The Use of a Water Mist Curtain as a Radiation Shield

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IWMA YOUNG TALENT AWARD

Contents

- Water mist systems
- Objectives of the research
- Previous experimental research
- Background work
- Theoretical calculations
- Experimental setup
- Results
- Future work
- Conclusion

What is a water mist system?

- Fire suppression system using water droplets range in size from 10-1000 µm
- Requires less space and less water than traditional systems
- Alternative clean agent suppressant after the signing of the Montreal Protocol in the late 1980's

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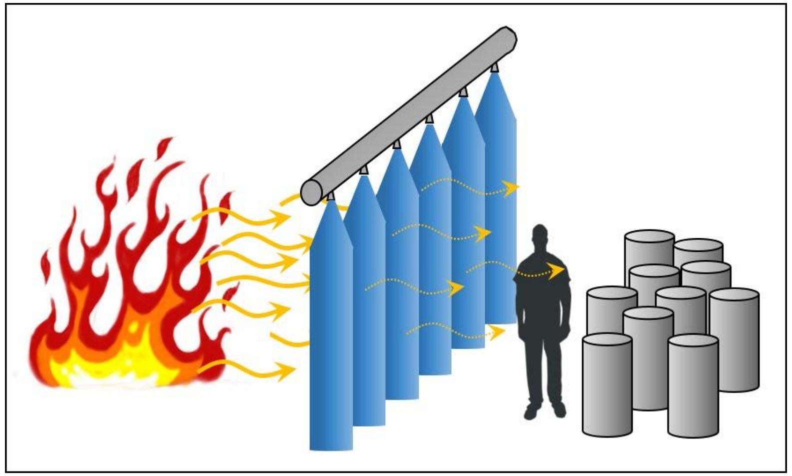
Potential uses of a water mist curtain shield

- Protect operational control rooms
  - Oil rigs
  - Marine vessels, etc
- Protecting high value targets from radiation exposure
- Prevent fire spread; i.e. compartmentation



Objectives of the research

- Measure the radiation attenuation through a high pressure low flow rate single nozzle water mist curtain
- Find the different radiation attenuation levels based on:
  - The vertical position within the water mist column
  - Vertical plane angle of the heat flux gauge
  - Radiation source

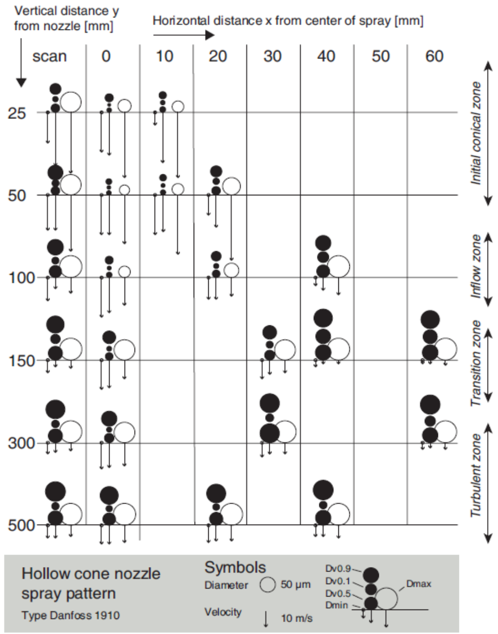
Previous experimental research

- Nozzle sizes tested:
  - Firefighting nozzles, sprinkler heads, and water mist heads
- Pressures and nozzle flow rate:
  - 0.076 - 10 bars
  - 0.12 – 4.7 L/min (mist), 360 – 1363 L/min (fire nozzle)
- Sources of radiation:
  - Gas radiant panel, liquid pool fire, wood crib fire, Fourier Spectrometer
- $D_v0.5$ sizes:
  - Varied by location in the spray column and the nozzle (24 – 550+ µm)
- 10-70% attenuation

[Ref. 1-7]

Background work

- Continuation of the PhD work conducted by Prof. Bjarne Husted
  - Experimental and CFD results on high pressure water mist systems comparing hollow and full cone nozzles:
    - Droplet sizes in various region of the mist column
    - Droplet velocities
    - Volumetric density



[Ref. 6]

Theoretical heat flux

Target $\dot{Q}''_{rad}$ (kW/m²) from the Radiant Panel				
Separation (m)	650ºC	700ºC	750ºC	800ºC
0.4	10.7	13.2	16.2	19.6
0.5	7.6	9.4	11.5	13.9
0.6	5.6	6.9	8.4	10.2
0.7	4.4	5.4	6.6	8.0
0.8	3.5	4.3	5.3	6.4
0.9	2.8	3.4	4.2	5.1
1	2.2	2.8	3.4	4.1

Target $\dot{Q}''_{rad}$ (kW/m²) from the Line Burner					
	Fire Size (kW)				
Separation (m)	30	35	40	46	48
0.4	2.5	2.7	3.0	3.3	3.4
0.5	1.8	2.0	2.2	2.5	2.6
0.6	1.3	1.5	1.7	1.9	2.0
0.7	1.0	1.2	1.3	1.5	1.6
0.8	0.8	1.0	1.1	1.2	1.3

$$\dot{Q}''_{rad} = F * \varepsilon * \sigma * (T_{panel}^4 - T_{amb}^4) \quad \textbf{(1)}$$

$$\dot{Q}''_{rad} = \frac{\dot{Q}}{A_T} * \chi \quad \textbf{(2)}$$

$$\dot{Q}''_{rad,1\ side\ of\ fire} = \dot{Q}''_{rad} * \frac{A_E}{A_T} * F \quad \textbf{(3)}$$

[Ref. 8]

[Ref. 9]

