Factors Affecting Efficiency of Water Mist Suppression of Solid Combustible Fires in Open Environment

Hong-Zeng (Bert) Yu
FM Global

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Background

- **FM Global tested combined sprinkler-fine water spray protection in the 1960s for wood pallet fires in a 2300-m^3 building.**
  - 4.2-mm nozzles operating at 69 bar to supplement sprinkler protection

- **FM Global tested fine water sprays for the protection of light hazard, residential fires in 1970s and early 1980s.**
  - 5.6-mm nozzle had the best suppression result for nozzles from 4.1 to 11.2 mm at the same application density

Background

- Water mist was applied to other light hazard occupancies in 1990s and 2000s, mainly for marine and some land-based applications .
- Standard bodies recently expanded water mist applications to higher solid combustible fire hazards with limited or no fire test data:
  - CEN/TS 14972, "Fixed firefighting systems – Watermist systems – Design and installation", allows for the protection of European ordinary hazard group 3 (OH-3).
  - NFPA 750 (2015), "Water mist systems" – allows for NFPA OH-1 and OH-2 occupancies.

    OH-1: Storage heights up to 2.4 m for commodities with moderate fire heat release rate.

    OH-2: Storage heights up to 3.7 m for moderate heat release rate, or up to 2.4 m high for high fire heat release rate.

Current Needs

- **Identify the key factors for suppressing solid combustible fires in open environment**
- **Expand the database for water mist suppression of solid combustible fires**

Outline

- Test commodities and fuel array configurations
- Assessment of droplet size's impact on fire plume penetration and propensity of droplet deposition on fuel surface
- Water mist operating conditions
- Fire tests and results
- Conclusions

Test Commodities

Class 2 Commodity (EUR Commodity Category I)

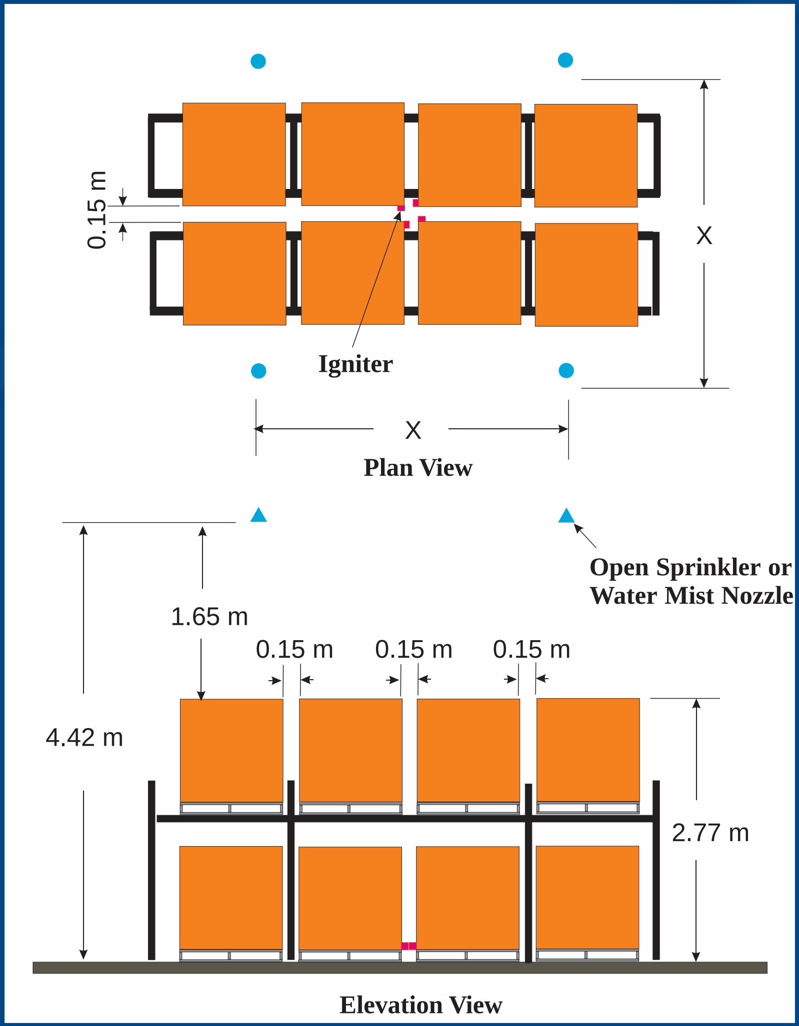
- 1.06 x 1.06 x 1.19 m high per pallet load
- Cartons: 35.8 kg
- Metal liner: 20.7 kg
- Hardwood pallet: 23.0 kg

