Water Mist Fire Protection

Mechanisms and Requirements

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Water Mist Protection Versus Sprinkler Protection

- Advantages
  - More adaptable to space constraints in system installation
  - More adaptable to drop size requirement for fire extinguishment
  - Less system weight
  - Less water run-off
- Disadvantages
  - Shorter spray distance
  - Higher system cost
  - Lower system reliability

Current Water Mist Applications

- Marine and land-based machinery and turbine enclosures
- light fire hazards (cabins and public space on ships; residential interiors)
- Wet benches
- Chemical fume hoods
- Local protection of ignitable liquids in open environment
- Continuous wood board presses
- Industrial oil cookers
- Deep fat fryers
- Vehicles and heavy duty machinery equipment
- Data processing halls/rooms in data centers
- Cable tunnels
- Heritage buildings and museums
- Internal combustion engine test cells
- Portable extinguishers – in spacecraft or on land
- Transportation tunnels
- Wind turbine nacelles
- Car garages

Outline

- Key fire extinguishing mechanisms for water mist sprays
- Spray requirements for fulfilling the individual extinguishing mechanisms
- Summary

Fire Suppression Mechanisms of Water Mist Sprays

- Definition of water mist sprays
  - Water sprays in which 99% of the discharged water is from droplets smaller than 1000 µm (NFPA 750).
- With the above wide droplet size range, depending on the fire hazard, water mist sprays may be engineered to suppress or extinguish fires by:
  - Primary mechanism: Gas-phase flame extinction
    - ✓ cooling
    - ✓ vitiation
    - ✓ producing favorable aerodynamic condition
    - ✓ overloading mist droplets in the protected space
  - Secondary mechanism: Wetting fuel surfaces
  - Combination of the above

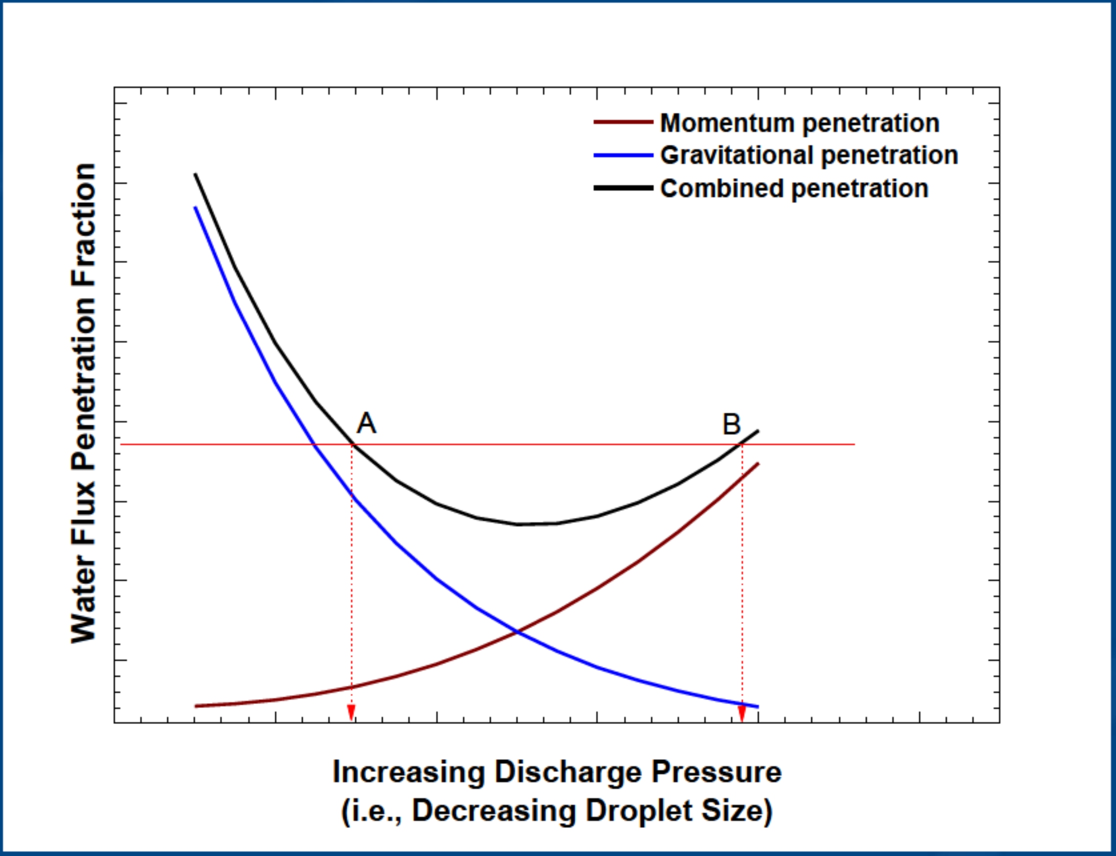
Suppression by Wetting Fuel Surfaces

Sprays must be able to:

- Penetrate the fire plume
- Sufficiently deposit water droplets on the fuel surface

Spray Penetration of Fire Plume

- Gravitation versus Momentum



Droplet Deposition on Fuel Surface

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

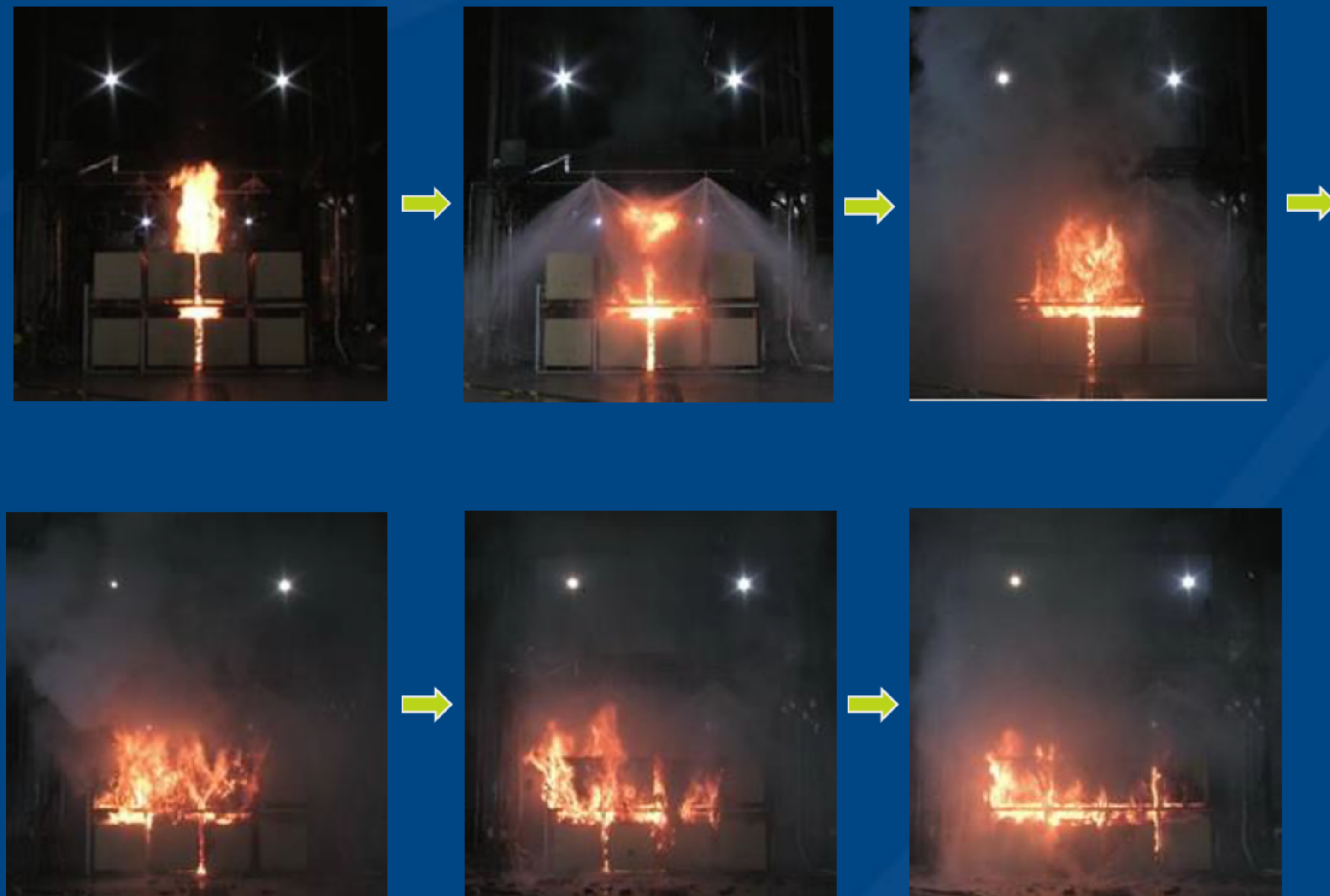
dU/dz : Inverse of time for flow change

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

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

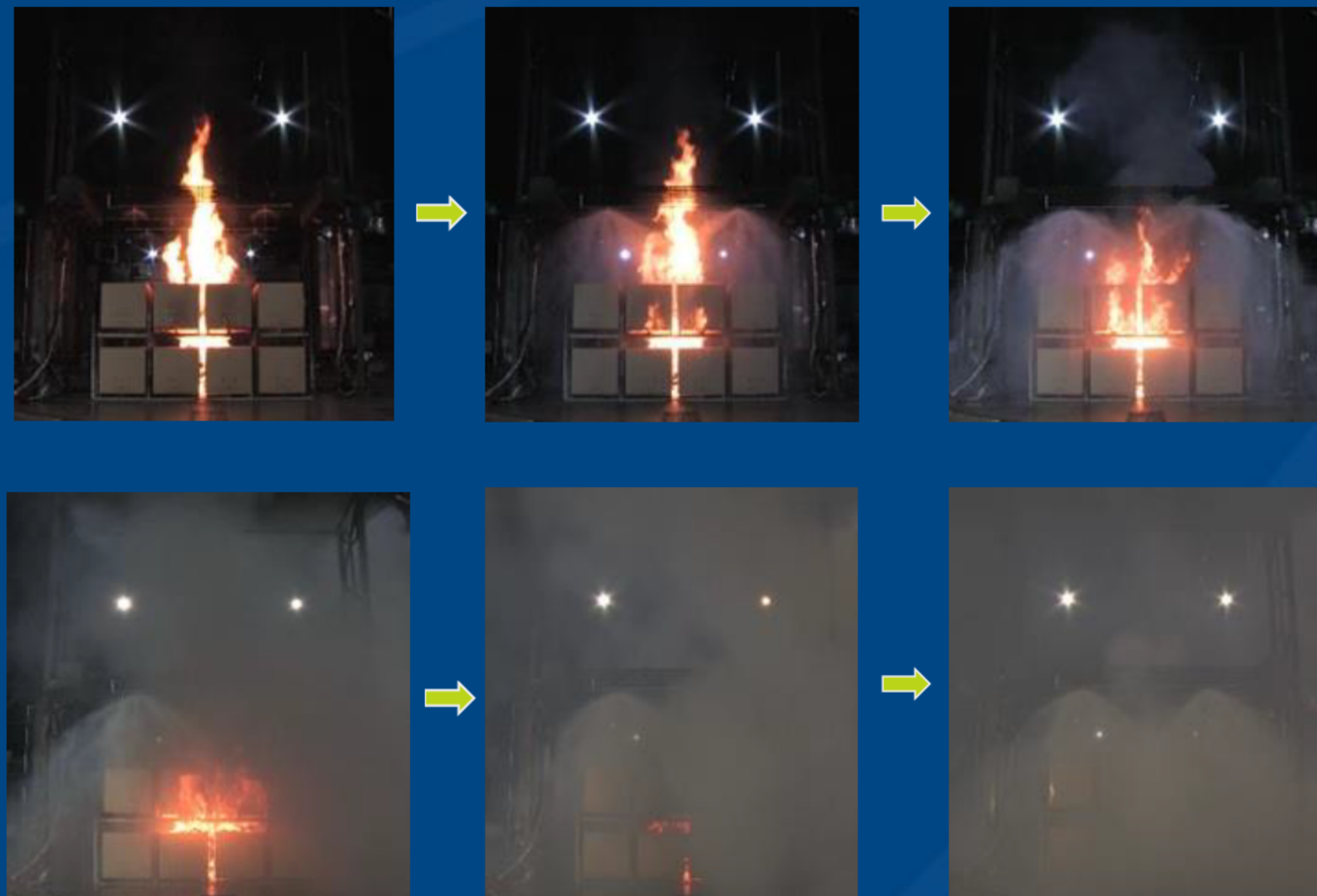
Corrugated Carton Fires in Open Environment

Corrugated cardboard cartons; 6.1 mm/min; Stoke number ~ 0.2



Corrugated Carton Fires in Open Environment

Corrugated cardboard cartons; 6.1 mm/min; Stoke number ~ 2.5



Pool Fire Intensification by Large Droplets

- Pool liquid spattering by water droplet impingement
- Spontaneous water droplet evaporation in pool liquid

Spattering (St > 1 and droplet momentum force >> liquid surface tension force)

