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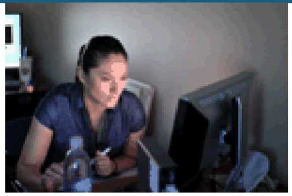
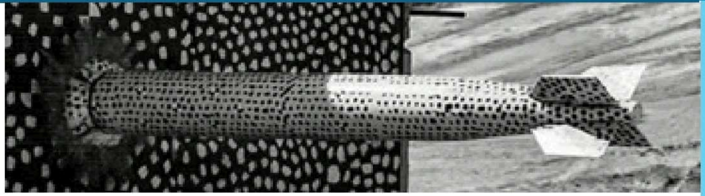
SAND2019-3235C

Validation of a Low Mach Fire Environment Model with Vertical Porous Burner Experiments





PRESENTED BY

Andrew Kurzawski, Sarah Scott, John Hewson

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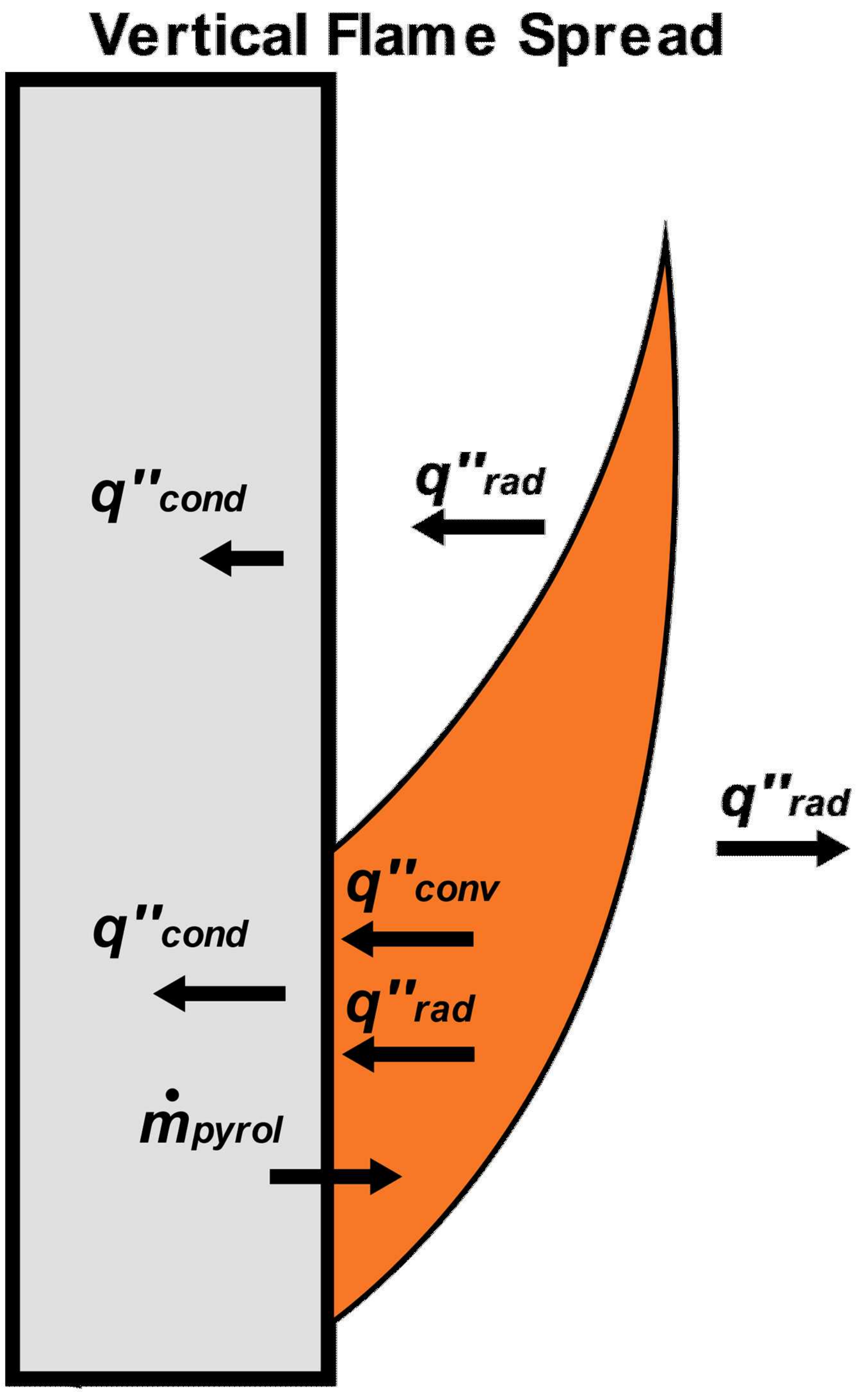
Motivation

Comparison of simulation predictions with experiments is important to understand bias

Vertical flame spread presents a challenging heat and mass transfer modeling problem

Measurement and Computation of Fire Phenomena (MaCFP) database provides a platform for open source experimental data and model validation

- Buoyant plumes
- Pool fires
- Wall fires



Experimental Configuration

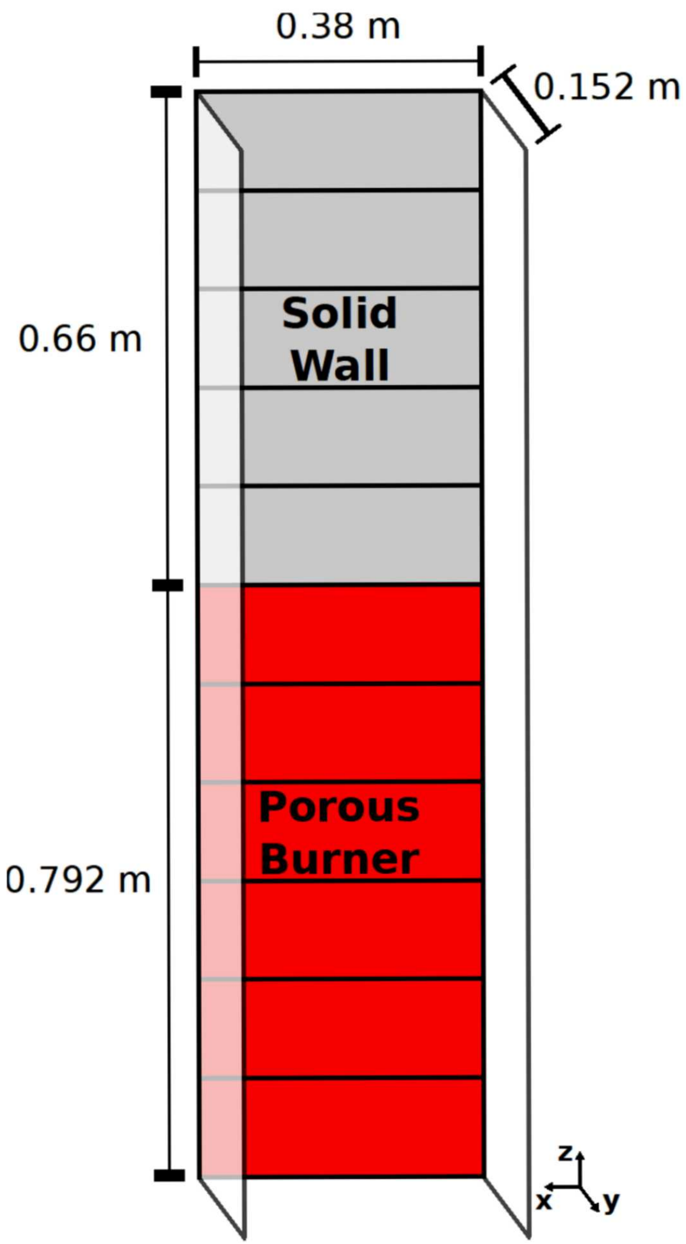
Porous, water-cooled burner data from MaCFP database[1]

