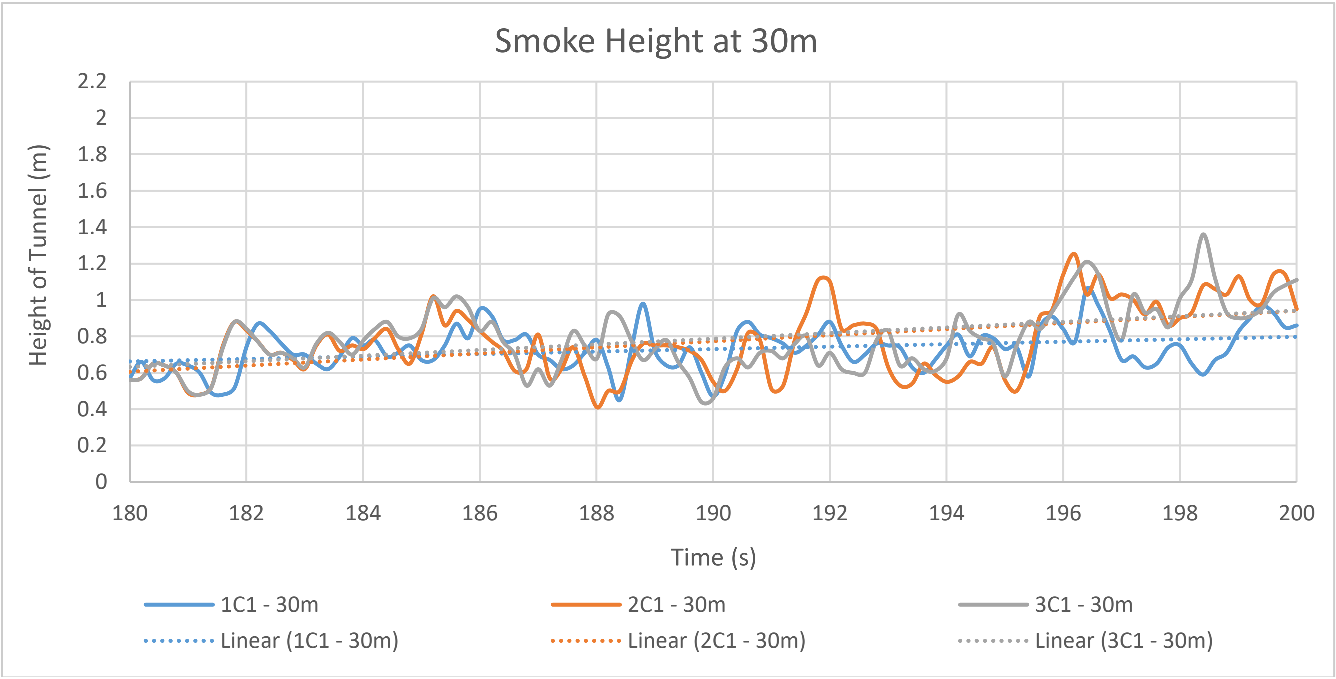


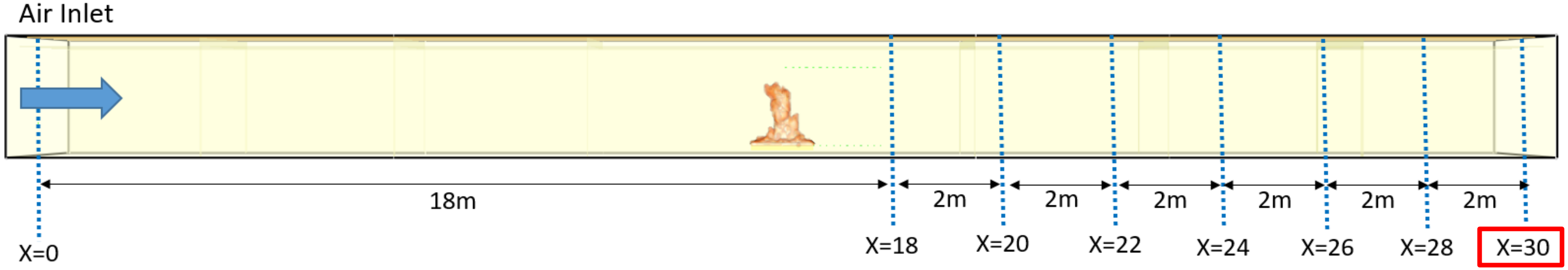


6. Results & Discussion

Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

Thus, the nozzle configuration 2C1 and 3C1 have the best performance regarding with the increase of the average free smoke height, which one correspond to an average of 0.3m.