Cartoned Expanded Plastic (CEP) (EUR Commodity Category IV)

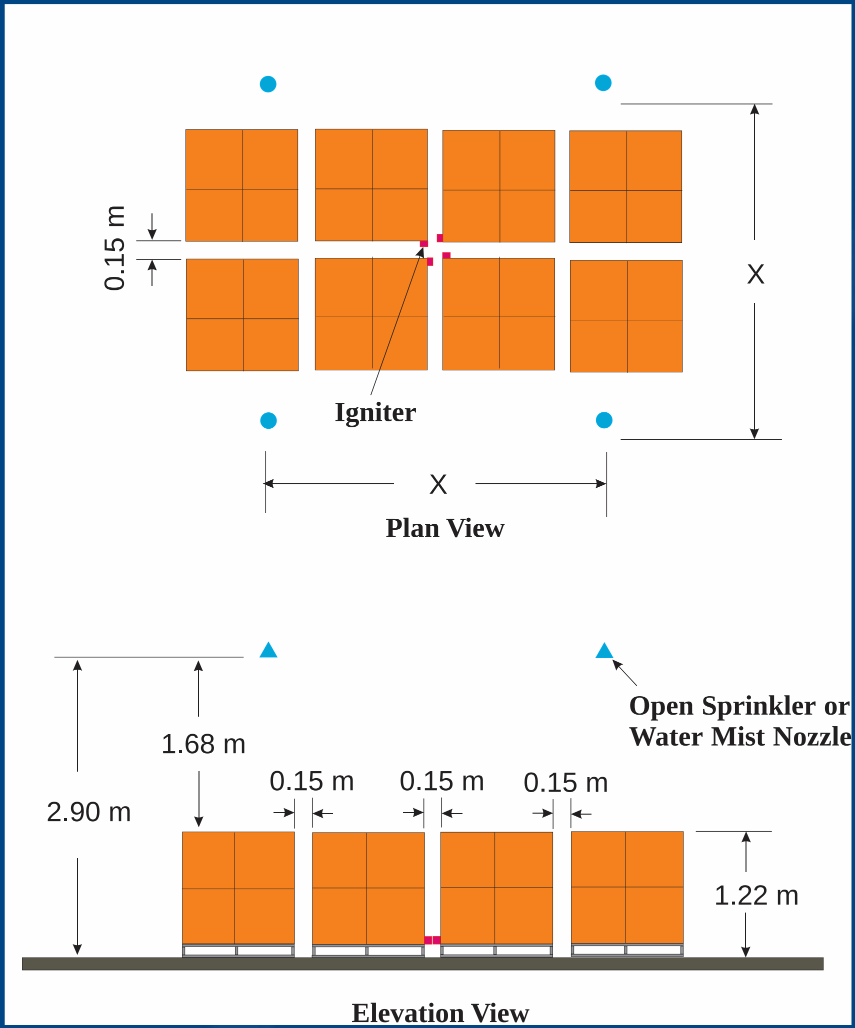
- 1.07 x 1.07 x 1.20 m high per pallet load
- Cartons: 20.3 kg
- PS meat trays: 24.3 kg
- Hardwood pallet: 23.0 kg

Test Fuel Array and Nozzle Arrangement

Class 2 Commodity



Cartoned Expanded Plastic (CEP)