Water-cooled heat transfer wall above burner

Fuel: Propylene at 17.05 $g/m^2/s$

Measured data

- Gas Temperature
- Heat flux to the water cooled wall/burner panels
- Soot depth



[1]de Ris 2002, data at https://github.com/MaCFP/macfp-db

Numerical Model

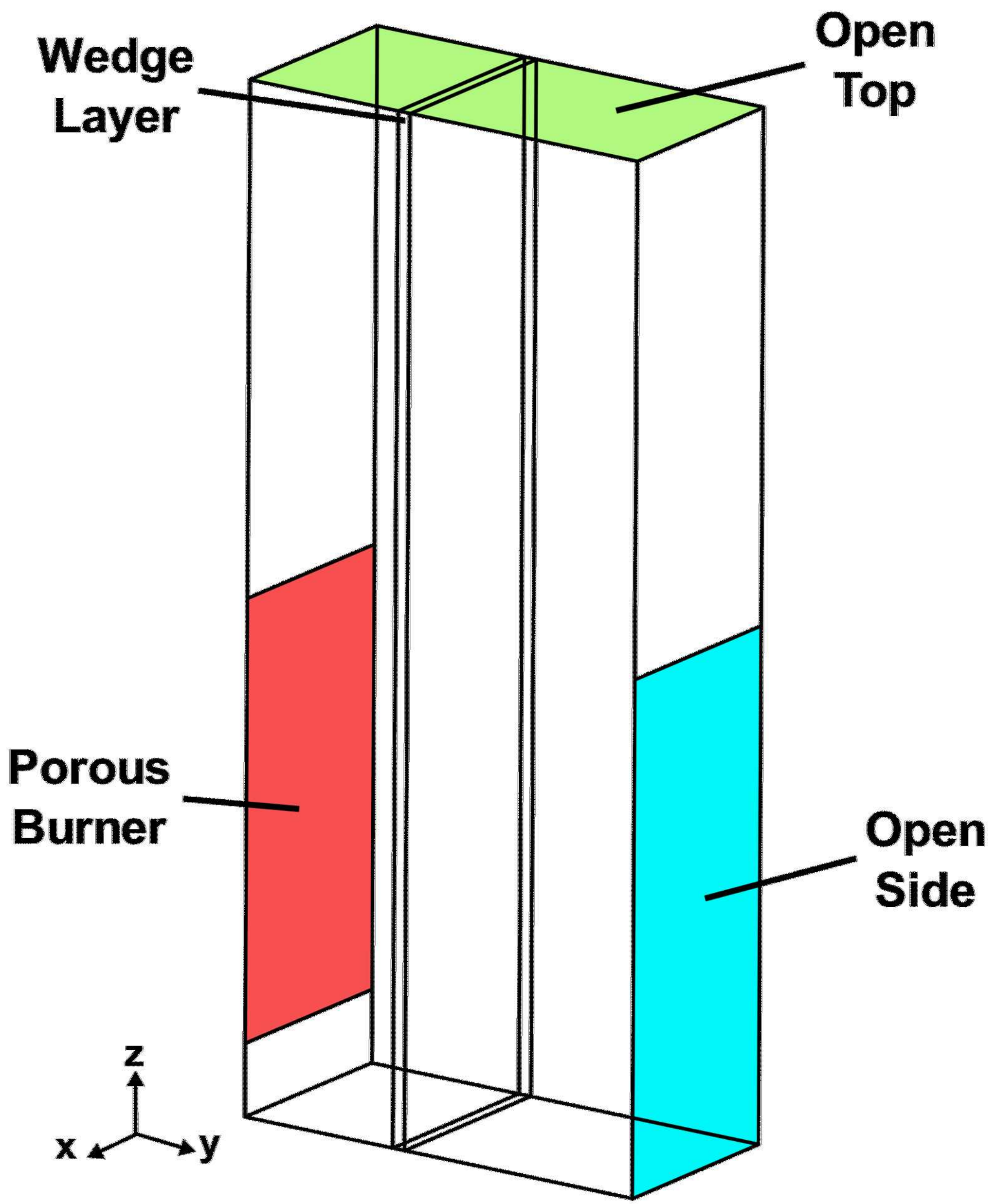
Sierra/Fuego CFD software coupled with Nalu for participating media radiation

- Control-volume finite-element code (CVFEM)
- Eddy dissipation concept (EDC) combustion
- $k - \epsilon$ turbulence

Wall-modeled porous burner injects mass in to domain

Wedge layer transition to coarser mesh

Open boundaries for entrainment/outflow



Discretization

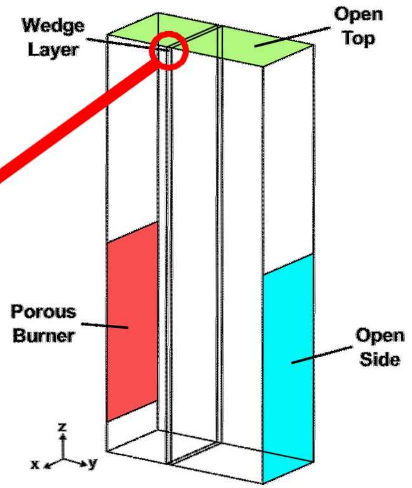
3 meshes based on off-wall (y-direction) discretization:

