ENABLING OPTIMIZATION AND GROWTH OF CARBON FIBER PRODUCTION THROUGH COMPUTATIONAL FLUID DYNAMICS [CFD] MODELING ANALYSIS

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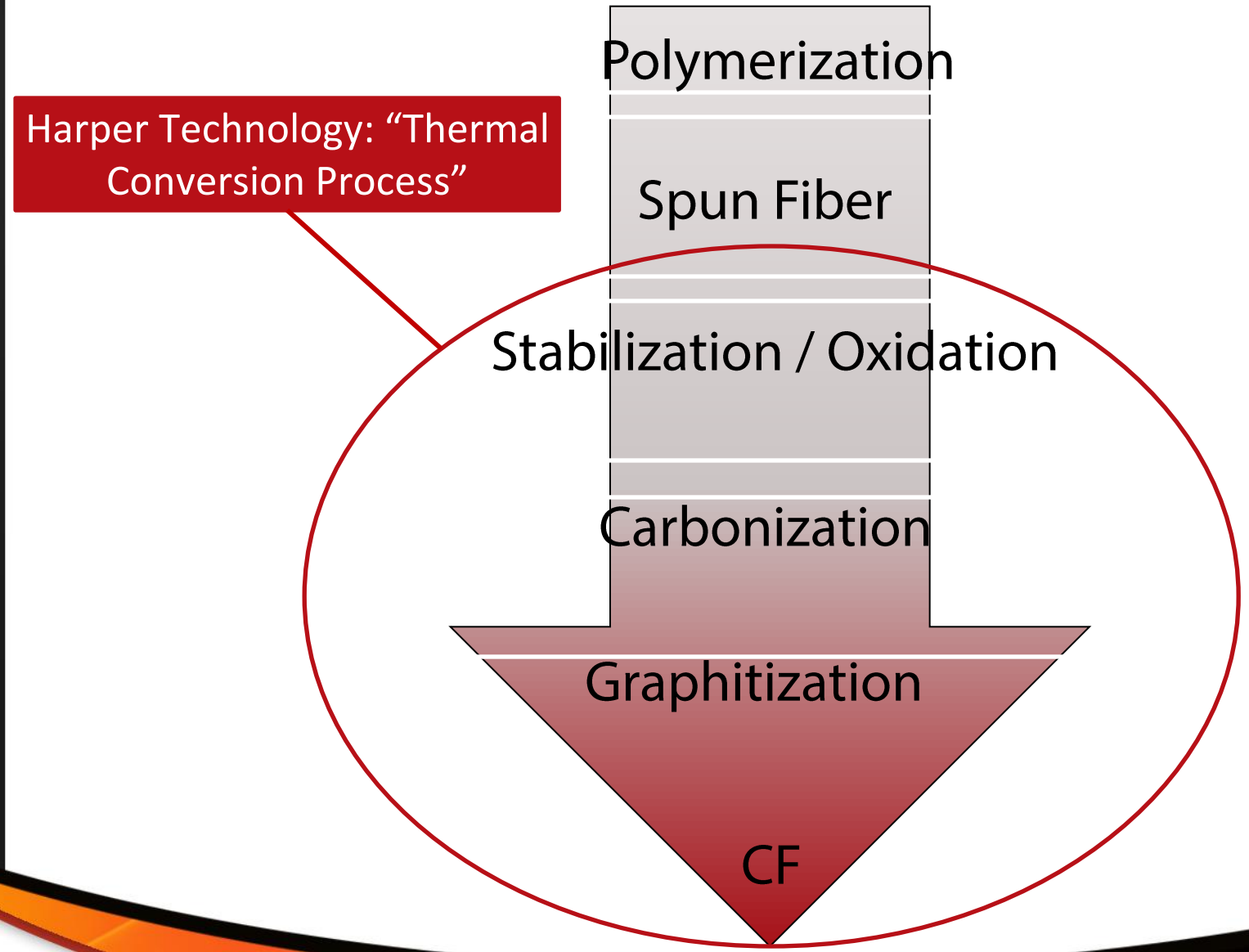
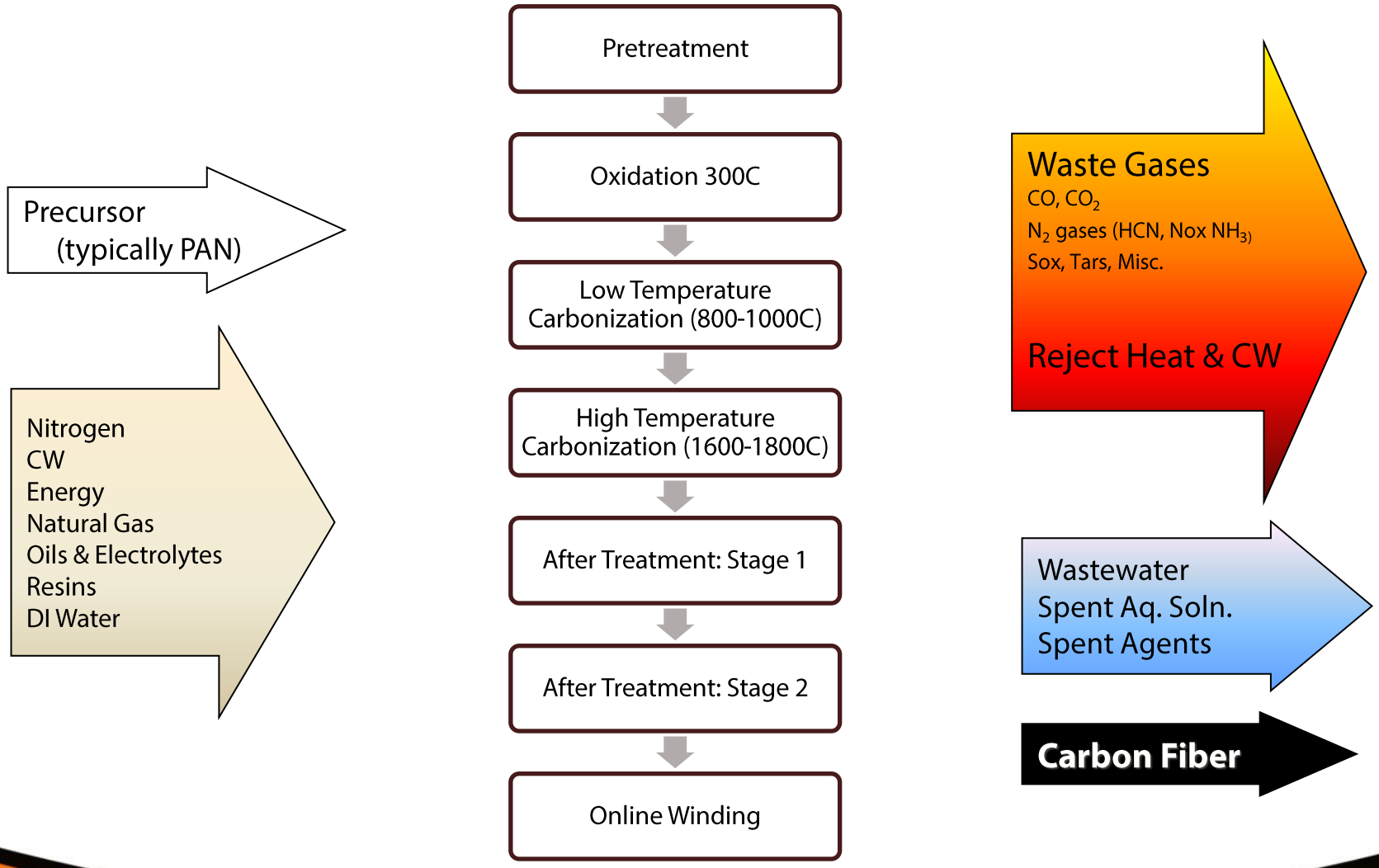
Agenda