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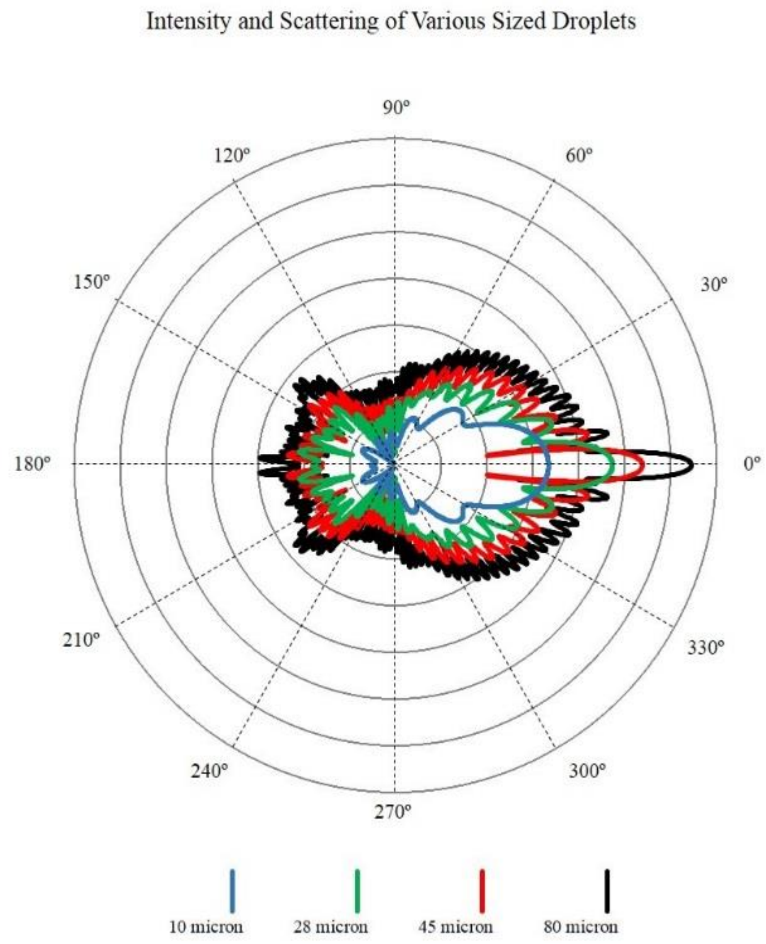
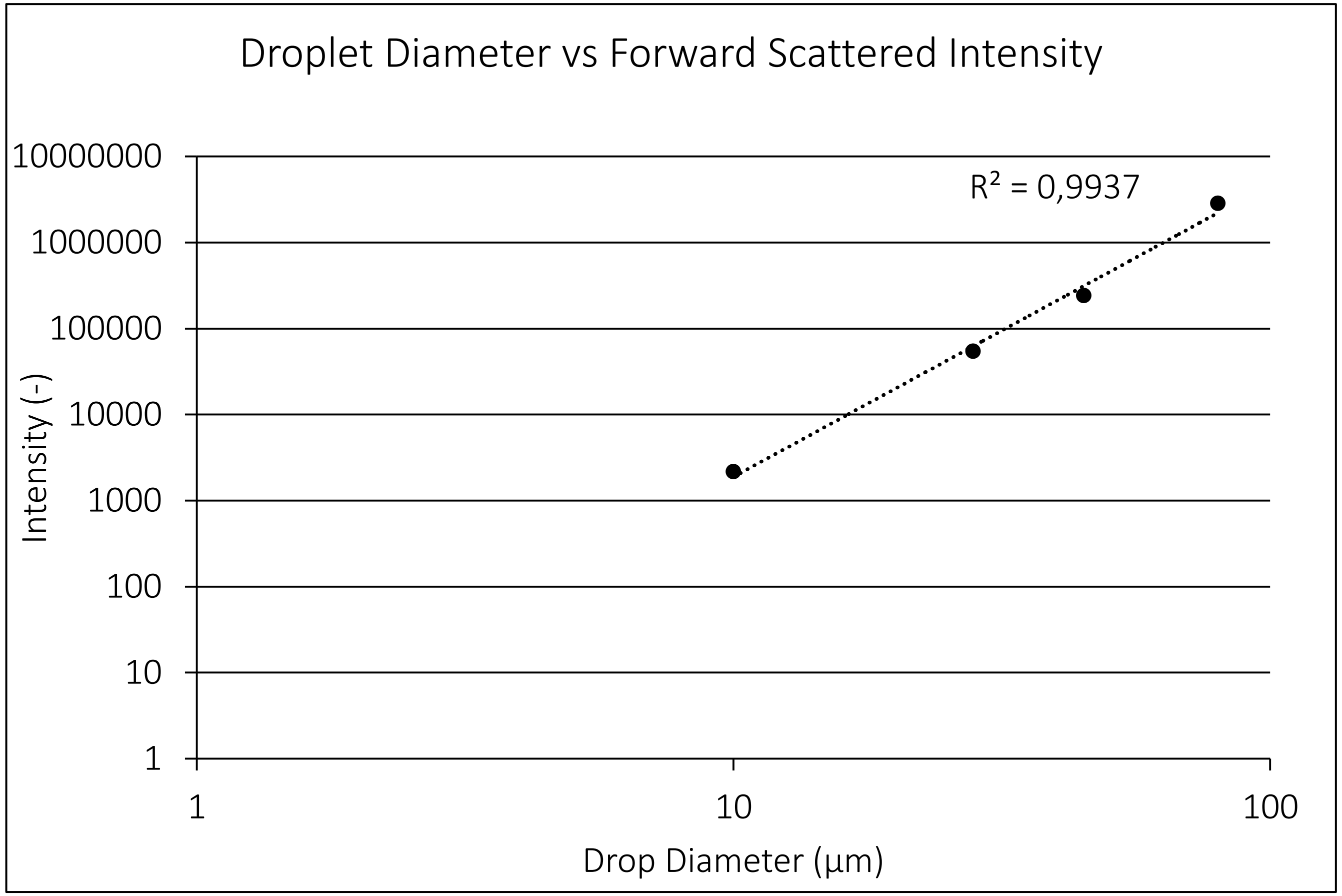
Theoretical Mie scattering