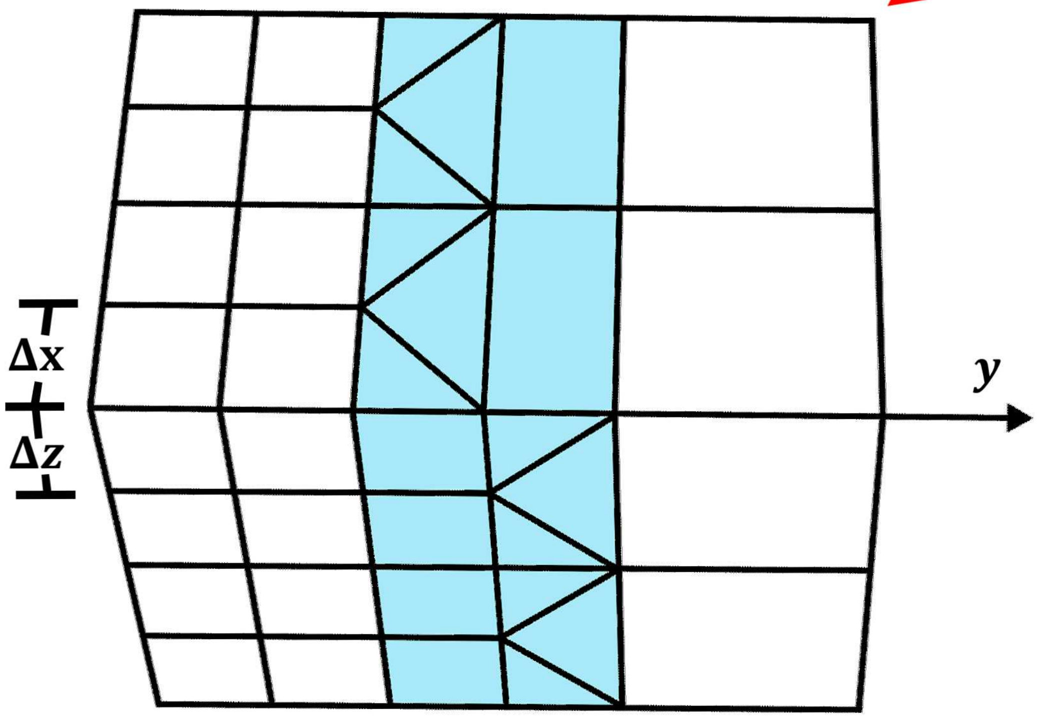
- $\Delta y = 2.5, 5, 10\ mm$
- $\Delta x \approx \Delta z \approx 2.5\Delta y$

Wedge layer at 30.4 cm from burner facilitates transition to a coarser mesh

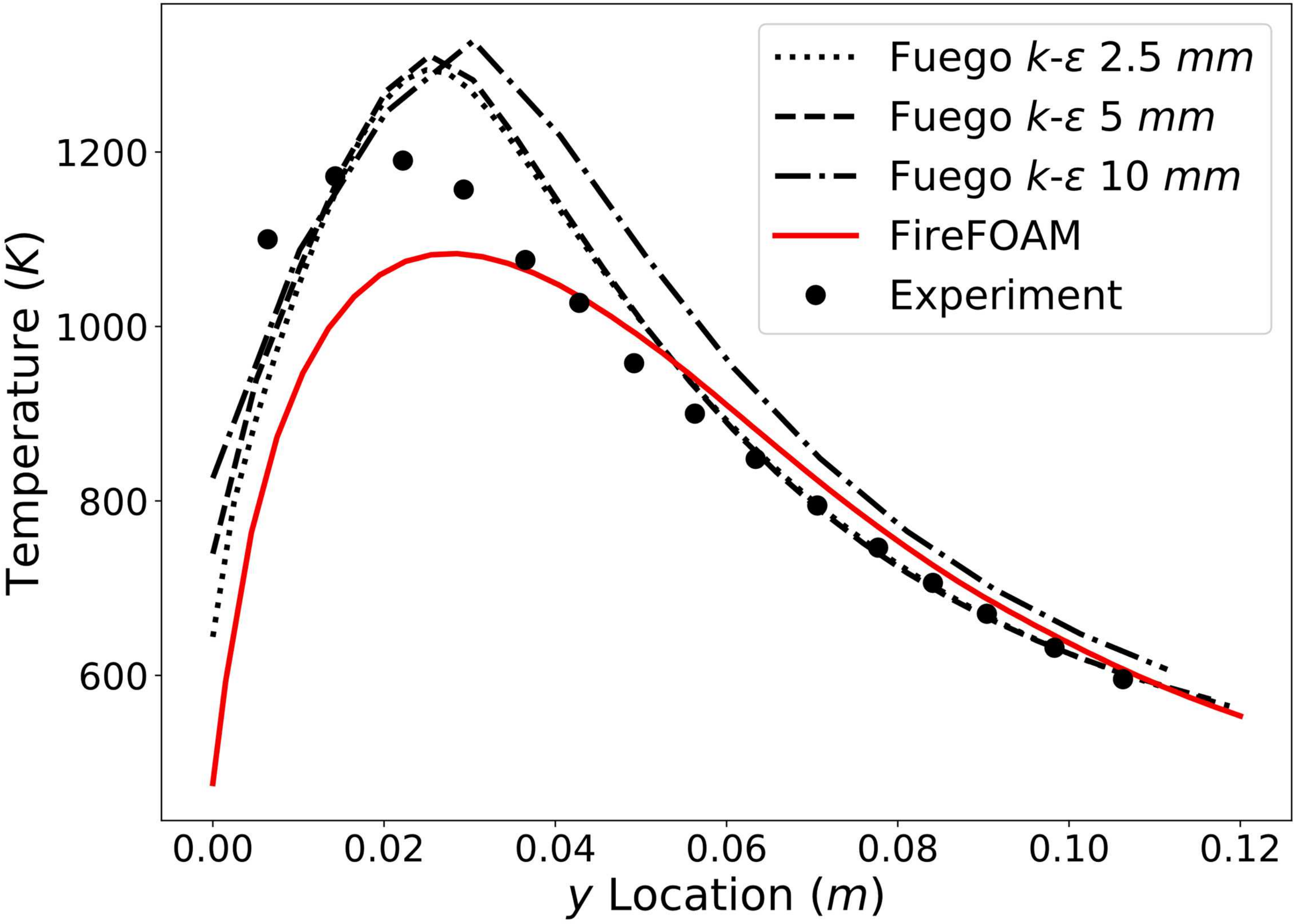
Number of nodes

- 1,950,598 at $\Delta y = 2.5\ mm$
- 247,915 at $\Delta y = 5\ mm$
- 35,286 at $\Delta y = 10$ mm