- Carbonization line overview
- CFD gas flow modeling applied to oxidation oven end seals
- CFD gas flow modeling applied to LT furnace vents

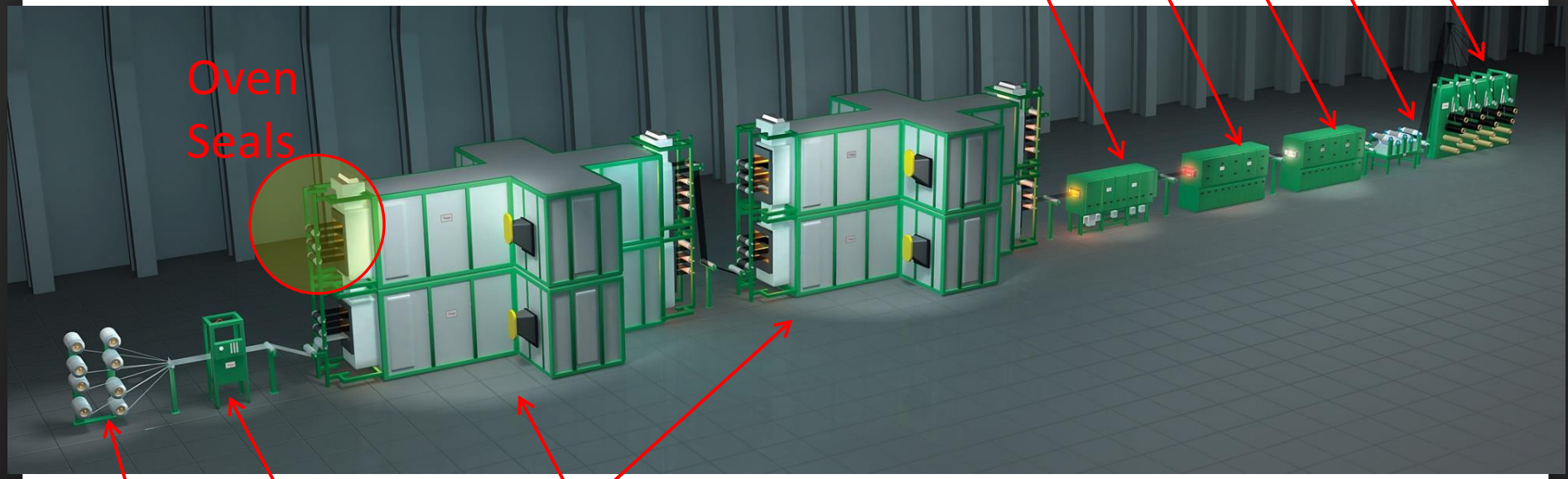
Carbon Fiber Process Overview



Carbon Fiber Thermal Conversion Process



Example Carbonization Line



Carbon Line Optimization and Growth Challenges

OVENS

- Efficiency – Floor Space
  - 100% of heated length at temperature
- Efficiency – Energy Consumption
  - Prevent cold air infiltration
- Safety - Prevent escape of oven gas
  - Eliminate HCN in working areas

