

Using Well-Stirred-Reactor Modeling and Physical Scaling to Develop a Water Mist Protection to Extinguish Ignitable Liquid Fires in a Naturally-Ventilated Building

**Hong-Zeng (Bert) Yu
FM Global**

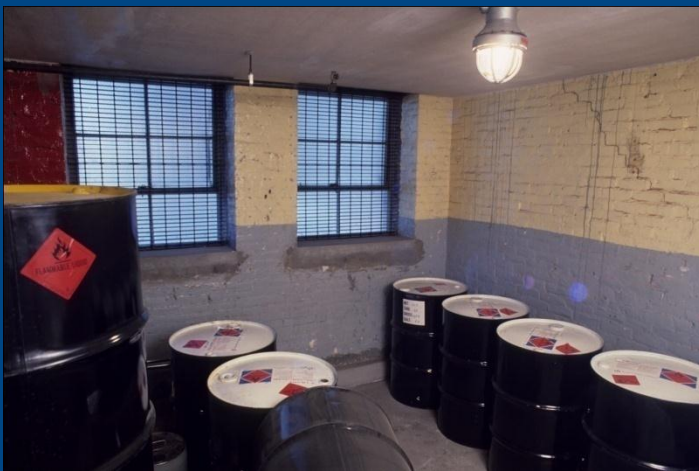
**2012 International Water Mist Conference
Barcelona, Spain
November 14-15, 2012**

Ignitable Liquid Occupancies

- Dispensing (Use) occupancy



- Storage occupancy



Challenges for Water Mist Protection of Use Occupancy



- Low flash point liquids
- Large door openings
- High ceilings
- Ceiling nozzles only
- Obstructed fires

Previous Development

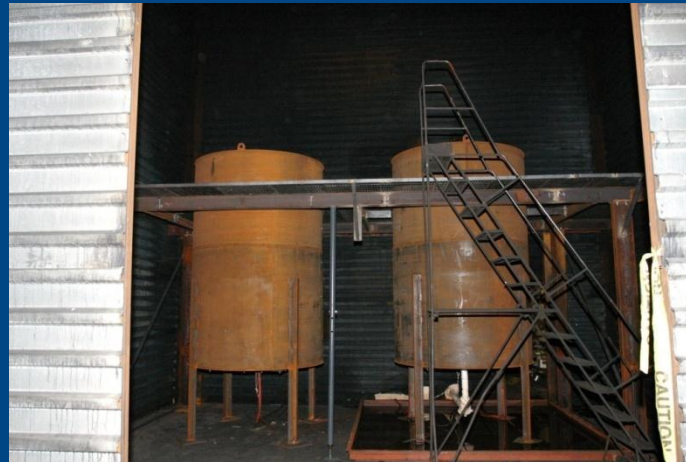
- Used a 0.49-scale facility to determine a total flooding protection to extinguish heptane spill fires in a 7.47x7.47x7.47-m building with door openings ranging from 1.83x3.73 m high to 3.73x3.73 m.
- Validated the water mist protection in the full-scale building.



Previous Full-Scale Validation Test

Conditions for a 7.47x7.47x7.47-m Building

- Door opening: from 1.83x3.73 m to 3.73x3.73 m
- Simulated fuel tanks: two 1.83 m diameter x 2.74 m high tanks, 0.91 m apart, and 0.91 m above floor
- Fire scenario: cascading heptane fire spilling from the top of one tank at 38 liter/min
- Mezzanine obstruction: 70% opening, perforated steel grating 3.05 m above the floor



Question: Can the protection be linearly extended to larger buildings ?



By linearly extending the protection with the floor area, what would be the largest 7.5-m high building in which the fire can be extinguished within 5 minutes after ignition?

The protection characteristics and fire hazard are as follows:

- **Water mist discharge after ignition: 30 s.**
- **Full-scale water mist protection:**
 - Median droplet size: 108 μm
 - Discharge rate per nozzle: 17.9 liters/min
 - Spray angle: 60°
 - Downward spray momentum per nozzle: 31.5 newtons
 - Nozzle spacing: 1.86 x 1.86 m
- **Fire hazard:**
 - Door opening: 3.73x3.73 m
 - Fuel tanks: 1.83 m diameter x 2.74 m high; 0.91 m above the floor
 - Heptane spill rate: 38 liters/min (max. 8 MW)
 - Mezzanine: perforated steel grating with 70% opening; 3.1 m above floor