Temperature Results



Thermocouple correction for temperature:

$$0 = \epsilon_{tc}(G - \sigma T_{tc}^4) + h_{tc}(T_g - T_{tc})$$

Where the heat transfer coefficient is estimated as:

$$h_{tc} \approx 100 \left(\frac{T_{tc}}{T_\infty}\right)^{4/5}$$

Compared to FireFOAM results from Ren 2016

- In MaCFP database
- Large eddy simulation
- EDC combustion

Use $\Delta y = 5\ mm$ as baseline case

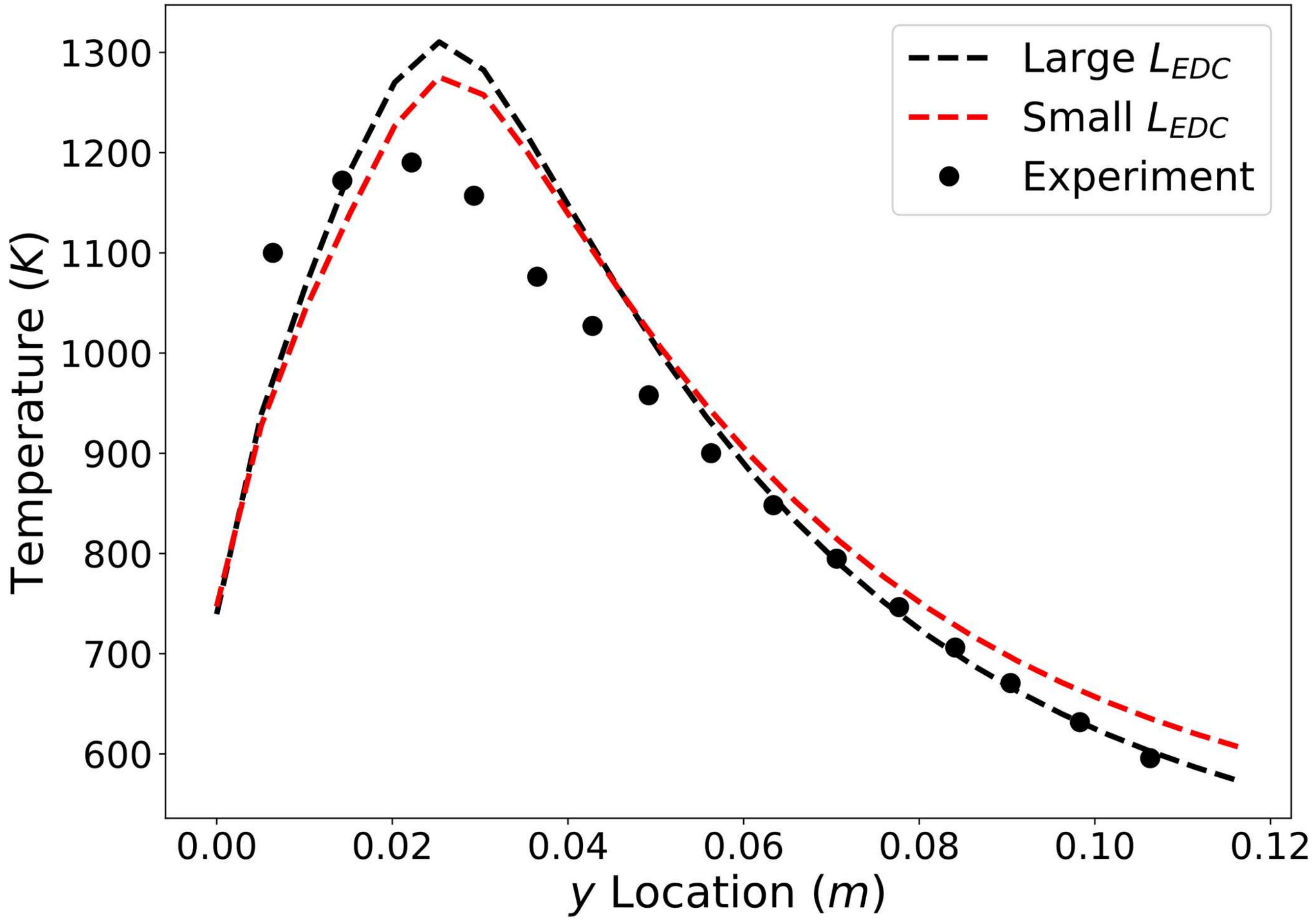
Temperature Results – EDC Absorption Coefficient Length Scale

Large = 0.5 m for pool fires

Small = 0.5 cm on the order of the grid near the wall (essentially no averaging for absorption coefficient)

Decreases peak temperature (increased absorptivity/emissivity, put in a number)

Increases temperature outside of flaming region (cooler gas absorbs some radiation from the flame?)