Oven End Seals – Modeling Objectives

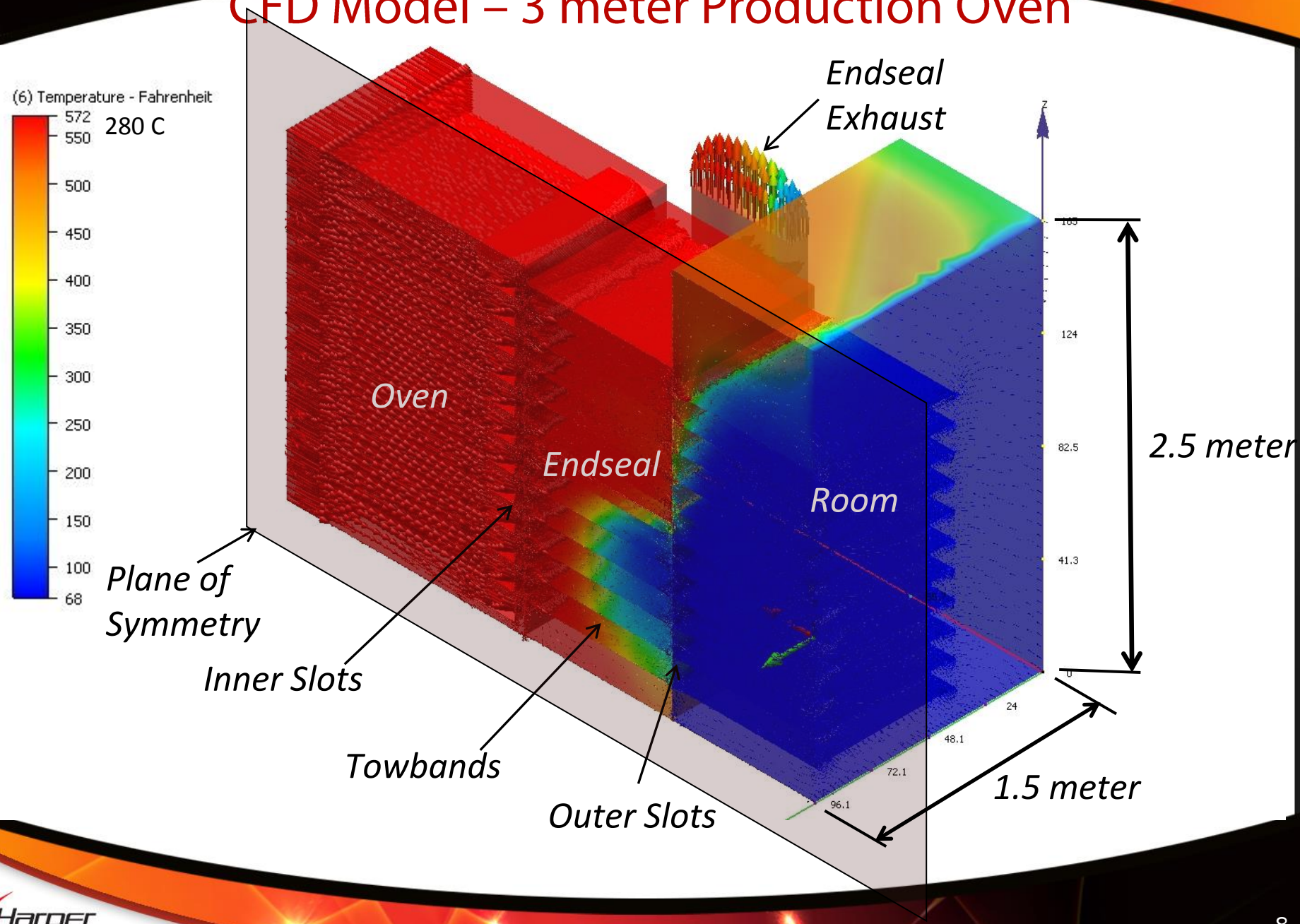
- Predict temperature uniformity
- Predict escape of oven gas