- Simplified method for solving the complex radiation transfer equation
- Physics approach to solving the scattering and extinction of an electromagnetic wave hitting a spherical particle
- MiePlot
  - Single source point, scattering analysis of a single droplet
  - Input: wavelength, droplet size/distribution, refractive indices
  - Outputs: several options but Intensity vs Scattering Angle of greatest interest

Theoretical Mie scattering





Theoretical Mie scattering

- Reasons Mie Scattering can not be used
  - Type of radiant source: point source vs sheet source
    - Aka single ray vs multiple rays entering the droplet
    - Single wavelength size vs large spectrum
  - Monodispersed vs polydispersed water mist cloud
  - The location where the ray(s) enters into the droplet

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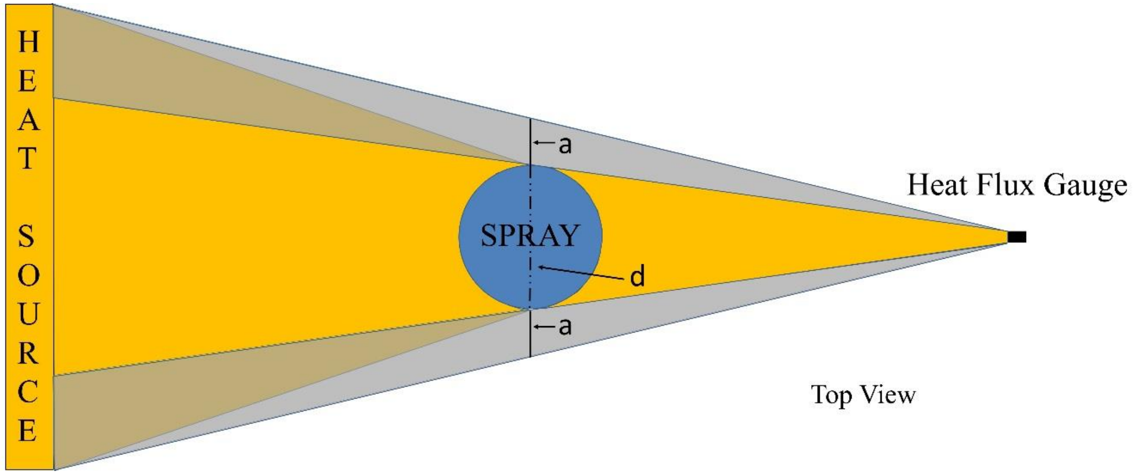
Attenuation calculation



$$Attenuation = 1 - \frac{Measured\ radiation\ \boldsymbol{with}\ water\ mist\ (\boldsymbol{Eqn\ 7})}{Measured\ radiation\ \boldsymbol{without}\ water\ mist\ (\boldsymbol{Eqn\ 6})} \quad \textbf{(4)}$$

$$\dot{Q}''_{rad,w/o\ mist(unimpeded)} = \dot{Q}''_{total\ rad,w/o\ mist} * \frac{Unimpeded\ Length}{Cross\ Sectional\ Length} \quad \textbf{(5)}$$

$$\dot{Q}''_{rad,w/o\ mist(H2O)} = \dot{Q}''_{total\ rad,w/o\ mist} * \frac{Spray\ Diameter}{Cross\ Sectional\ Length} \quad \textbf{(6)}$$

$$\dot{Q}''_{rad,with\ mist(H2O)} = \dot{Q}''_{total\ rad,with\ mist} - \dot{Q}''_{rad,w/o\ mist(unimpeded)} \quad \textbf{(7)}$$