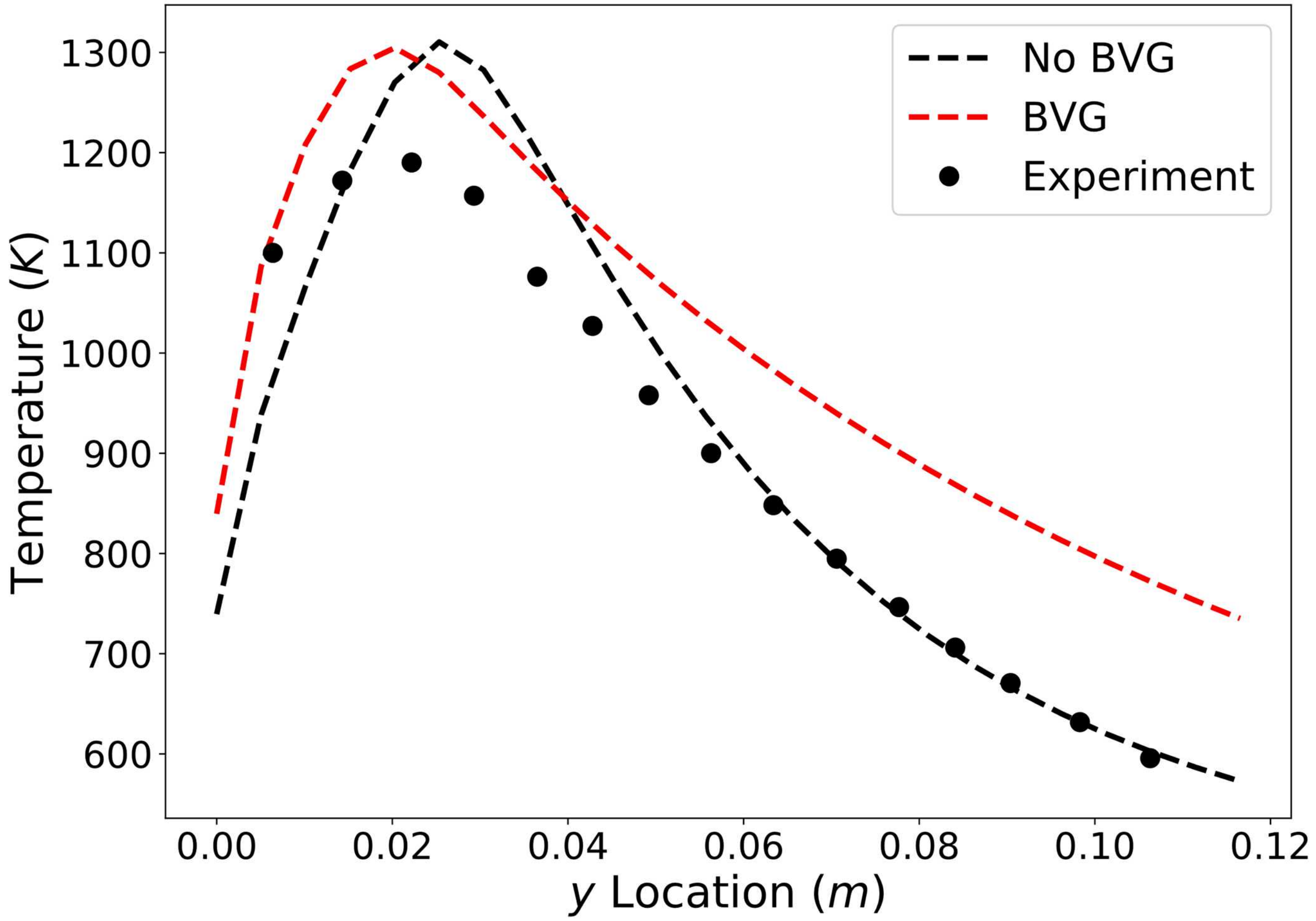


Temperature Results – Buoyant Vorticity Generation Model

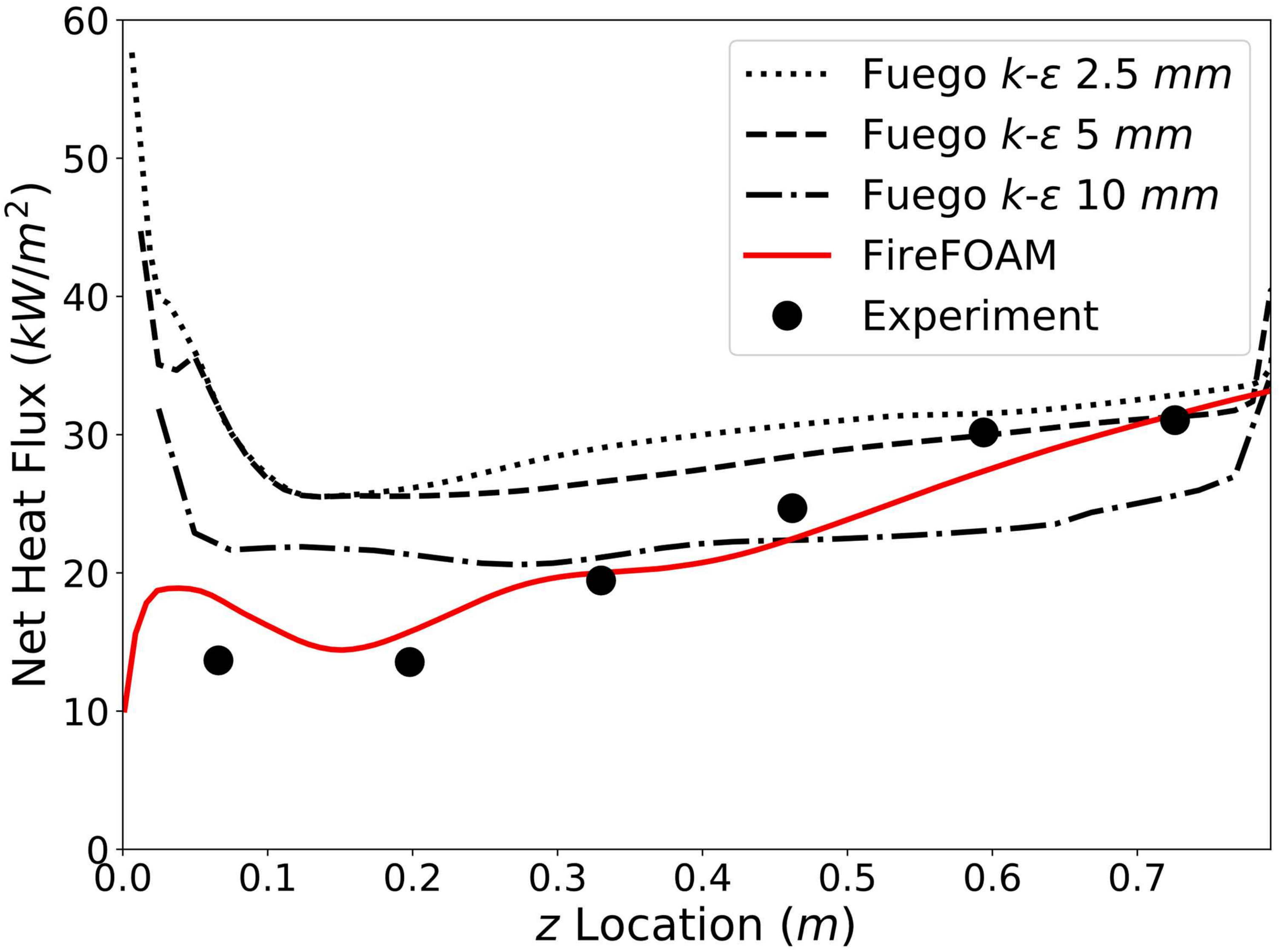
Buoyant Vorticity Generation model aims to include buoyancy induced turbulence

Augment turbulent kinetic energy production with

$$G_B = \frac{C_{bvg}(\mu+\mu_t)\left\|\frac{\partial \rho}{\partial x_j}\times\frac{\partial P}{\partial x_j}\right\|}{\rho^2}$$