- Predict cold air infiltration

… While Varying Oven Width, Height, and # Passes

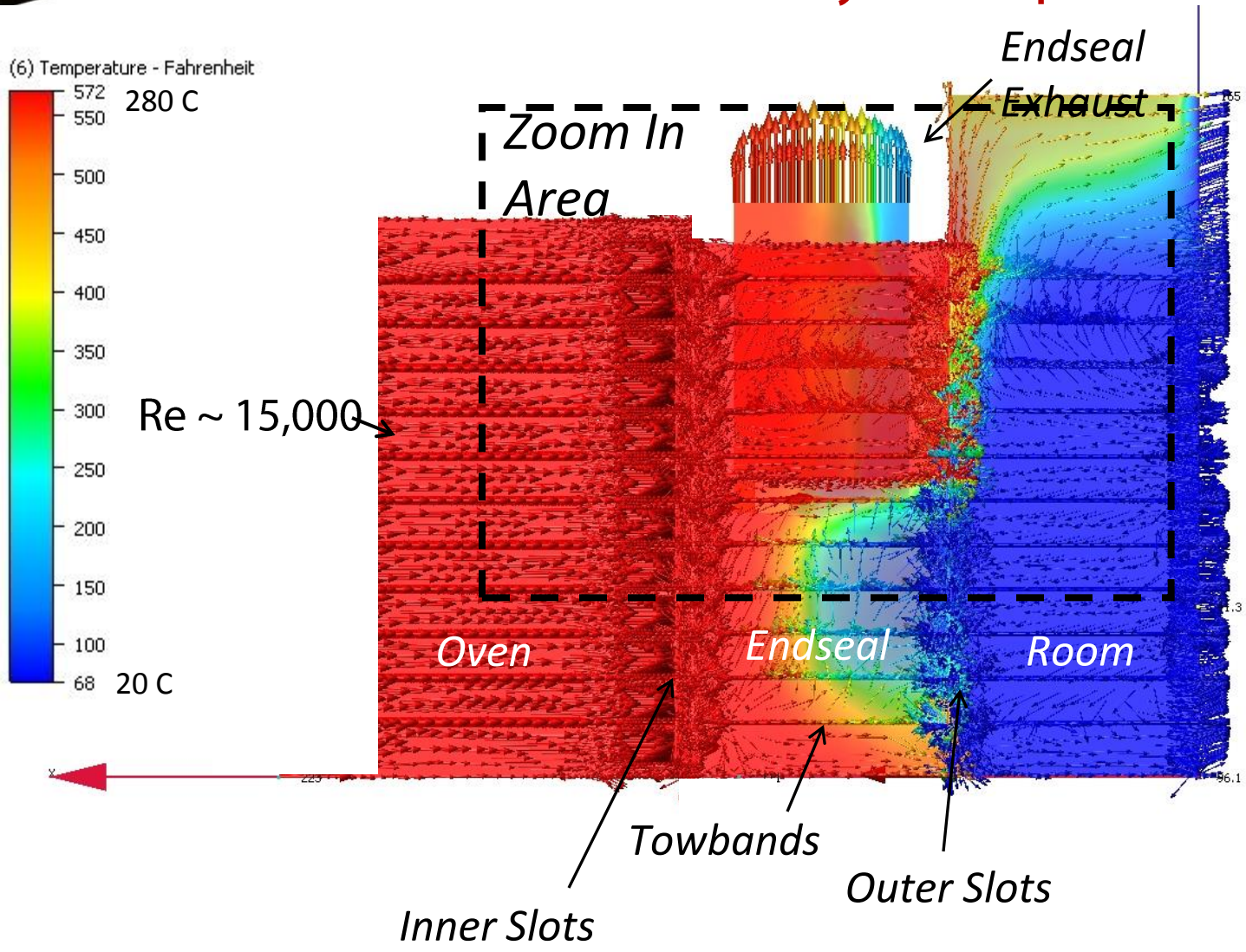
Focus on End Seals - Features in CFD Model