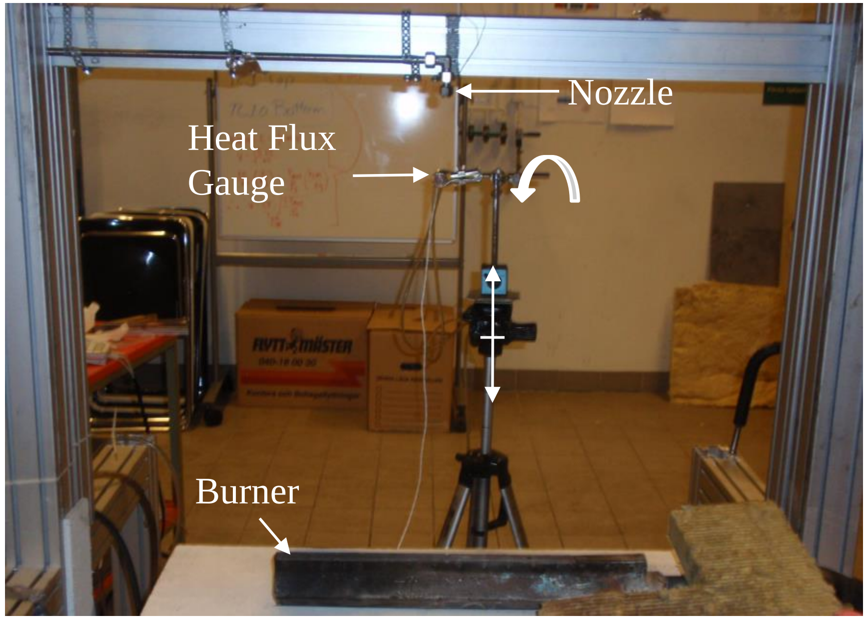
Experimental setup

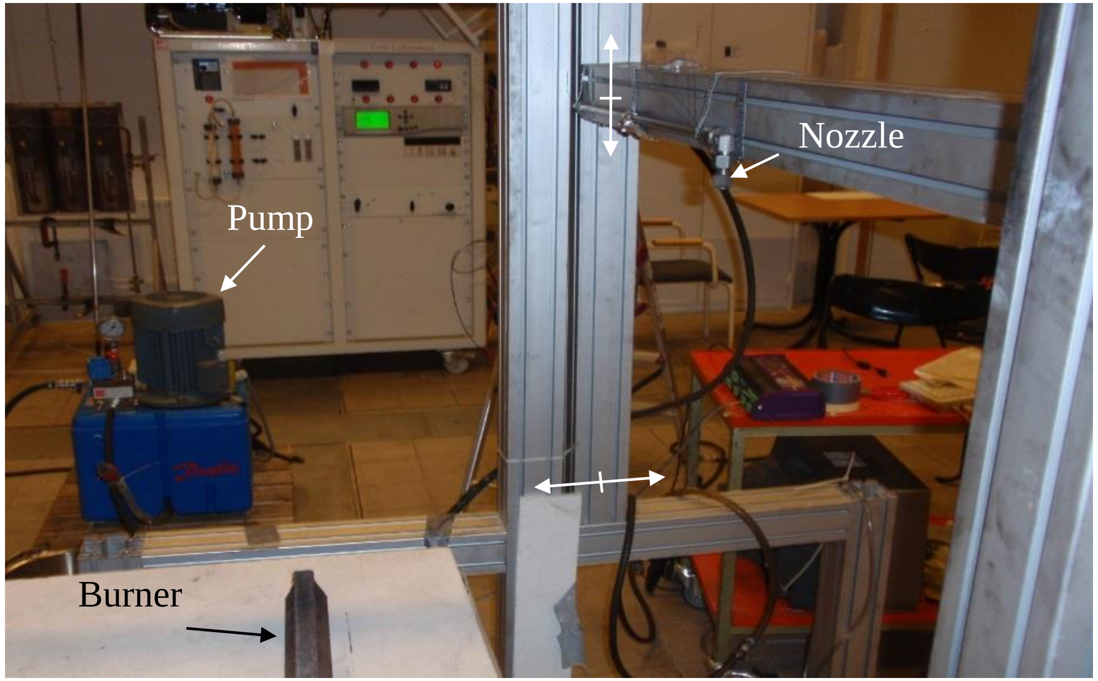
- Danfoss Water Mist System
  - Power Pack PPH 6.3 with a piston pump (4 L/min)
  - Single nozzle: 1910 Hollow Cone Nozzle (0.42 L/min)
  - Operating pressure: 100 Bars
  - Single fluid spray
  - $D_v0.5$'s = 28-35, 40, 48 µm

https://stateofgreen.com/en/profiles/danfoss/solutions/fire-suppression-with-water-mist-in-microbiological-laboratory

Experimental setup

- Overall Structure
  - Radiant panel and diffusion flame heat sources
  - Adjustable super-structure