Heat Flux at the Wall



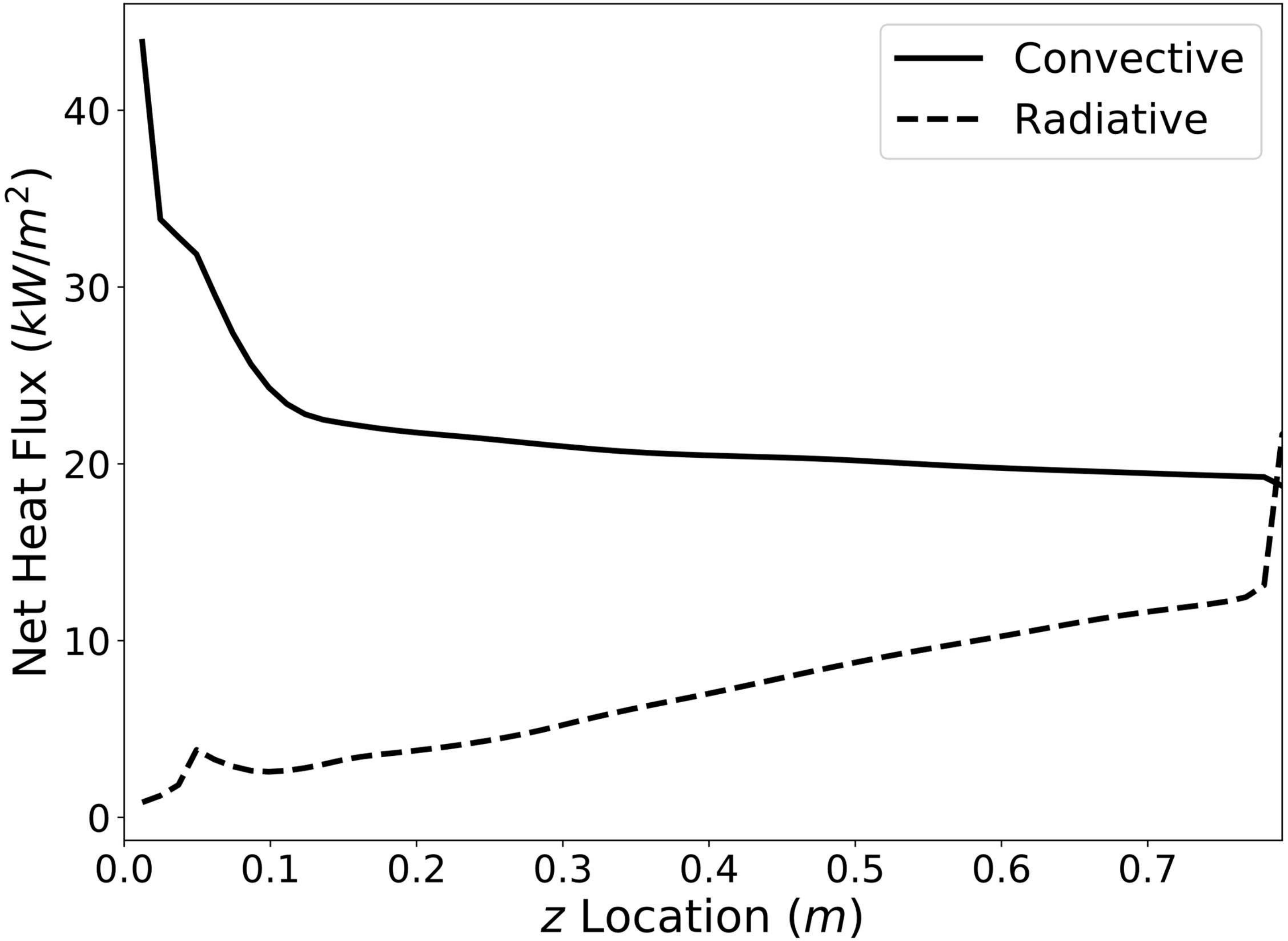
Heat Flux Components

Heat flux components for $\Delta y = 5\ mm$ case

Compared to FireFoam (Ren 2016) Fuego predicts a higher convective heat flux and lower radiative flux

Legacy EDC model tuned for larger fires

Reducing the EDC absorptivity length scale (L_{EDC}) increases radiative component



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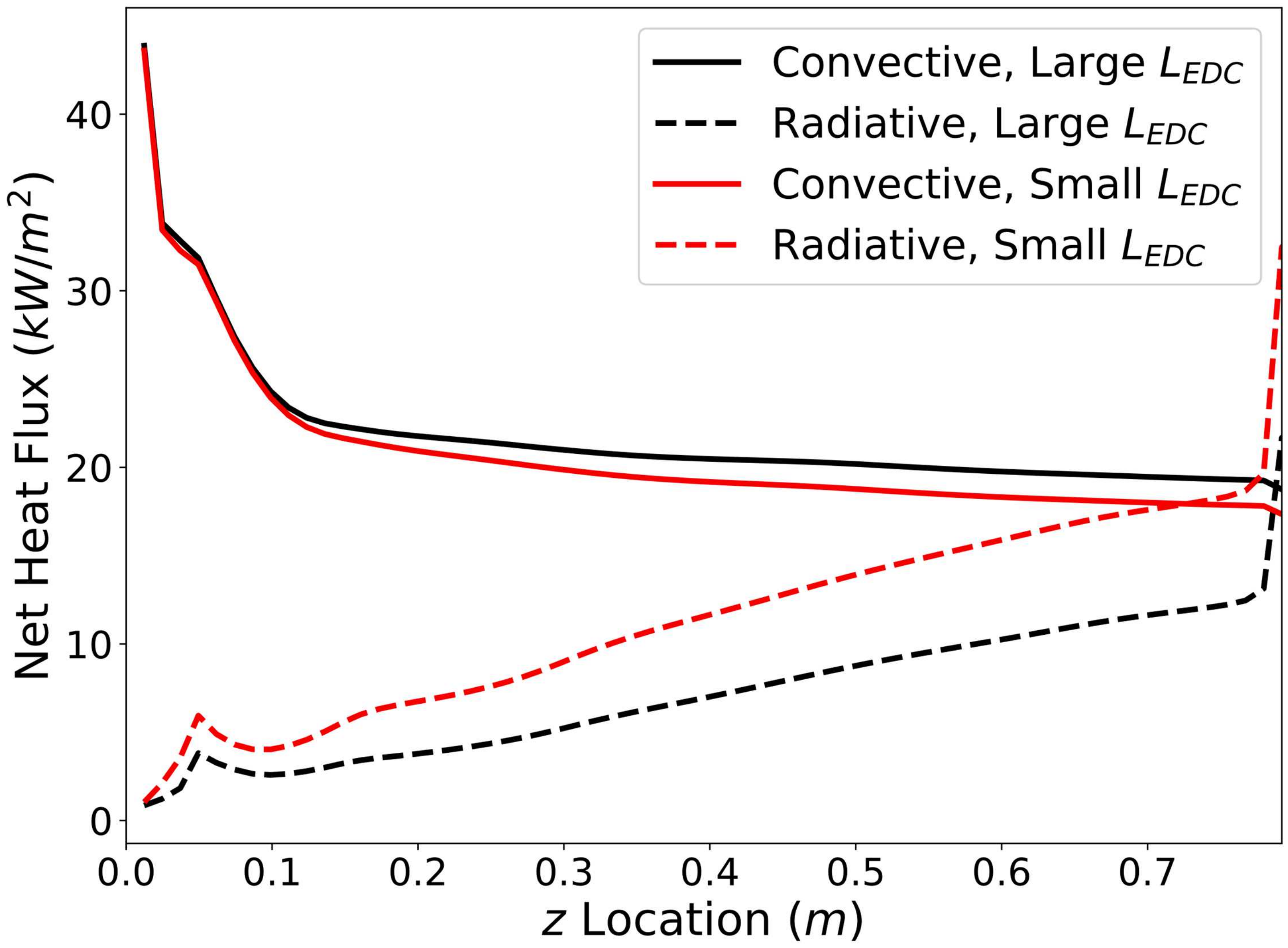