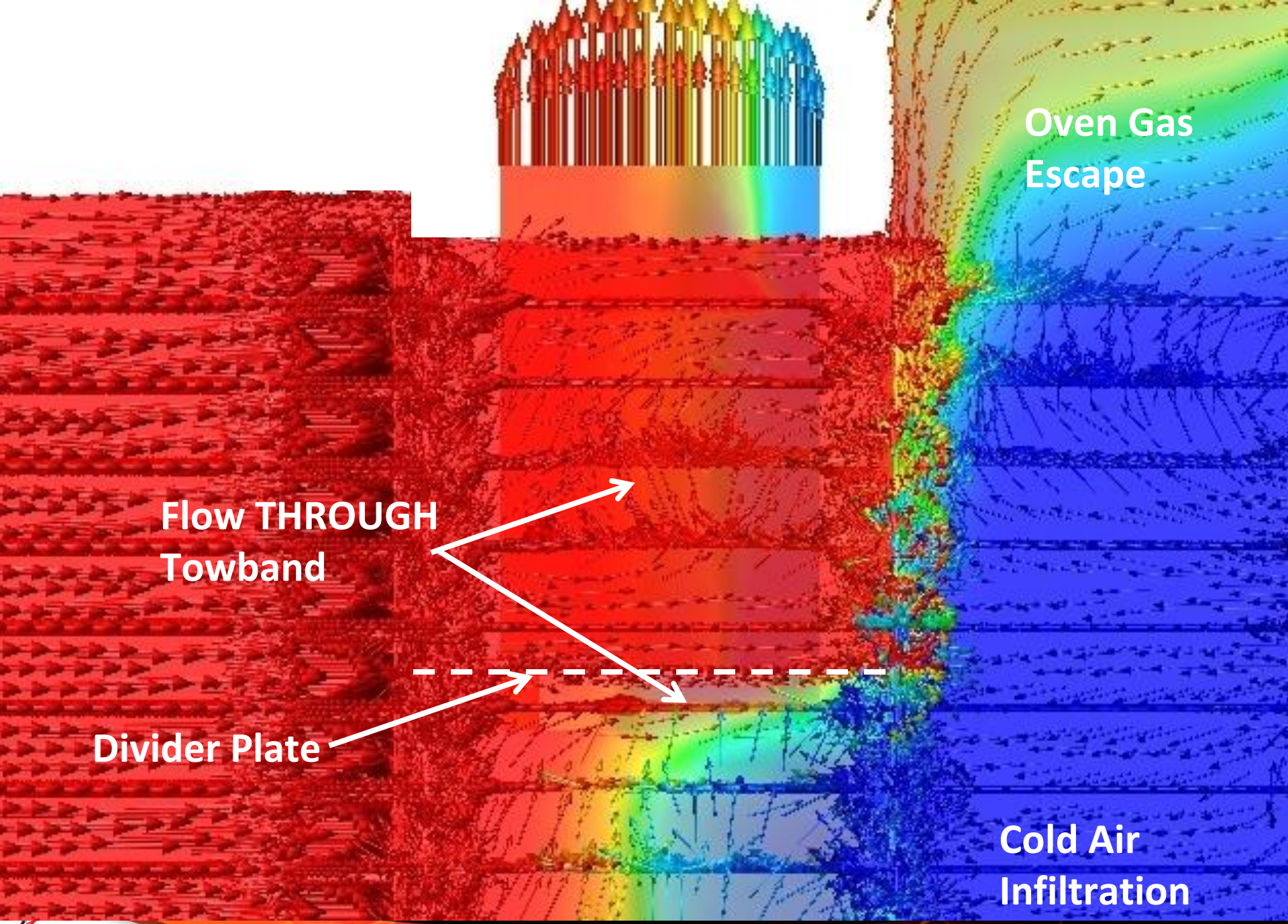
1. Exhaust flow rate
2. Slot opening height (inside and outside)
3. Number of divider plates
4. Exhaust damper position