Water Mist Scaling Relationships

$$Re_d = \frac{d|\bar{u}_d - \bar{u}_g|}{v_g}$$

Scaling Parameters	$Re_d \leq 1$
Scale Ratio $S=L_2/L_1$	S^1
Time	$S^{1/2}$
Temperature, Concentrations	S^0
Drop Number Density	$S^{-3/4}$
Velocity	$S^{1/2}$
Ventilation Rate	$S^{5/2}$
Fire Heat Release Rate	$S^{5/2}$
Water Mist Discharge Rate	$S^{5/2}$
Axial Spray Momentum	S^3
Droplet Diameter	$S^{1/4}$

0.49-Scale Test Conditions and Expectation

Conditions

- Water mist discharge after ignition: 21 s.
- Water mist spray characteristics:
 - Median size: 90 μm
 - Discharge rate per nozzle: 2.85 liters/min
 - Spray angle: 60°
 - Downward spray momentum: 3.5 Newton (at 41 bar, for the selected nozzle)
 - Nozzle spacing: 0.91x0.91 m
- Fire hazard:
 - Enclosure height: 3.66 m
 - Door opening: 1.83x1.83 m
 - Fuel tanks: 0.91m diameter x 1.37 m high; 0.44 m above the floor
 - Heptane spill rate: 6.1 liters/min (max. 1.3 MW)
 - Mezzanine: perforated steel grating with 70% opening, 1.46 m above the floor

Expectation

Fire is to be extinguished less than 3.5 minutes after ignition.

Well-Stirred Reactor Calculations for the 0.49-Scale Mockup - 1



Enclosure dimensions:

5.49x24.4x3.66 m high (134 m²)

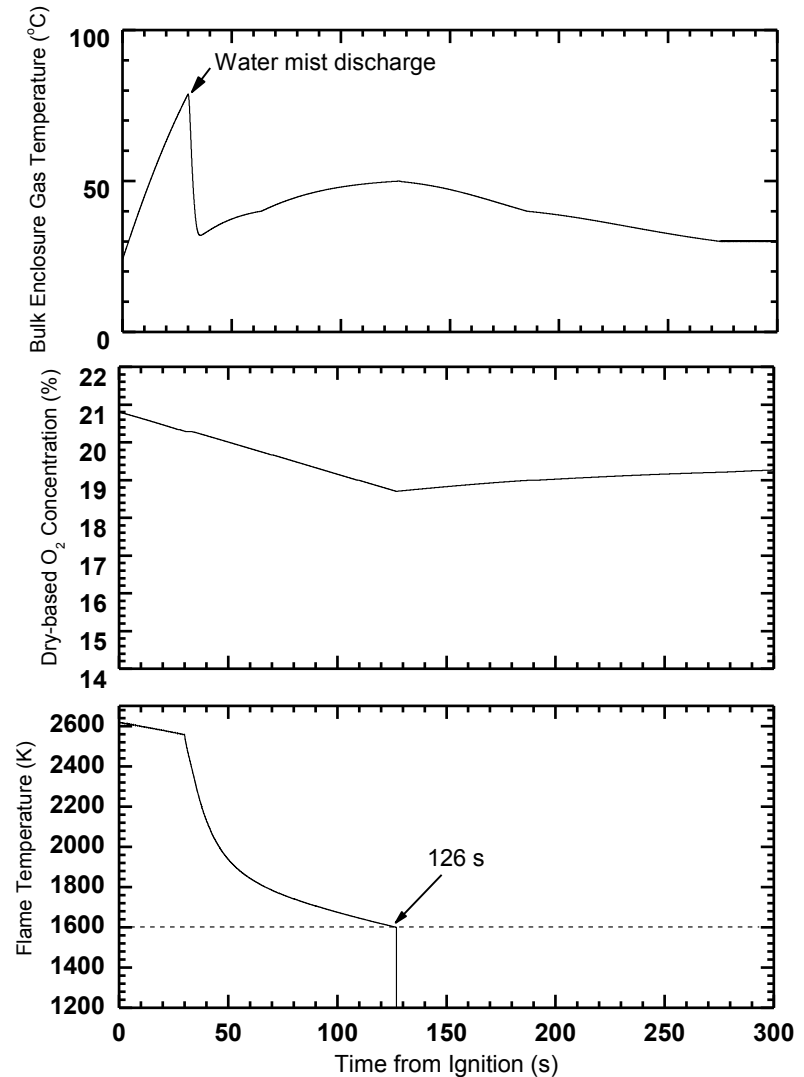
Total water mist discharge rate:

385 liters/min

Door opening: 1.83x1.83 m

Two door nozzles:

Each discharges 2.85 liters/min.