Soot Depth

Soot depth measured by deposition on a glass rod

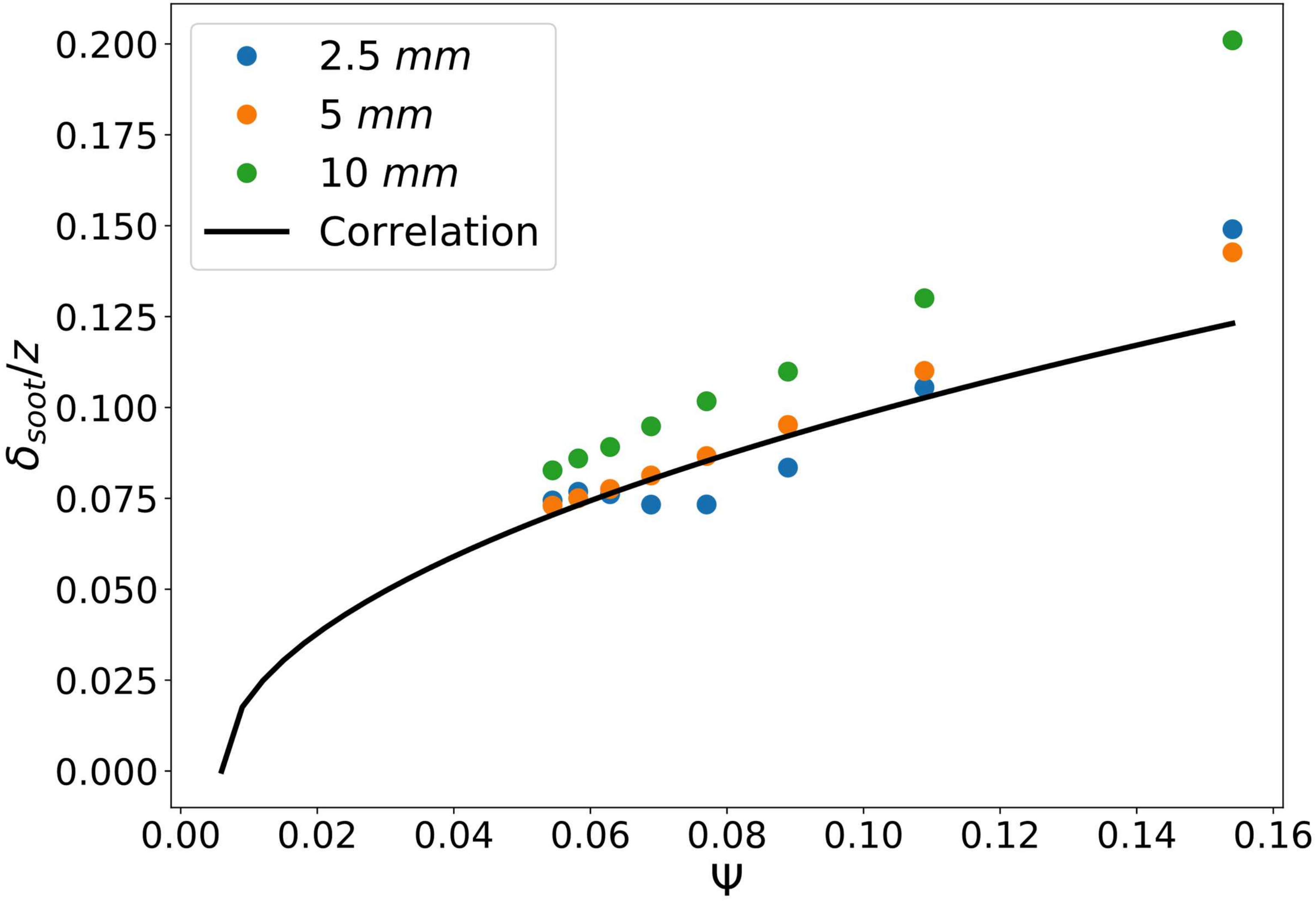
de Ris (2002) found the relative fuel to air mass ratio, Ψ, correlates several quantities of interest across a range of fuel flow rates