Application density: 6.1 mm/min

8.1 mm/min

Water Mist Nozzle Operating Conditions

Nozzle	Operating Pressure (bar)	Downward Spray Thrust Force per Nozzle (newton)	Spray Angle (degrees)	Nozzle Spacing (m x m)	Median Droplet Diameter (µm)	Application Density (mm/min)
A	100	71.0	110	2.6 x 2.6	75	6.1
B	16.5	40.0	110	3 x 3	218	8.1
C	20	18.3	110	3 x 3	345	4.1
	44.8	41.0	110		265	6.1
	79.3	72.5	110		220	8.1

Sprinkler Operating Conditions

Operating Pressure (bar)	Downward Thrust Force per Sprinkler (newton)	Median Droplet Diameter (µm)	Spray Angle (degrees)	Nozzle Spacing (m x m)	Nominal Density (mm/min)
0.5	6.9	1400	115	3 x 3	6.1
0.9	12.4	1200	115	3 x 3	8.1

Fire Suppression Factors

- Cooling of Fire Environment
- Air inerting and displacement
- Radiation attenuation

→ Traditional attributes for suppressing enclosure fires

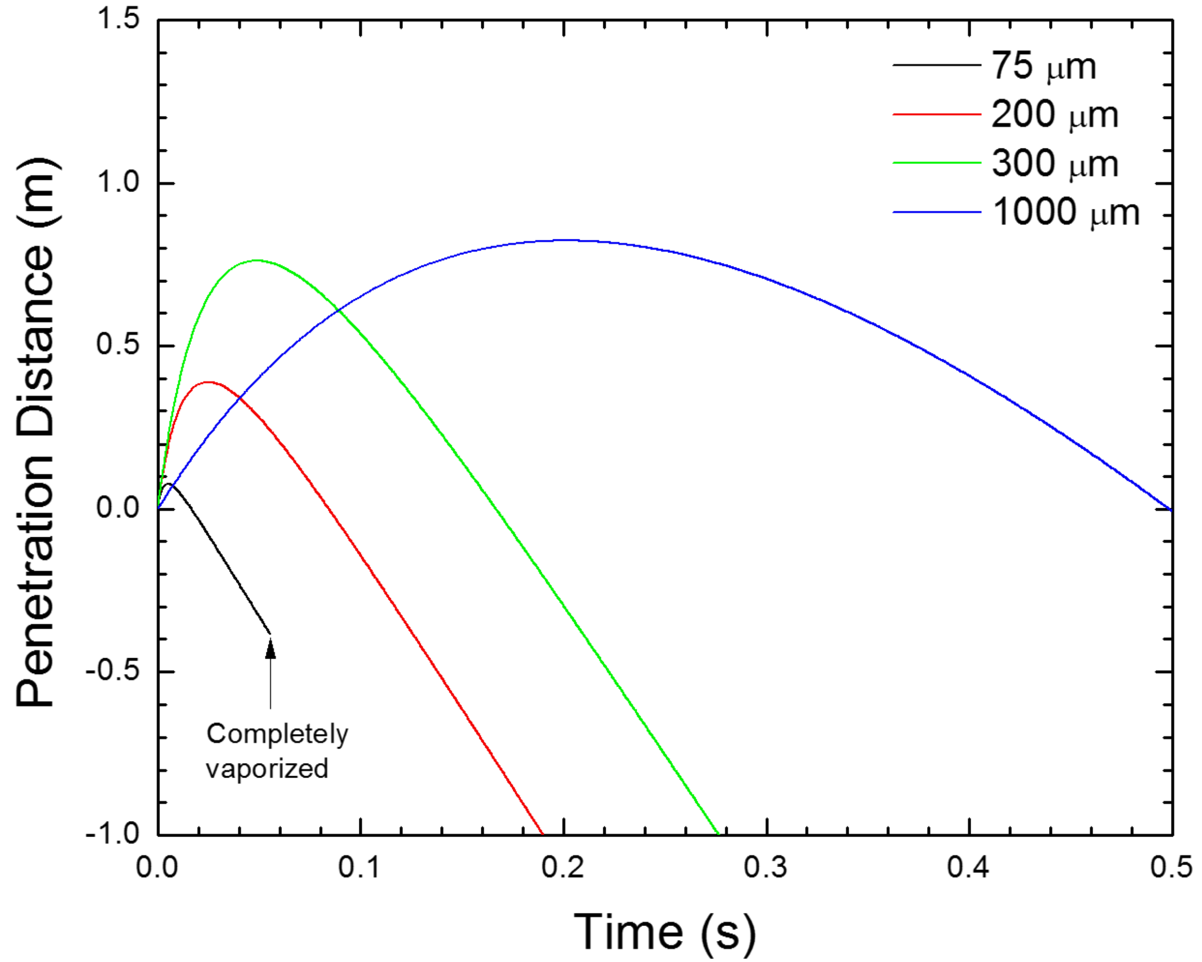
- Water flux landed on fuel surfaces
  - Application density
  - Fire plume penetration capability
  - Propensity of droplet deposition on fuel surfaces in gas stream