Well-Stirred Reactor Calculations for the 0.49-Scale Mockup - 2



Enclosure dimensions:

5.49x24.4x3.66 m high (134 m²)

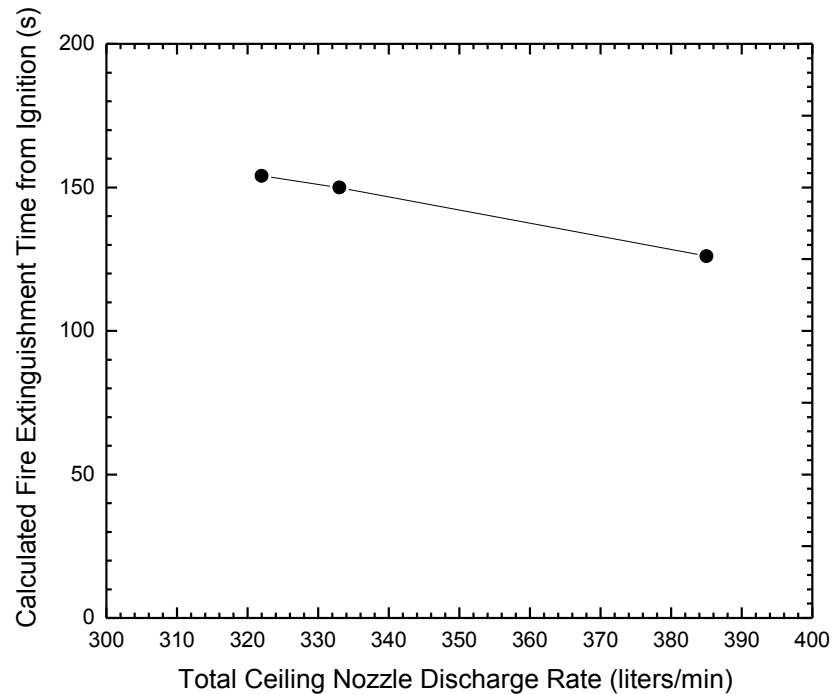
Total water mist discharge rate:

322, 333, 385 liters/min

Door opening: 1.83x1.83 m

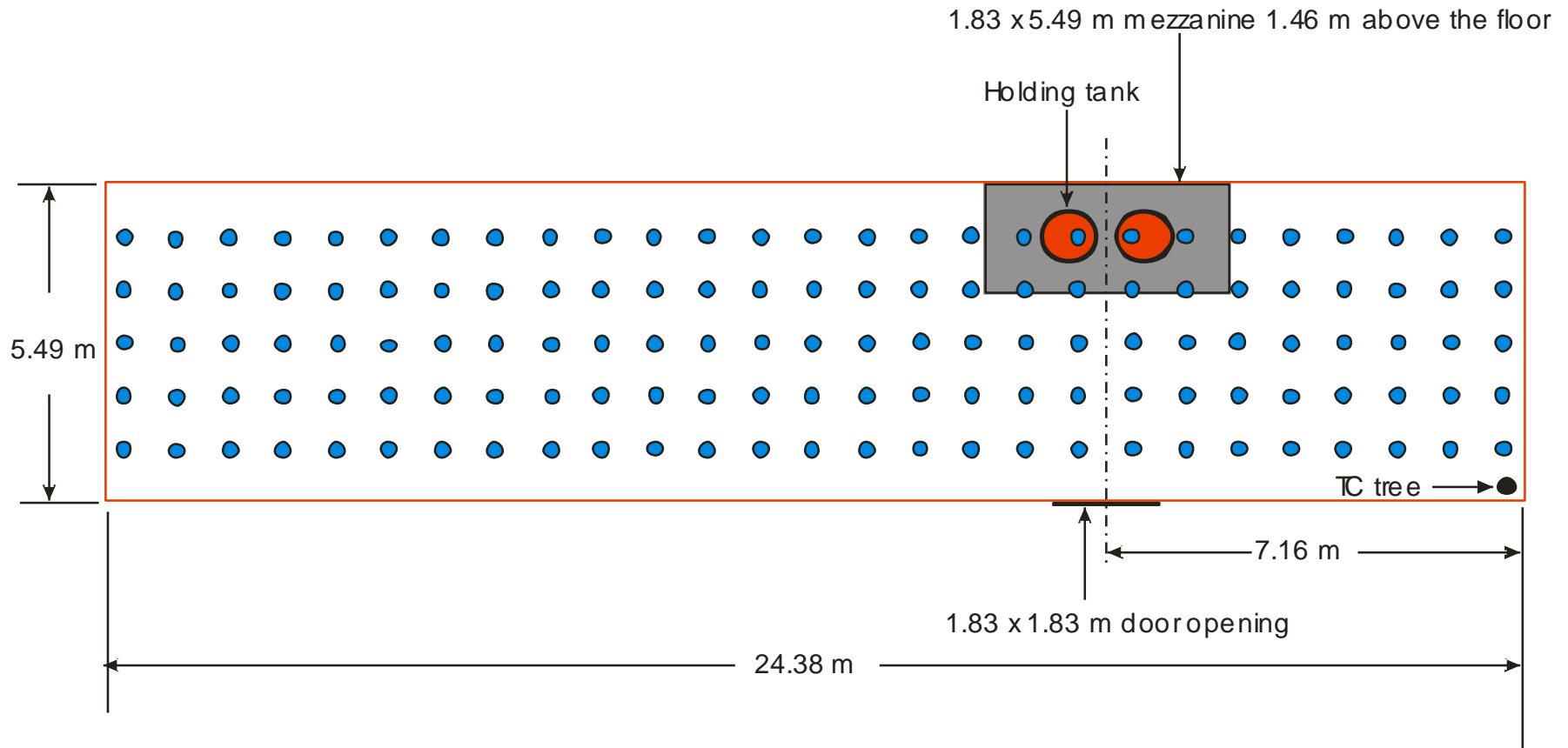
Two door nozzles:

Each discharges 2.85 liters/min.

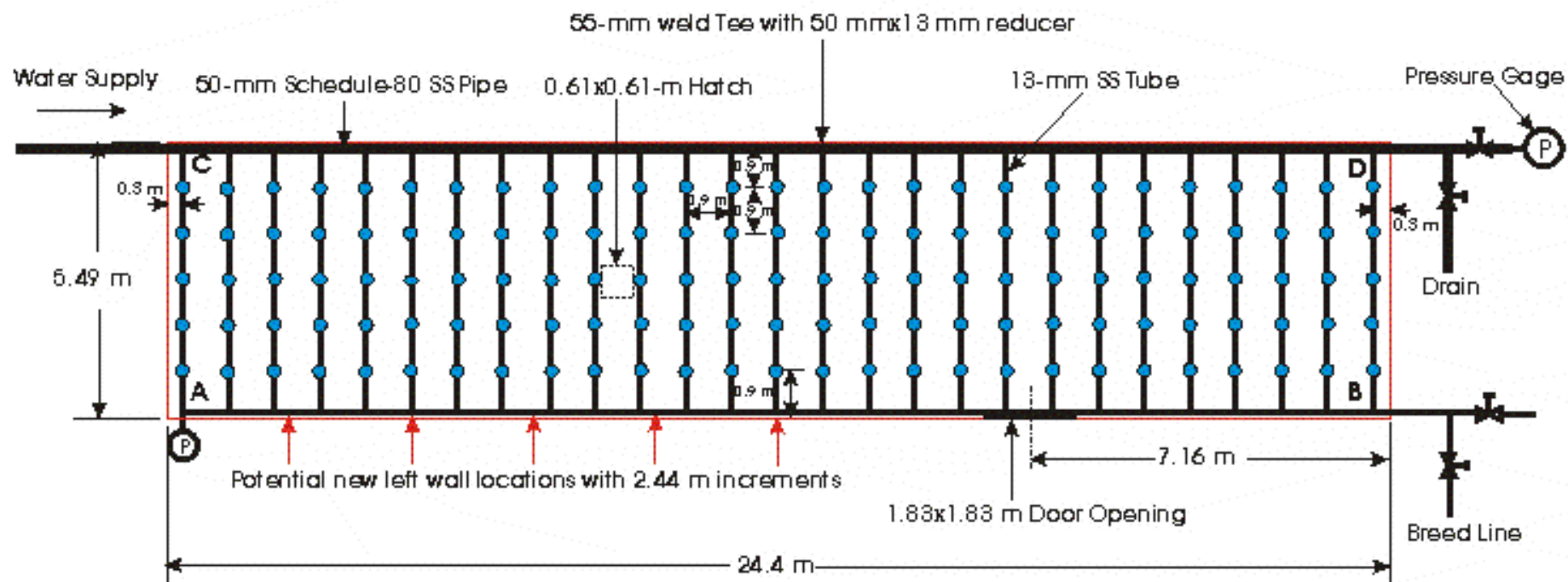


0.49-Scale Mock-up Plan View

Mock-up building dimensions: 24.38 x 5.49 x 3.66 m high
(134 m² x 3.66 m)