$$\Psi = \frac{s \int_0^z \dot{m}'' dz}{\rho_A z \sqrt{2gz}}$$

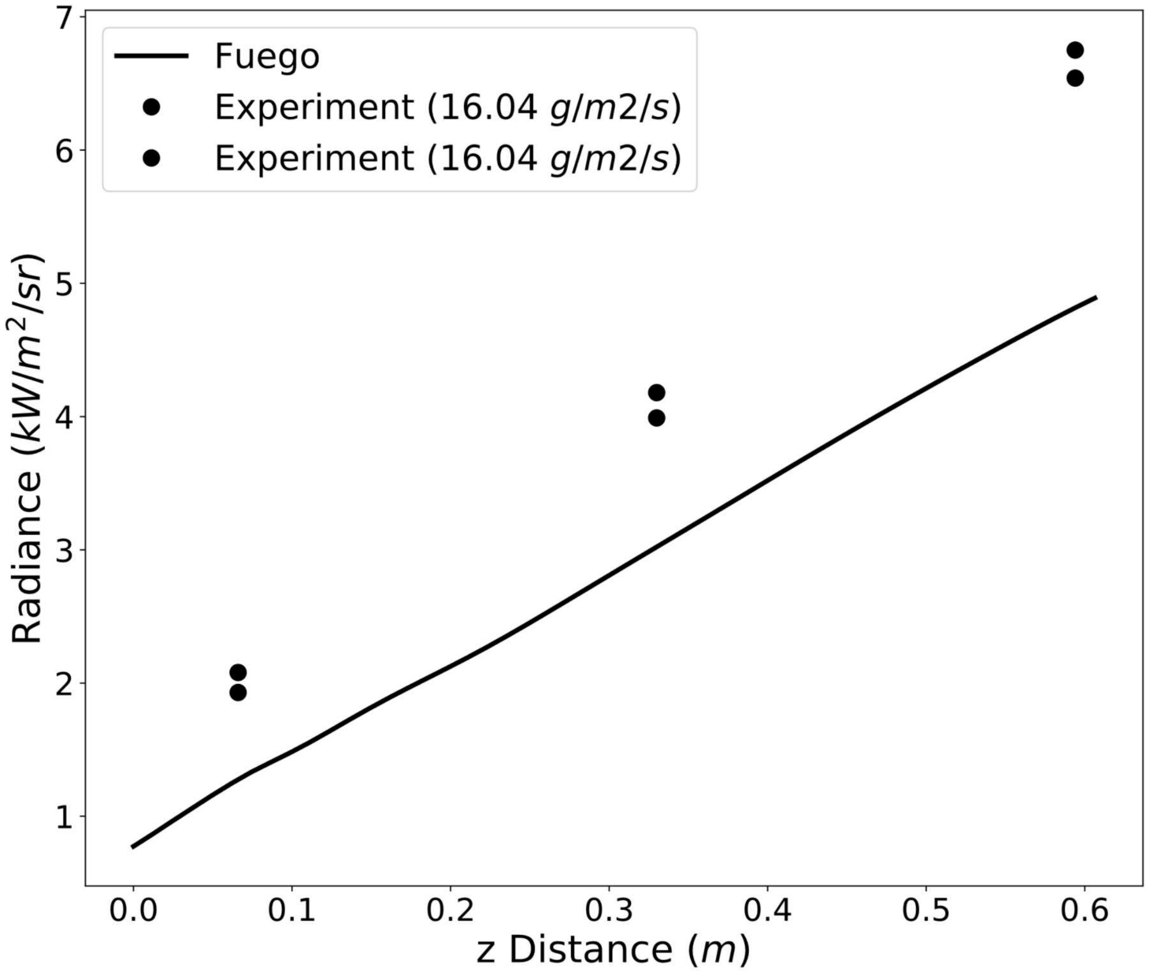
For the soot depth, a ½ power was used

$$\frac{\delta_{soot}}{z} = 0.32(\Psi - \Psi_0)^{1/2}$$

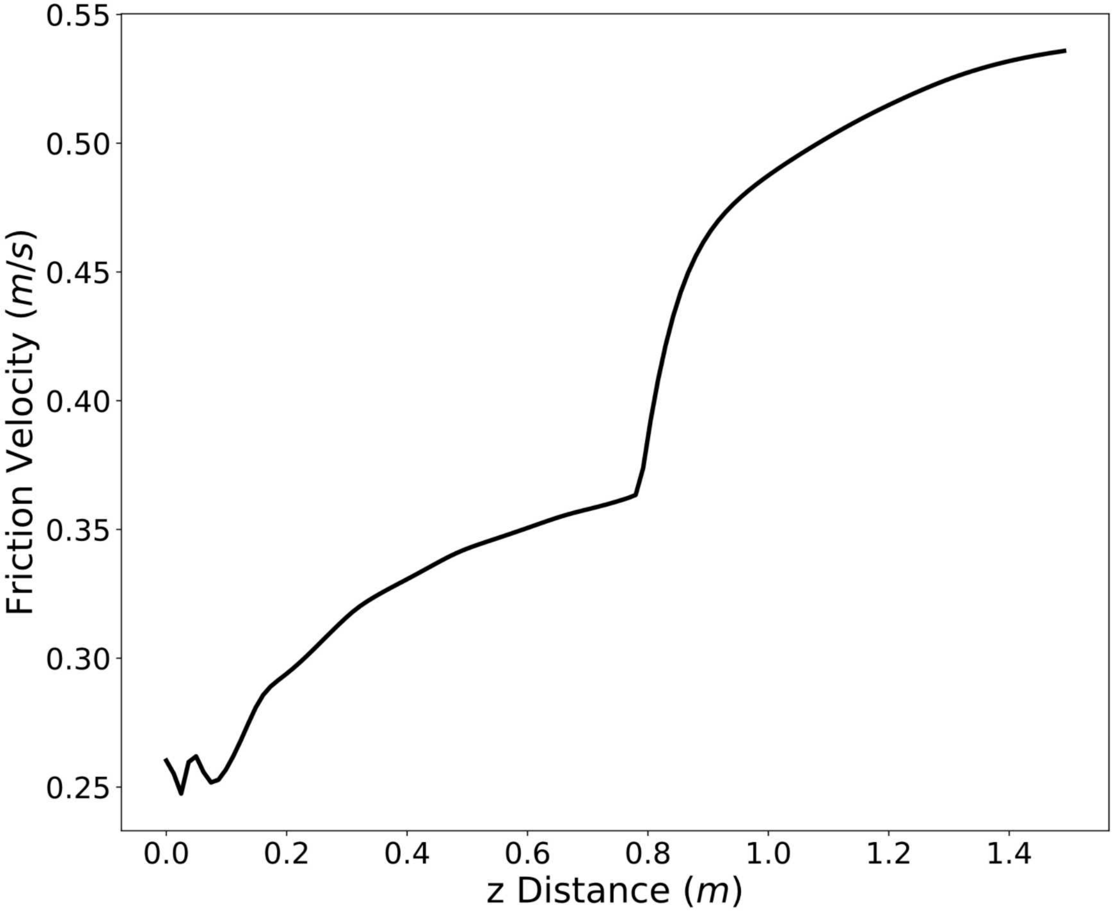
We estimate δ_{soot} as the location where the temperature is 1000 K



Radiance


Fuego
Experiment (16.04 $g/m2/s$)
Experiment (16.04 $g/m2/s$)
Radiance ($kW/m^2/sr$)
z Distance (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1
2
3
4
5
6
7

Friction Velocity/Shear Stress



Summary

The EDC, $k - \epsilon$, and PMR model combination tested in the work identified the following biases

- Over-prediction of flame temperature
- Under-prediction of radiant flux
- Possible over-prediction of convective flux

Points to a need for model development around PMR source/sink terms

Future efforts focusing on non-adiabatic flamelet modeling