Relative Fire Plume Penetration of Droplets

Compare relative evolution of single droplets discharged downward into an upward hot gas stream corresponding to an expected fire plume condition:

- Hot gas stream: 500°C, 10 m/s upward, 3% vapor concentration.
- Water mist discharge: 50 m/s downward,
  20°C starting droplet temperature.
- Sprinkler droplet discharge: 1000 μm, 10 m/s downward,
  20°C starting droplet temperature

Relative Fire Plume Penetration of Droplets



Propensity of Droplet Deposition on Fuel Surface

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Stoke number = (Time for droplet response)/(Time for flow change)

$$St = \left(\frac{\rho_w d^2}{18\mu}\right)\left(\frac{dU}{dz}\right)$$

ρ_w : water density; d : droplet diameter; μ : gas viscosity

dU/dz : Inverse of time for flow change

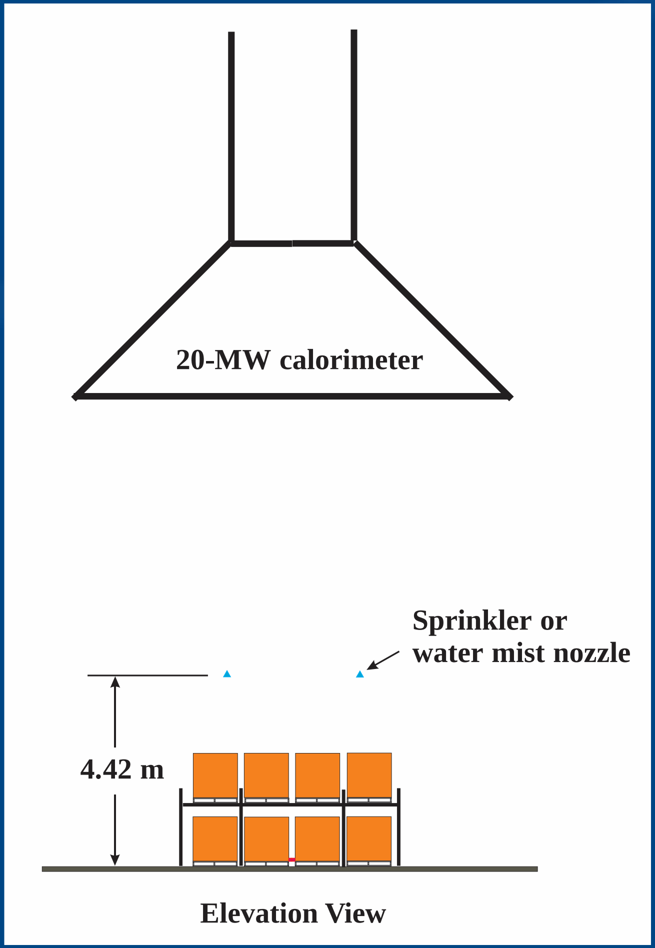
When St < 1 ⟶ low propensity of droplet deposition on fuel surface.
St > 1 ⟶ high propensity of droplet deposition on fuel surface.