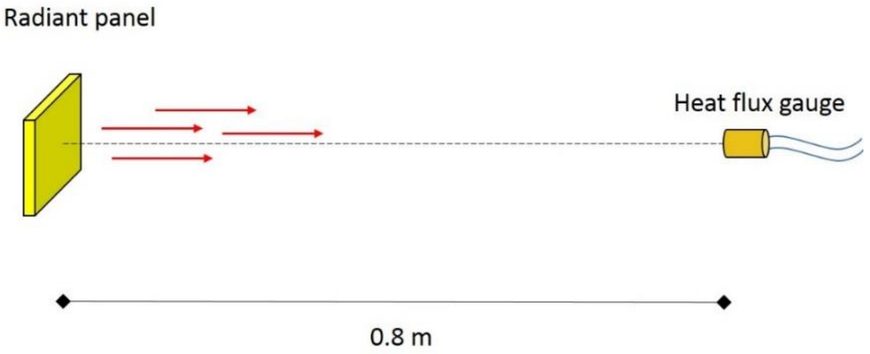


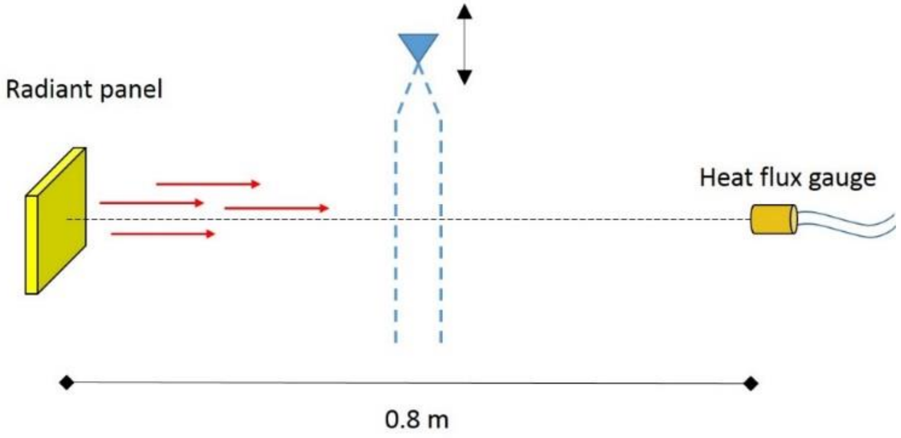


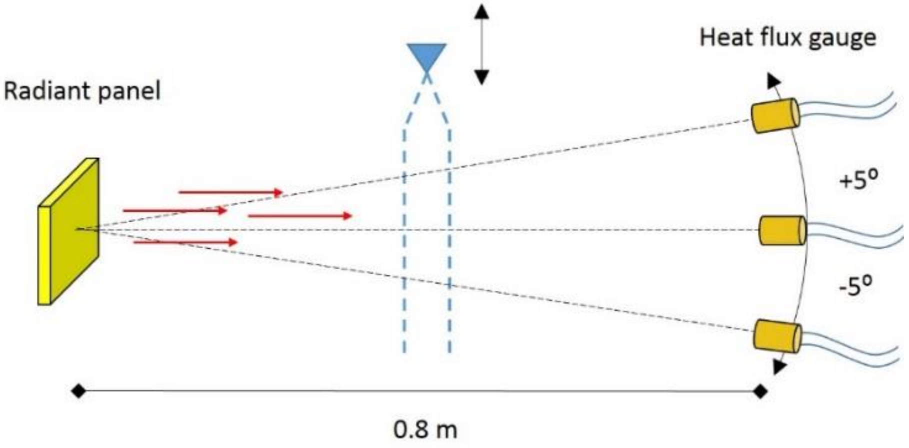
Experimental setup

3 burner propane radiant panel: 39 x 47 cm

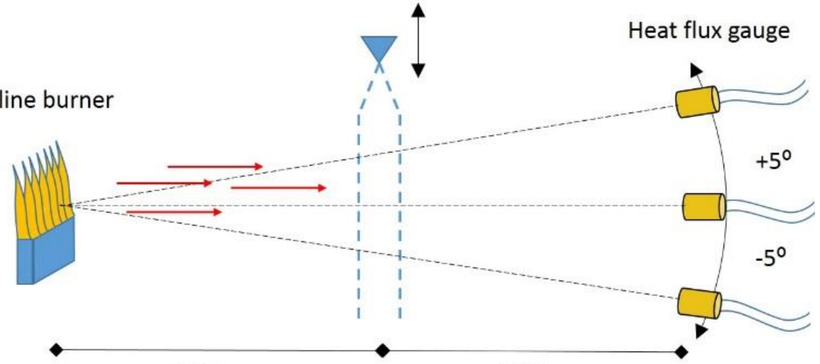
≈700^{o}C ± 50^{o}C

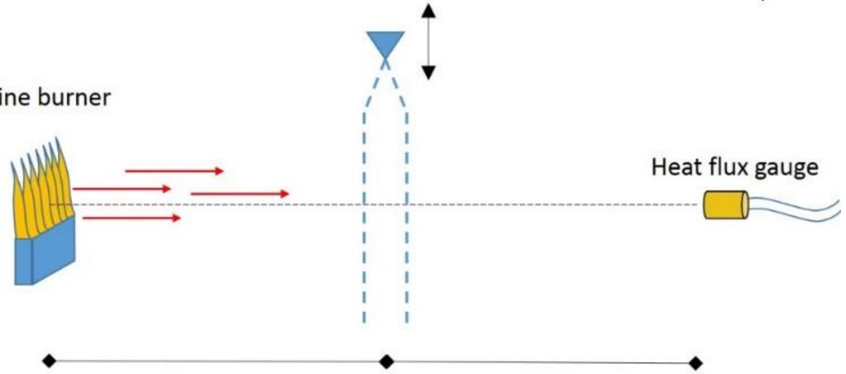






Experimental setup

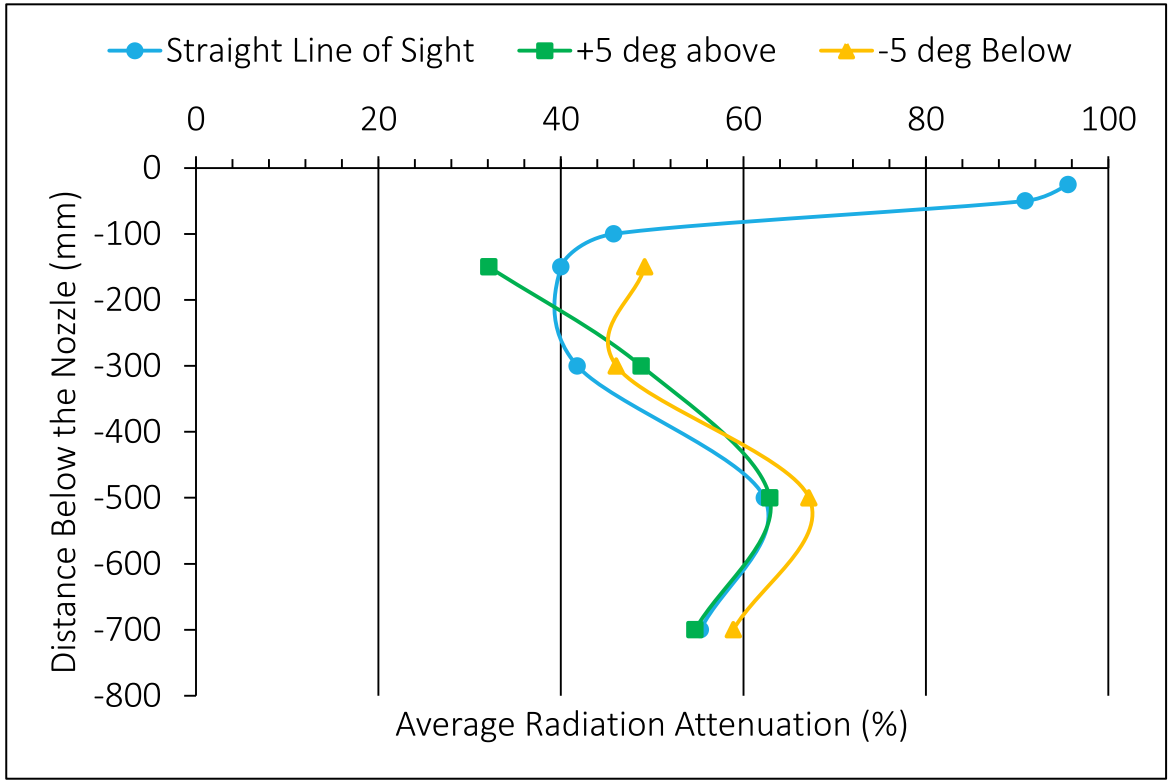