CFD Model – 3 meter Production Oven

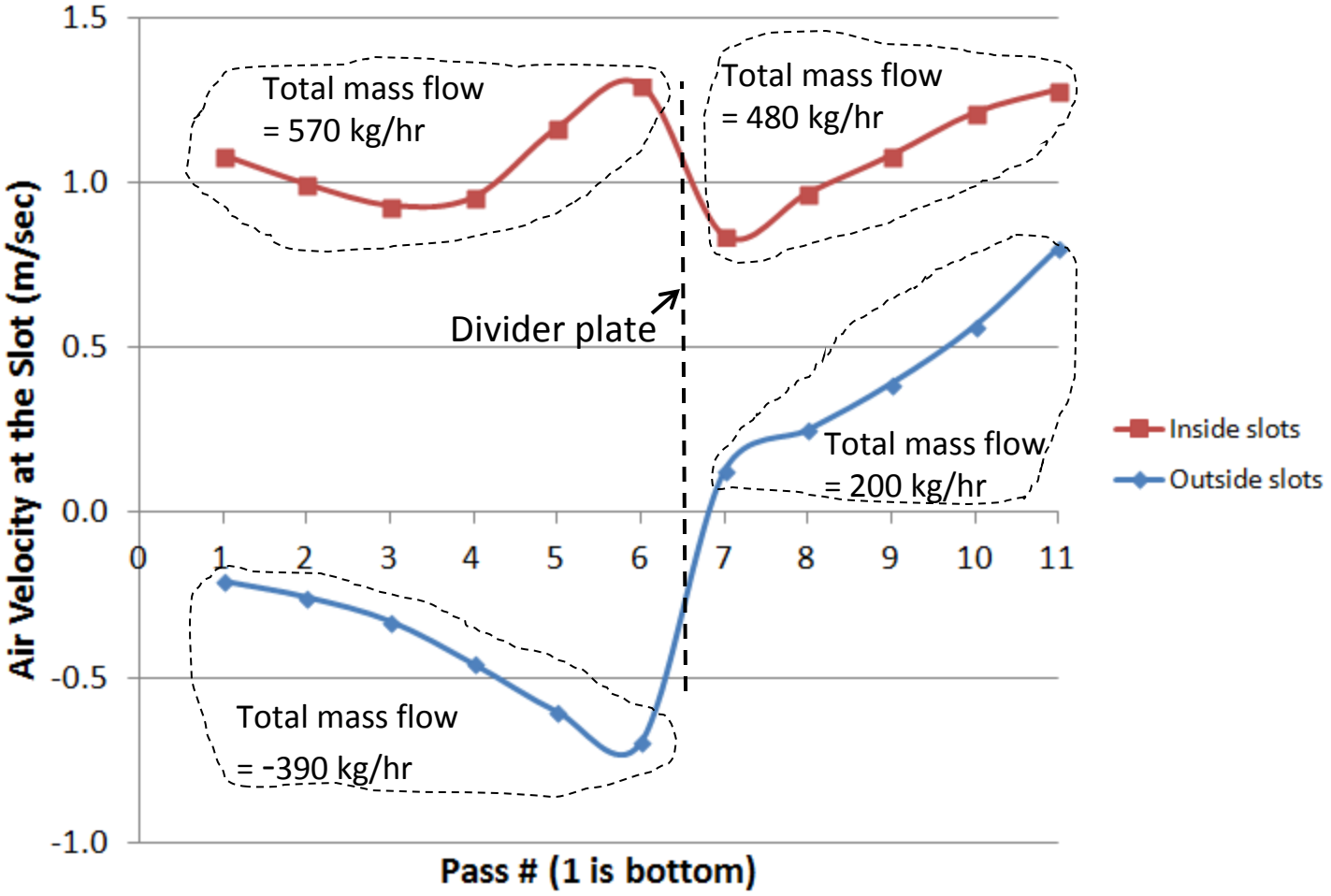


CFD Results – Velocity &Temperature

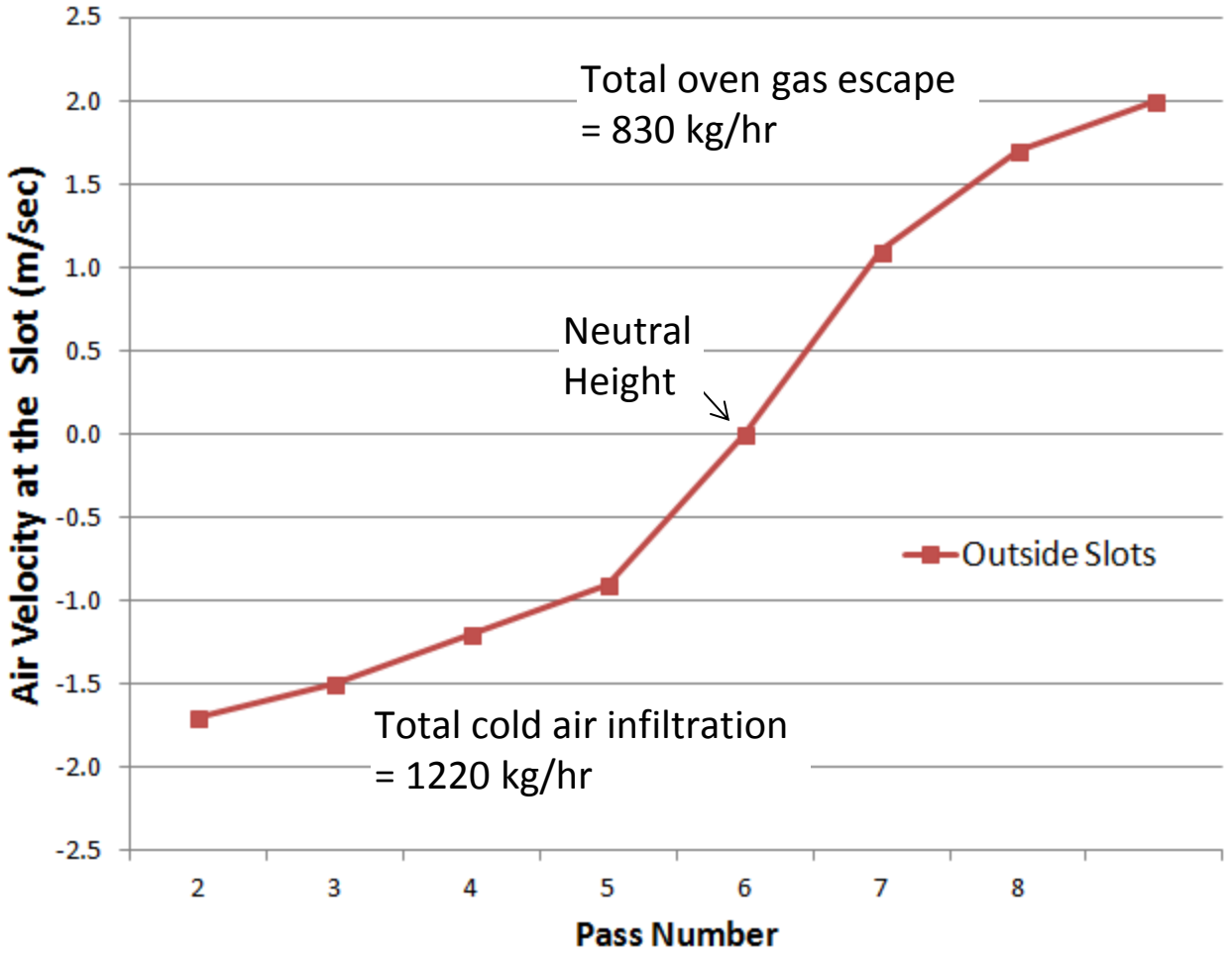