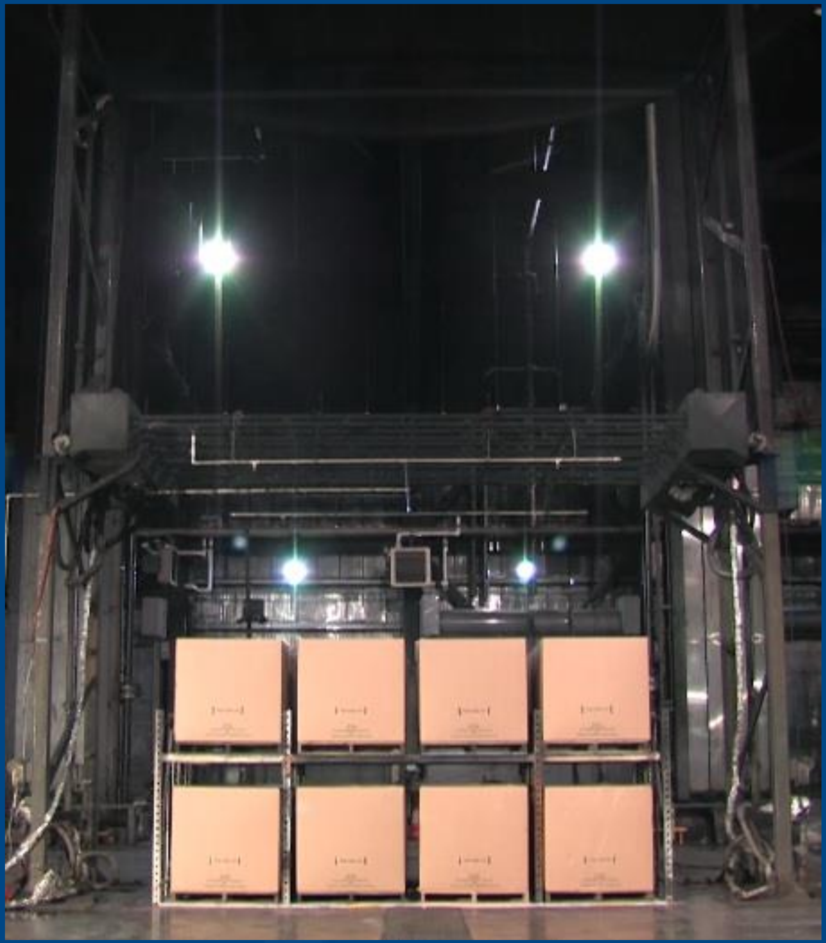
Estimated Stoke numbers at *d*U/*dz* = 23 s^{-1} and 500°C gas temperature:

Droplet Diameter (µm)	Stoke Number
75	0.2
200	1.4
300	3.2
1000	35.8

Fire Test Under 20-MW Calorimeter

Class 2 Commodity

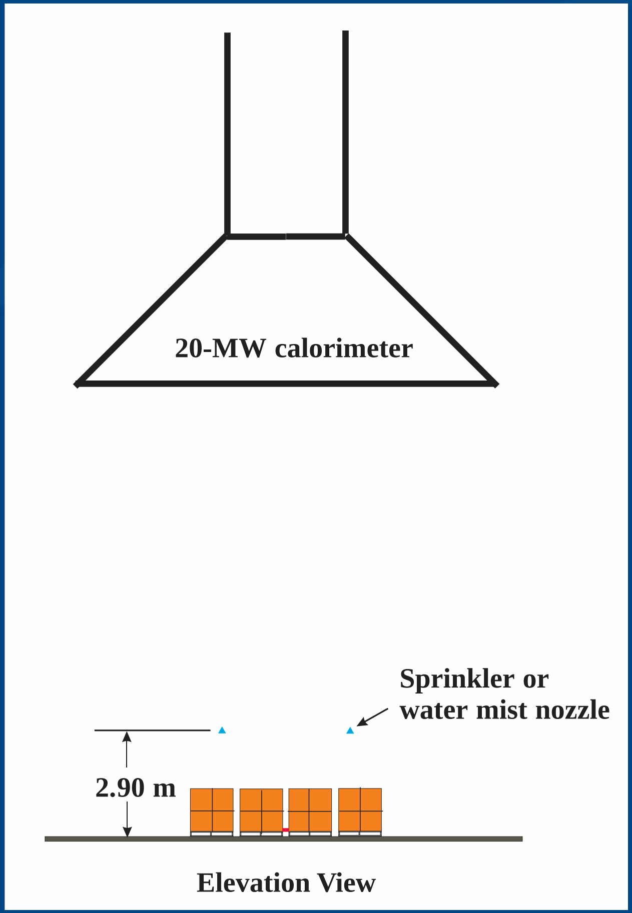




- Fuel array ignited at the base of the central vertical flue
- Water supply started when fire convective heat flow rate reached 1000 kW

Fire Test under 20-MW Calorimeter

Cartoned Expanded Plastic (CEP)



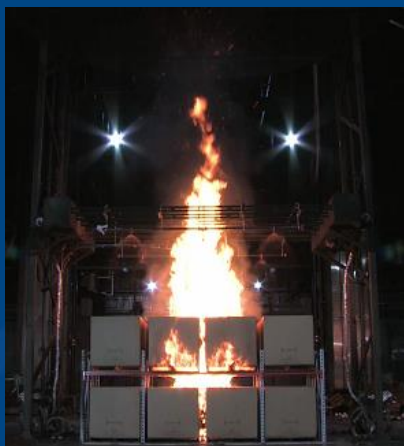
- Fuel array ignited at the base of the central vertical flue
- Water supply started when fire convective heat flow rate reached 1000 kW

Test Conditions Under 20-MW Calorimeter

Test ID	Commodity	Sprinkler/Nozzle	Sprinkler/Nozzle Clearance above Fuel Array (m)	Application Density (mm/min)	Sprinkler/Nozzle Spacing (m x m)
Cal-1	Class 2	Sprinkler	1.7	6.1	3 x 3
Cal-2	CEP	Sprinkler	1.7	8.1	3 x 3
Cal-3	Class 2	Nozzle A	1.7	6.1	2.6 x 2.6
Cal-4	Class 2	Nozzle C	1.7	6.1	3 x 3
Cal-5	Class 2	Nozzle C	1.7	4.1	3 x 3
Cal-6	CEP	Nozzle C	1.7	8.1	3 x 3
Cal-7	CEP	Nozzle B	1.7	8.1	3 x 3

Test Cal-1

Sprinkler; Class 2; 6.1 mm/min

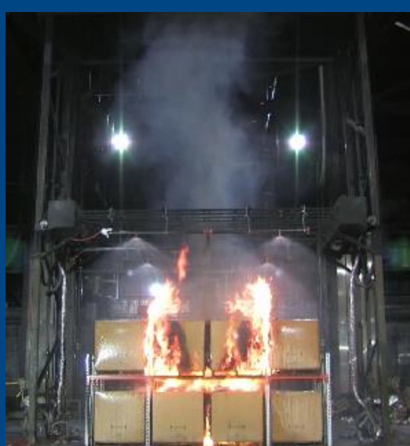


1:05

1:27

1:28

1:30



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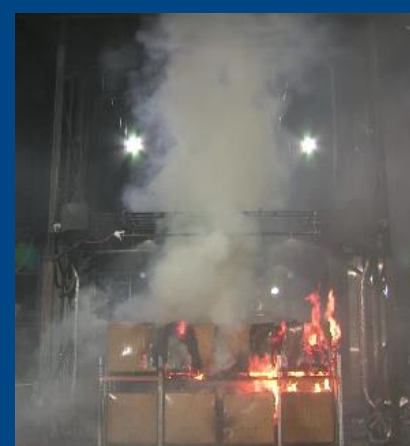
7:15