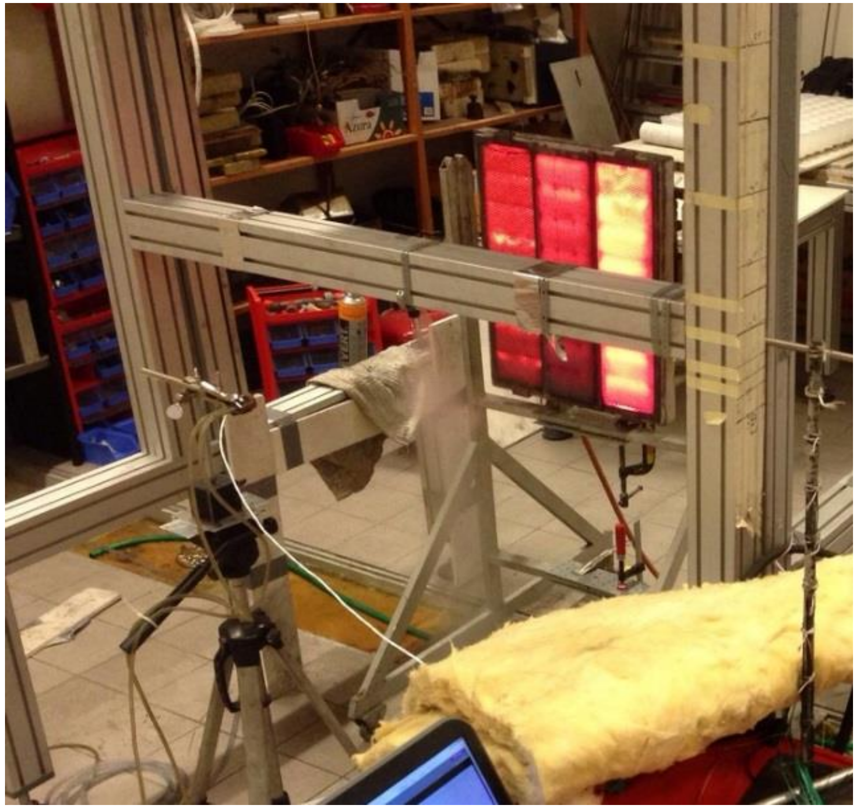


Gas line burner (Propane): 2 x 39 cm

Propane flow at 20 L/min (≈46 kW)

Results (radiant panel)





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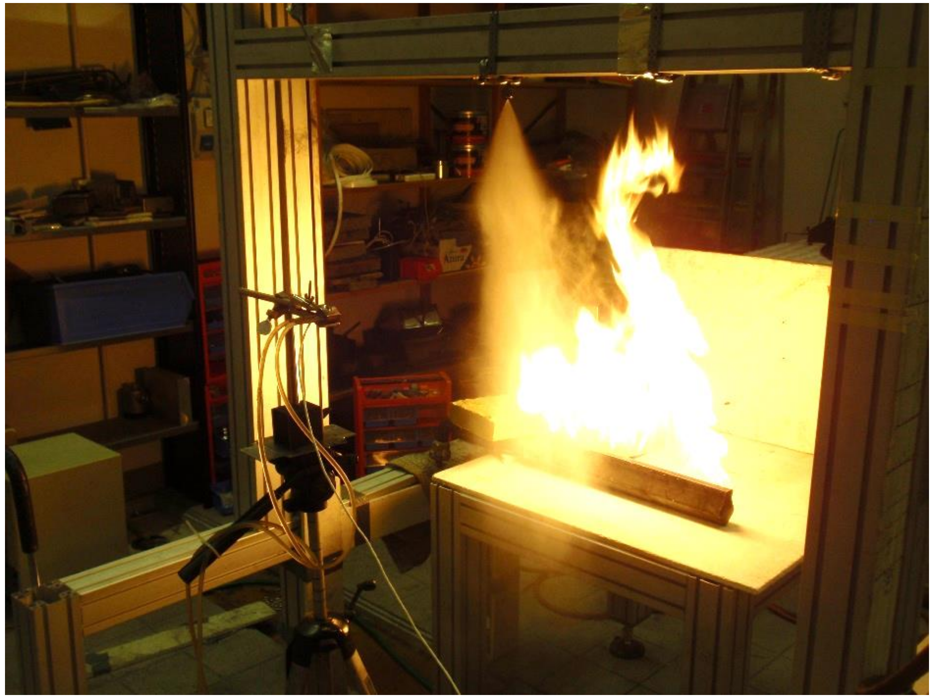
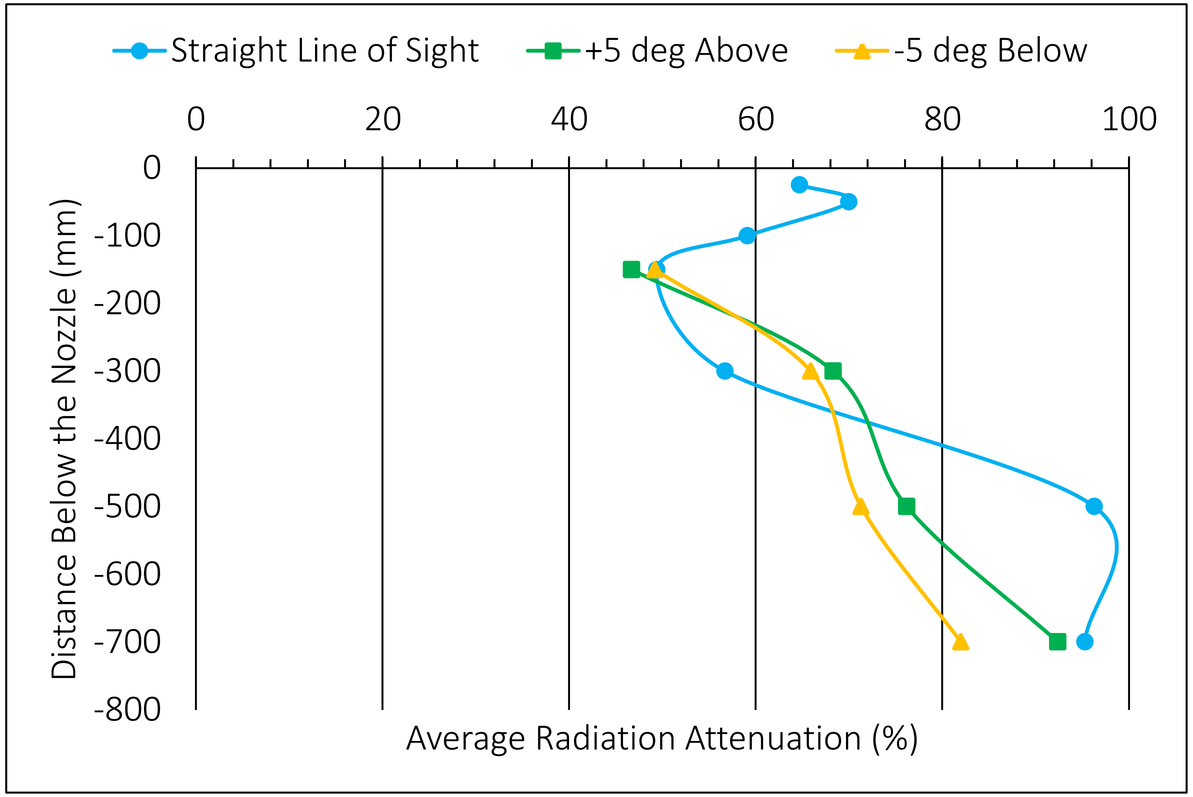
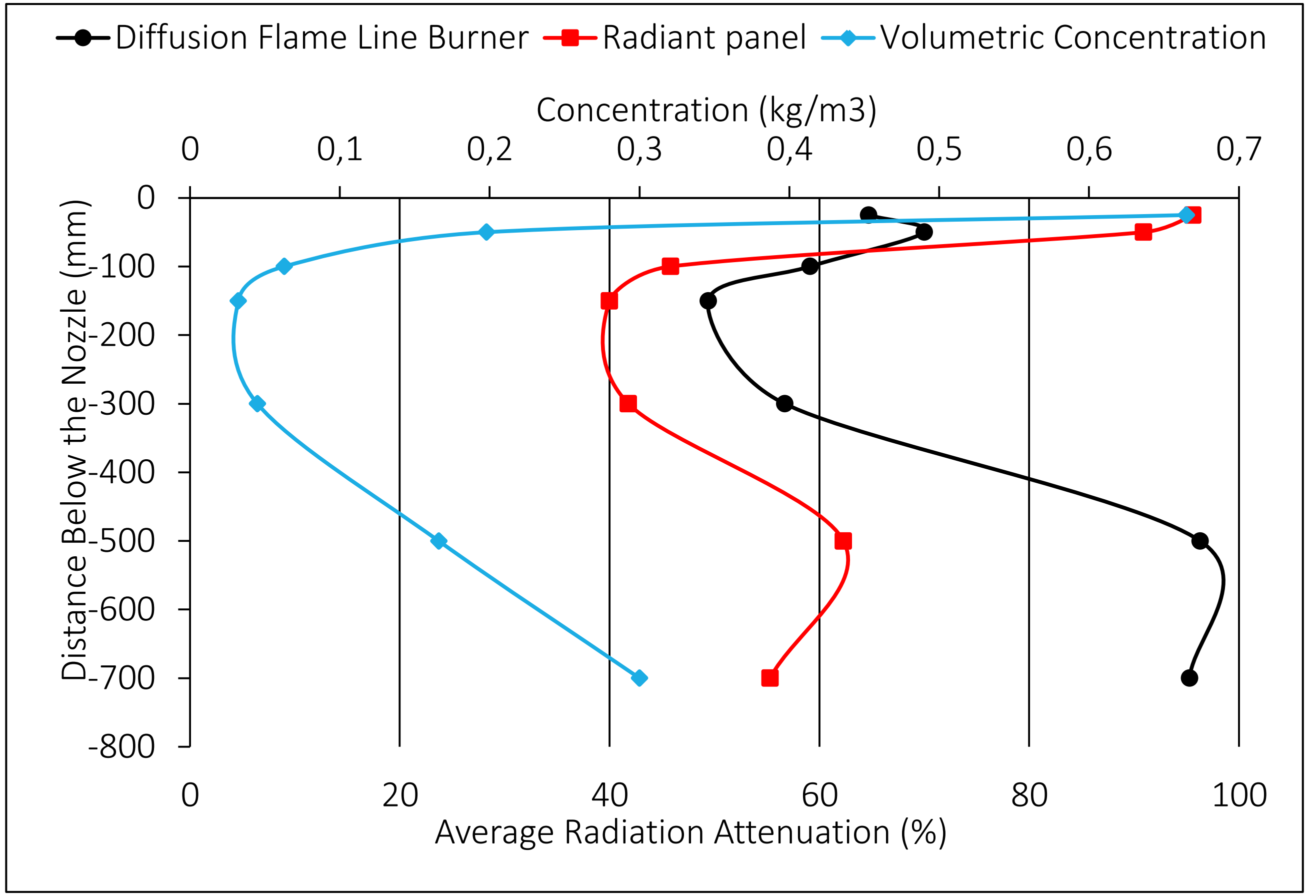
Results (diffusion line burner)