Nozzle Piping in 0.49-Scale Enclosure



0.49-Scale Mock-Up



0.49-Scale Mock-Up



Door Nozzles



A Heptane Spill Fire Test in the 0.49-Scale Building

Building dimensions: 5.49x24.4x3.66 m high (134 m² x 3.66 m high)
Total water mist discharge rate: 385 liters/min

Fire extinguishing time

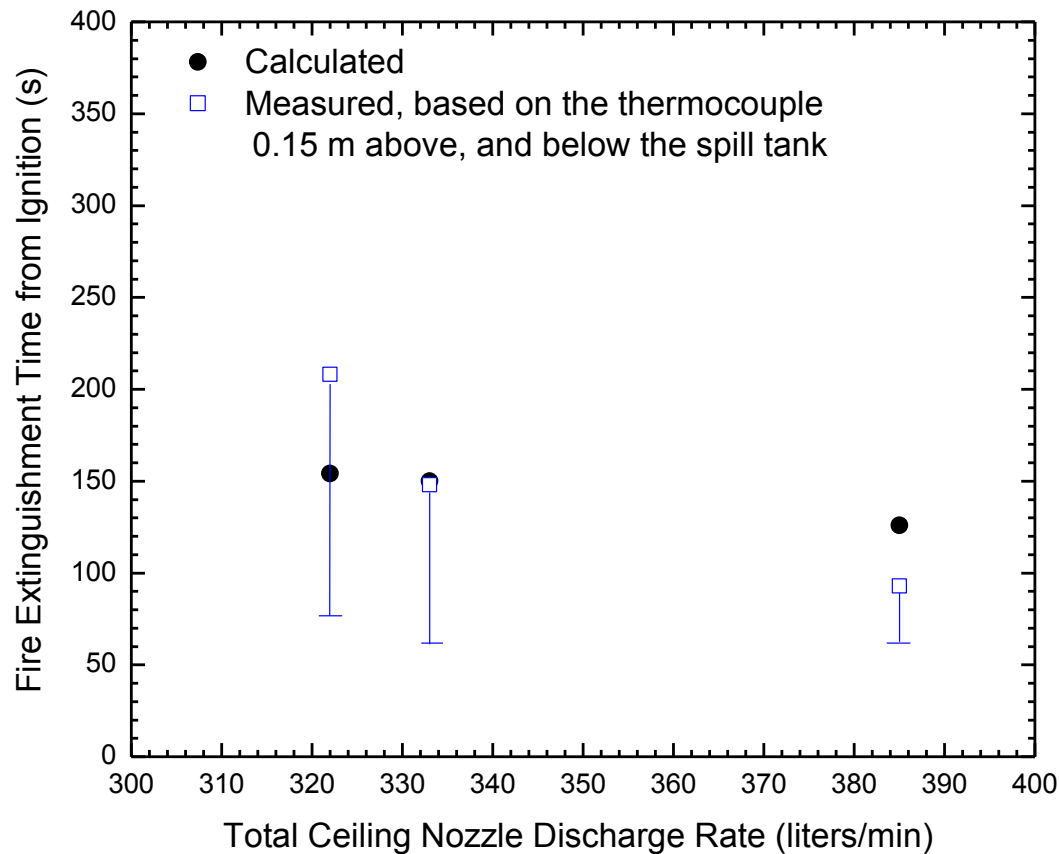
Tested → 62 - 93 s after ignition.
Calculated → 126 s after ignition.



Summary of 0.49-Scale Results

Building dimensions: 5.49x24.4x3.66 m high (134 m² x 3.66 m high)

Door opening: 1.83 x 1.83 m



Full-Scale Protection

- **Building dimensions: 11.5 x 50.8 x 7.5 m high (584 m² x 7.5 m high)**
- **Water mist discharge after ignition: less than 30 s.**
- **Full-scale water mist protection:**
 - Median droplet size: 108 μm
 - Discharge rate per nozzle: 17.9 liters/min
 - Spray angle: 60°
 - Downward spray momentum per nozzle: 31.5 newtons
 - Nozzle spacing: 1.83 x 1.83 m
- **Fire hazard:**
 - Door opening: 3.66x3.66 m
 - Fuel tanks: 1.83 m diameter x 2.74 m high; 0.91 m above the floor
 - Heptane spill rate: 38 liters/min
 - Mezzanine: perforated steel grating with 70% opening; 3.1 m above floor

Conclusions

- **A development of water mist protection has been demonstrated by using physical scaling and well-stirred-reactor modeling.**
- **These engineering tools help reduce the protection development cost and turn-around time.**