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Test Cal-2

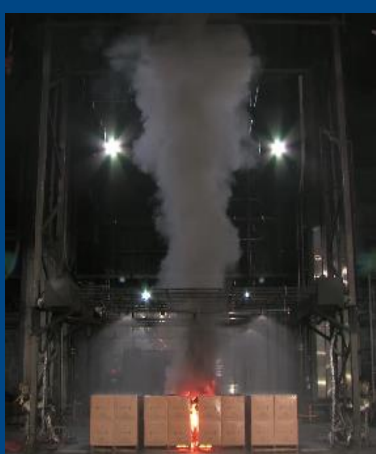
Sprinkler; CEP; 8.1 mm/min

1:07

1:11

1:16

1:29



1:46

2:46

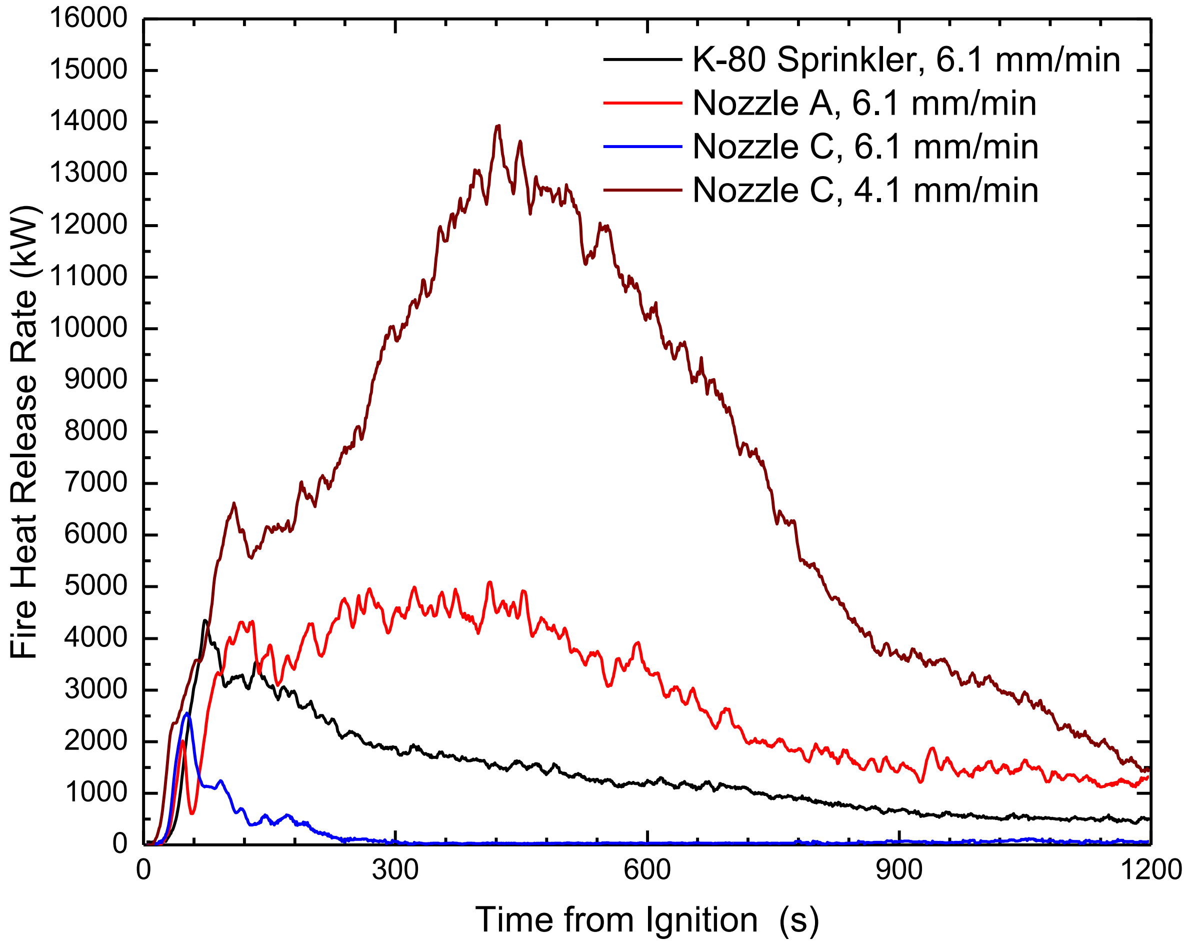
5:16

6:50

Class 2 Fire Test Summary

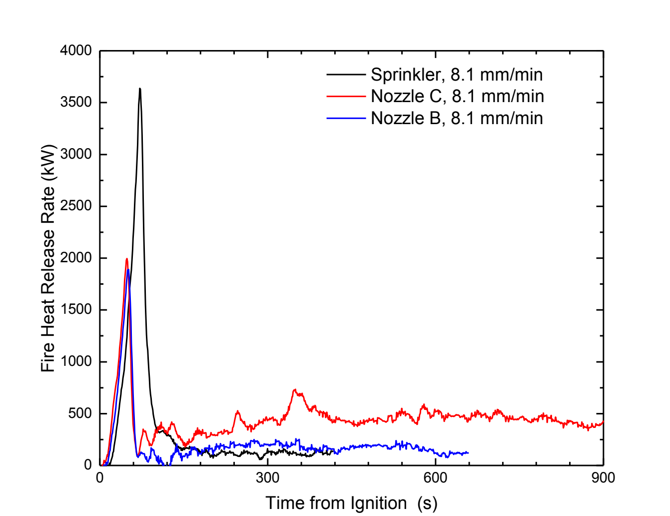
Test ID	Sprinkler/ Nozzle	Application Density (mm/min)	Median Droplet Diameter (µm)	Combined Spray Thrust Force in the Fire Plume (N)	Plume Uplift Force at Sprinkler/Nozzle Elevation at Water Application Time (N)	Fire Spread to the Ends of Fuel Array?
Cal-1	Sprinkler	6.1	1400	3.2	15.1	One End → Marginally Suppressed
Cal-3	Nozzle A	6.1	75	52.9	14.6	Both Ends → Not Suppressed
Cal-4	Nozzle C	6.1	265	21.5	16.9	No → Suppressed
Cal-5	Nozzle C	4.1	345	9.6	13.6	Both Ends → Not Suppressed

Class 2 Fire Test Summary



CEP Fire Test Summary

Test ID	Sprinkler/Nozzle	Application Density (mm/min)	Median Droplet Diameter (µm)	Combined Spray Thrust Force in the Fire Plume (N)	Plume Uplift Force at Sprinkler/Nozzle Elevation at Water Application Time (N)	Fire Spread to the Ends of Fuel Array?
Cal-2	Sprinkler	8.1	1200	6.7	16.7	No → Suppressed
Cal-6	Nozzle C	8.1	220	38.0	13.2	One End → Marginally Suppressed
Cal-7	Nozzle B	8.1	218	21.0	15.1	No → Suppressed



Conclusions

- Fire suppression was affected by application density and spray characteristics such as droplet size, discharge velocity and spray thrust force, not by nozzle configuration and operating pressure.
- Fire suppression in open environment could not be achieved if the sprays' median droplet diameter was not sufficiently large for the fire challenge.
- Fire suppression in open environment with water mist required water densities comparable to those of sprinkler protection.
- The downward spray thrust force was not a critical factor for fire suppression. However, when the spray exceedingly overpowered the fire plume, the highly disturbed flames tended to increase fire spread and thus worsened the suppression result.

Thank You