6. Results & Discussion

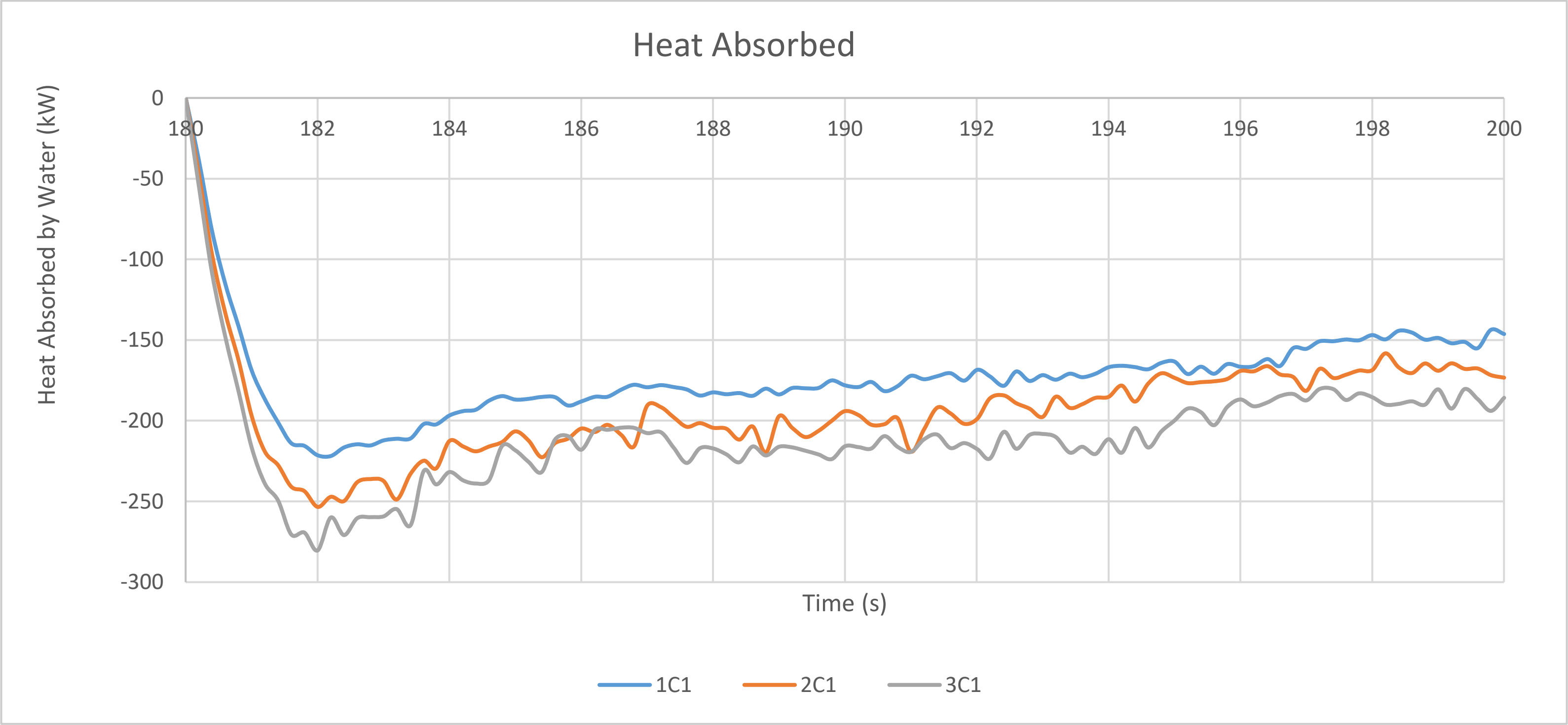
Network Spray Nozzle and Fire with Ventilation → 1C1, 2C1 & 3C1

0.5 MPa

0.7 MPa

0.9 MPa

Label	Pressure	Flow	Heat Absorbed
1C1	55.55%	87.20%	82.30%
2C1	77.70%	91.94%	91.80%
3C1	100%	100%	100%



7. Conclusions

As a general analysis:

- The most accurate results correspond to the re-fined mesh. However, **the fine mesh can be still used for calculations** allowing to reduce the computational time, with **variations** in the results between **0.1% and 5%.**

Evaluating the interaction of the spray nozzles and the longitudinal ventilation, it is possible to argue that:

- The nozzle system with the **lowest injection pressure** present the **lowest increment in the smoke free height.**

- The arrangement of spray nozzles with 0.7 and 0.9 MPa present the best performance related with the increment in the smoke free height.

- When the longitudinal ventilation system is operating, the average free smoke height corresponds to 0.6m. On the other hand, when the spray nozzle system is activated, the average free smoke height increases from 0.6m average to 0.8-1.0m average.

7. Conclusions

Regarding with the heat absorbed:

- Without the longitudinal ventilation working, the systems simulated have changed the injection pressure in 22% approximately and the flow in 10% approximately, the heat absorbed have only changed in 6% approximately.

- With the longitudinal ventilation working, the systems simulated have changed the injection pressure in 22% approximately and the flow in 10% approximately, the heat absorbed have only changed in 9% approximately.

Regarding with Tunnel Safety:

- Combining the longitudinal ventilation with a system of spray nozzles could allow to **decrease the air temperature** downstream from the fire. Hence, the structure, components and others would present **lower temperatures** and could avoid thermal damage.

- Despite that the longitudinal ventilation system in a tunnel are designed to fulfil life evacuation criteria upstream from the fire, **the combination with the spray nozzles would improve the tenability conditions downstream from to fire for the people, tunnel operators or firefighter**s.

Thank You