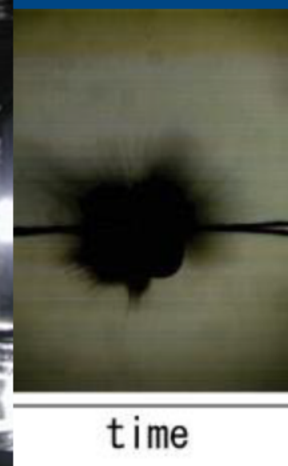
With Spray and Spattering

No Spray

Fire Intensification by Spontaneous Droplet Evaporation

Pool fire intensifies when spontaneous evaporation of water droplets in the pool occurs

Oil droplet atomized by spontaneous water evaporation in the oil droplet



Fire Extinguishment by Flame Extinction

Water mist sprays need to be able to:

- Penetrate fire plume or hot gas layer.
- Sufficiently cool and vitiate fire environment, and/or dilute fuel vapor concentration, or
- Induce strong gas current and turbulence to blow off flames from fuel surfaces, or to stop chemical reactions in the flames, or
- Disperse sufficient amount of small droplets in space to stop flame propagation.

Spray Cooling of Fire Gases

For a discharge rate,

$$\text{Total droplet vaporization rate} \propto \frac{\text{Total droplet surface area}}{\text{Droplet vaporization time}}$$

$$\text{Total droplet surface area} \propto D_d^{-1}$$

$$\text{Droplet vaporization time} \propto D_d^{2}$$

$$\text{So} \quad D_d \downarrow \; \Rightarrow \; (\text{Total vaporization rate}) \uparrow$$

However,

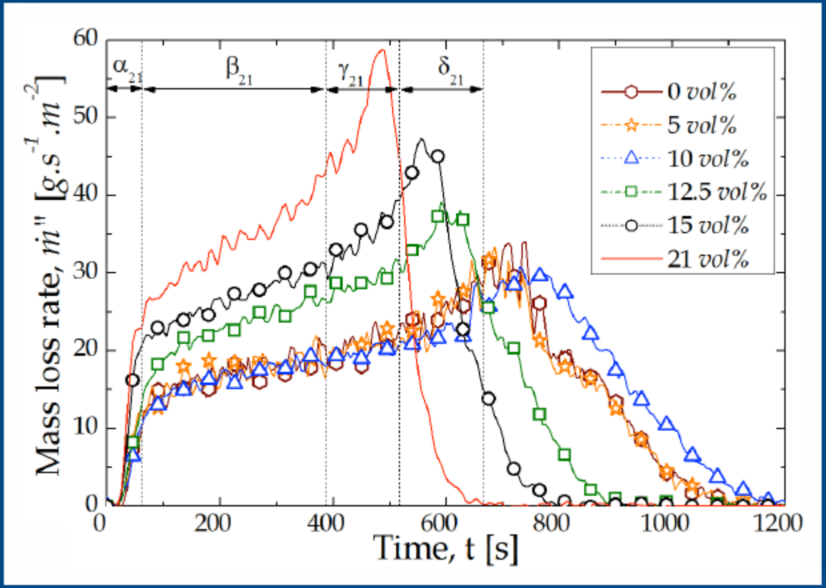
$$D_d \downarrow \Rightarrow (\text{Droplet number density}) \uparrow \Rightarrow (\text{Droplet spacing}) \downarrow,$$

$$\text{Droplet spacing} \leq 20 \text{ droplet diameters} \Rightarrow \text{Evaporation rate} \downarrow$$

Droplet size may need optimization to maximize total cooling rate.

Fire Extinguishment by Air Vitiation

- **Burning rate decreases with the reduction of oxygen concentration**
  - **PMMA fire under radiant heat flux of 50 kW/m^2 (Marquis et al., 2014 IAFSS)**



- **Dry-based oxygen concentrations for hydrocarbon flame extinction in room temperature environment:**
  - fuel vapor dilution alone (no cooling): ~12%
  - fuel vapor dilution and sufficient cooling: typically 16% and higher

Flame Extinction by Overloading Small Water Droplets in Space

Sufficiently loading the protected space with water mist:

- Mist concentration needs to at least absorb 30% of the fire heat release rate per unit volume.
- Droplets need to be sufficiently small so that the droplet vaporization time is comparable to or less than the flame residence time.

Mist Droplet Diameter (μm)	Mist Volume Concentration (-)
10	0.0066
50	0.0323

Summary

- **This talk has reviewed:**
  - the key fire extinguishment mechanisms associated with water mist sprays
  - the spray requirements for fulfilling the intended mechanisms
- **By understanding the fire hazard, water mist sprays need to be tailored for different fire types and conditions, and for the intended extinguishing performance.**

So one size does not fit all!

Thank You!