The Use of a Water Mist Curtain as a Radiation Shield

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IWMA YOUNG TALENT AWARD
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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
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
- $D_{0.5}$ 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 \( \dot{Q}_{\text{rad}}^* \) (kW/m\(^2\)) from the Radiant Panel**

<table>
<thead>
<tr>
<th>Separation (m)</th>
<th>650ºC</th>
<th>700ºC</th>
<th>750ºC</th>
<th>800ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>10.7</td>
<td>13.2</td>
<td>16.2</td>
<td>19.6</td>
</tr>
<tr>
<td>0.5</td>
<td>7.6</td>
<td>9.4</td>
<td>11.5</td>
<td>13.9</td>
</tr>
<tr>
<td>0.6</td>
<td>5.6</td>
<td>6.9</td>
<td>8.4</td>
<td>10.2</td>
</tr>
<tr>
<td>0.7</td>
<td>4.4</td>
<td>5.4</td>
<td>6.6</td>
<td>8.0</td>
</tr>
<tr>
<td>0.8</td>
<td>3.5</td>
<td>4.3</td>
<td>5.3</td>
<td>6.4</td>
</tr>
<tr>
<td>0.9</td>
<td>2.8</td>
<td>3.4</td>
<td>4.2</td>
<td>5.1</td>
</tr>
<tr>
<td>1</td>
<td>2.2</td>
<td>2.8</td>
<td>3.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

\[
\dot{Q}_{\text{rad}}^* = F \times \varepsilon \times \sigma \times (T_{\text{panel}}^4 - T_{\text{amb}}^4) \quad (1)
\]

**Target \( \dot{Q}_{\text{rad}}^* \) (kW/m\(^2\)) from the Line Burner**

<table>
<thead>
<tr>
<th>Fire Size (kW)</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>46</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation (m)</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>0.4</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>0.5</td>
<td>1.8</td>
<td>2.0</td>
<td>2.2</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>0.6</td>
<td>1.3</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>0.7</td>
<td>1.0</td>
<td>1.2</td>
<td>1.3</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

\[
\dot{Q}_{\text{rad}}^* = \frac{\dot{Q}}{A_T} \times \chi \quad (2)
\]

\[
\dot{Q}_{\text{rad, side of fire}}^* = \dot{Q}_{\text{rad}}^* \frac{A_E}{A_T} \times F \quad (3)
\]

[Ref. 8] [Ref. 9]
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

Intensity and Scattering of Various Sized Droplets

Droplet Diameter vs Forward Scattered Intensity

\[ R^2 = 0.9937 \]
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
Attenuation calculation

\[ \text{Attenuation} = 1 - \frac{\text{Measured radiation with water mist (Eqn 7)}}{\text{Measured radiation without water mist (Eqn 6)}} \] (4)

\[ \dot{Q}''_{\text{rad, w/o mist (unimpeded)}} = \dot{Q}''_{\text{total rad, w/o mist}} \times \frac{\text{Unimpeded Length}}{\text{Cross Sectional Length}} \] (5)

\[ \dot{Q}''_{\text{rad, w/o mist (H2O)}} = \dot{Q}''_{\text{total rad, w/o mist}} \times \frac{\text{Spray Diameter}}{\text{Cross Sectional Length}} \] (6)

\[ \dot{Q}''_{\text{rad, with mist (H2O)}} = \dot{Q}''_{\text{total rad, with mist}} - \dot{Q}''_{\text{rad, w/o mist (unimpeded)}} \] (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
  - \(D_v0.5's = 28-35, 40, 48 \mu m\)

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°C ± 50°C
Experimental setup

Gas line burner (Propane): 2 x 39 cm
Propane flow at 20 L/min (≈46 kW)
Results (radiant panel)
Results (diffusion line burner)

![Image of a flame with measurement lines]

Graph showing the distance below the nozzle (mm) against average radiation attenuation (%). The graph includes lines for Straight Line of Sight, 5 degrees above, and 5 degrees below.

- At 0 mm distance, the attenuation starts around 0%.
- As distance increases, the attenuation increases, reaching approximately 80% at ±100 mm.

(For more detailed analysis, refer to the graph.)
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

$$y = 3.5917x - 0.88$$

$$R^2 = 0.9998$$
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
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!

References

Thank you!

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