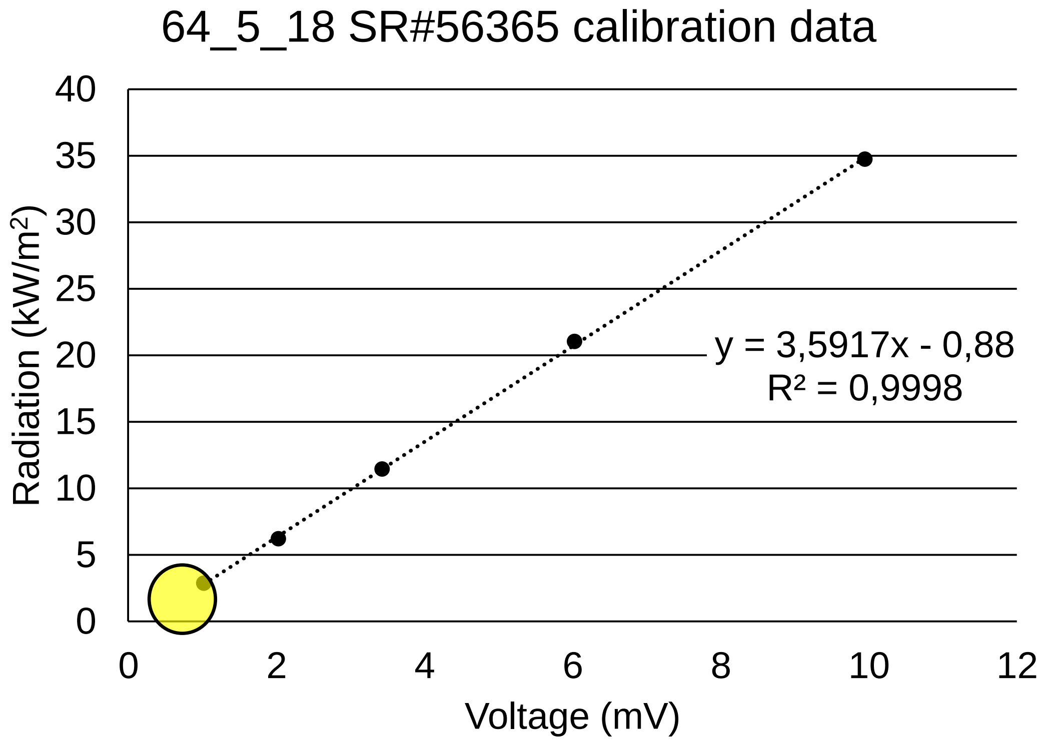
Results (straight line of sight)

- Attenuation levels for both sources follow the water concentration trend until 500 mm
- Droplet size drives attenuation levels past 500 mm
- More radiation is blocked from the line burner because of the higher number of wavelength sizes being emitted



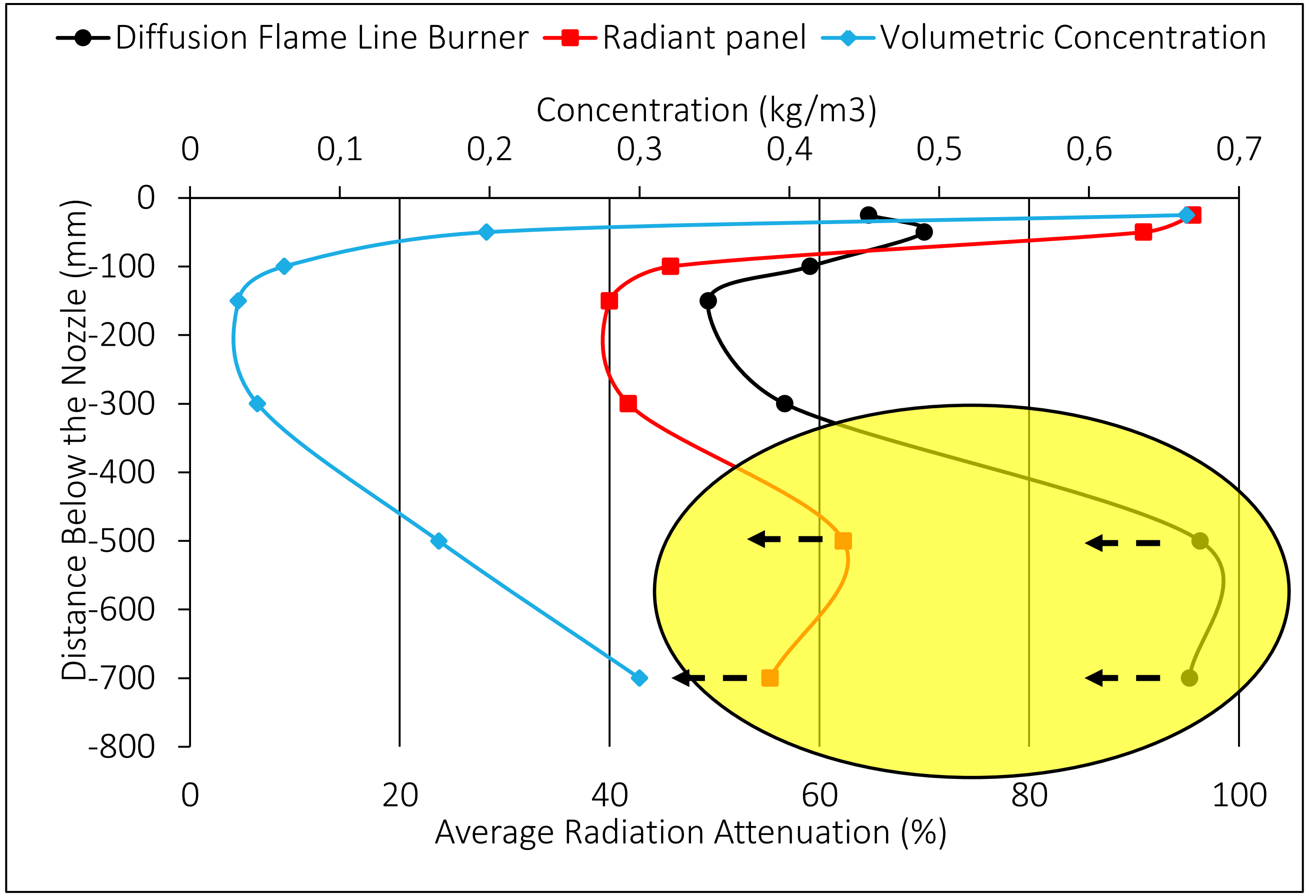
Uncertainties affecting the results

- Misalignment between the heat source, centerline of the spray, and the heat flux gauge
- Radiation levels measured fall below the known calibration curve of the heat flux gauge
- Equipment reading uncertainties
- Water mist/heat source interaction



Uncertainties affecting the results

- Water mist/heat source interaction at 500 and 700 mm below the nozzle
- Flame size decreased, thus reducing the incident heat flux and artificially increasing the attenuation



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Possible future work

- Investigate the influence of environmental conditions on the spray
- Integration of multiple nozzles
- Larger diffusion flame to increase separation distances
- Various nozzle orientations
- Incorporating various high pressure nozzle types

Conclusion

- Very difficult to predict attenuation for all systems from one test:
  - Pressure, nozzle flow rate, nozzle type, number of nozzles, nozzle orientation, environmental conditions, etc.
- More radiation is blocked from a diffusion flame type source than a radiant panel
- Attenuation is not the same for all positions along the vertical axis
- Droplet size, water concentration, and droplet residency time play a key role in attenuation levels

Thank you!

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Thank you!

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