Oven Gas
Escape
Flow THROUGH
Towband
Divider Plate
Cold Air
Infiltration

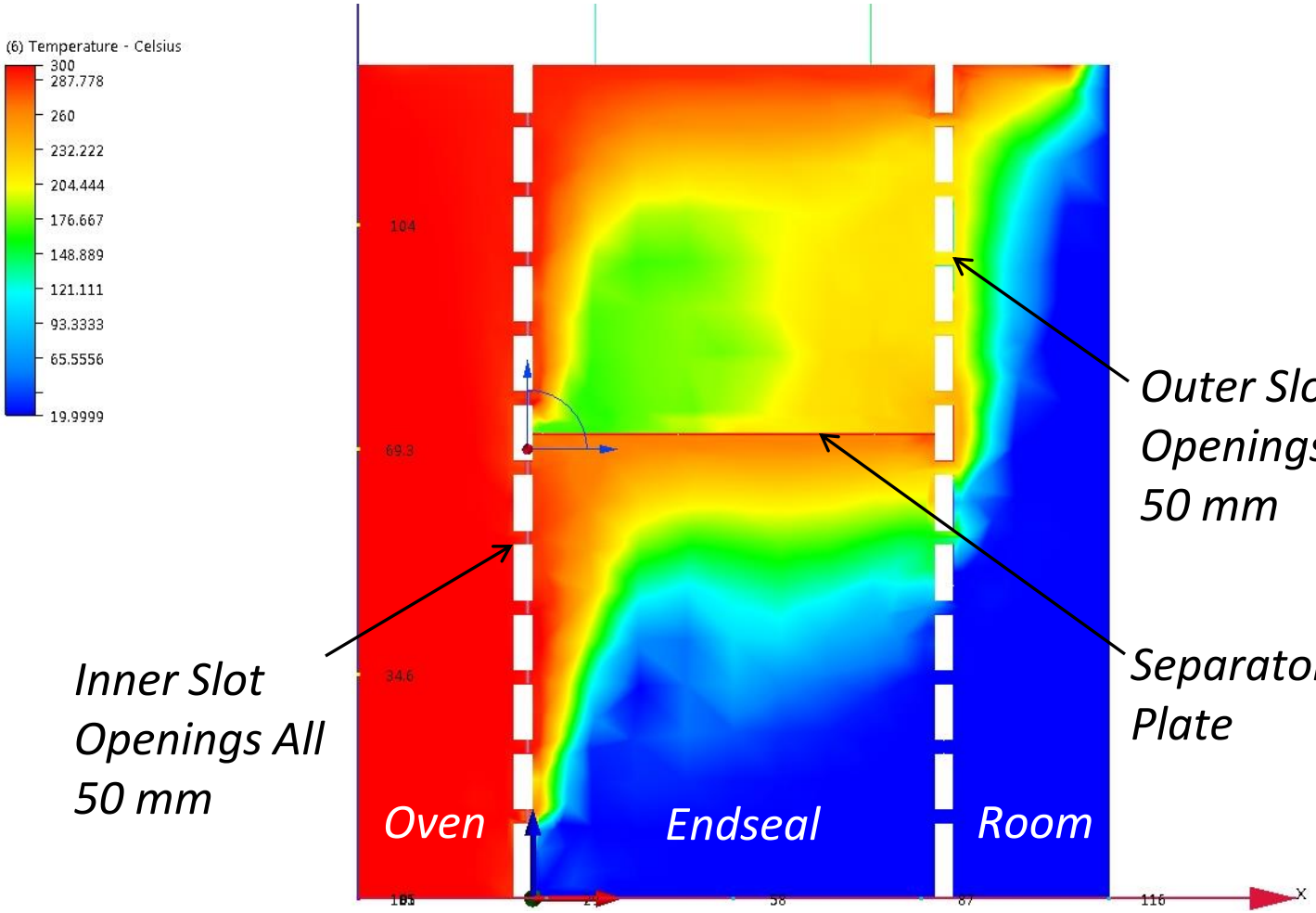
CFD Results Summary: Oxidation Oven End Seals



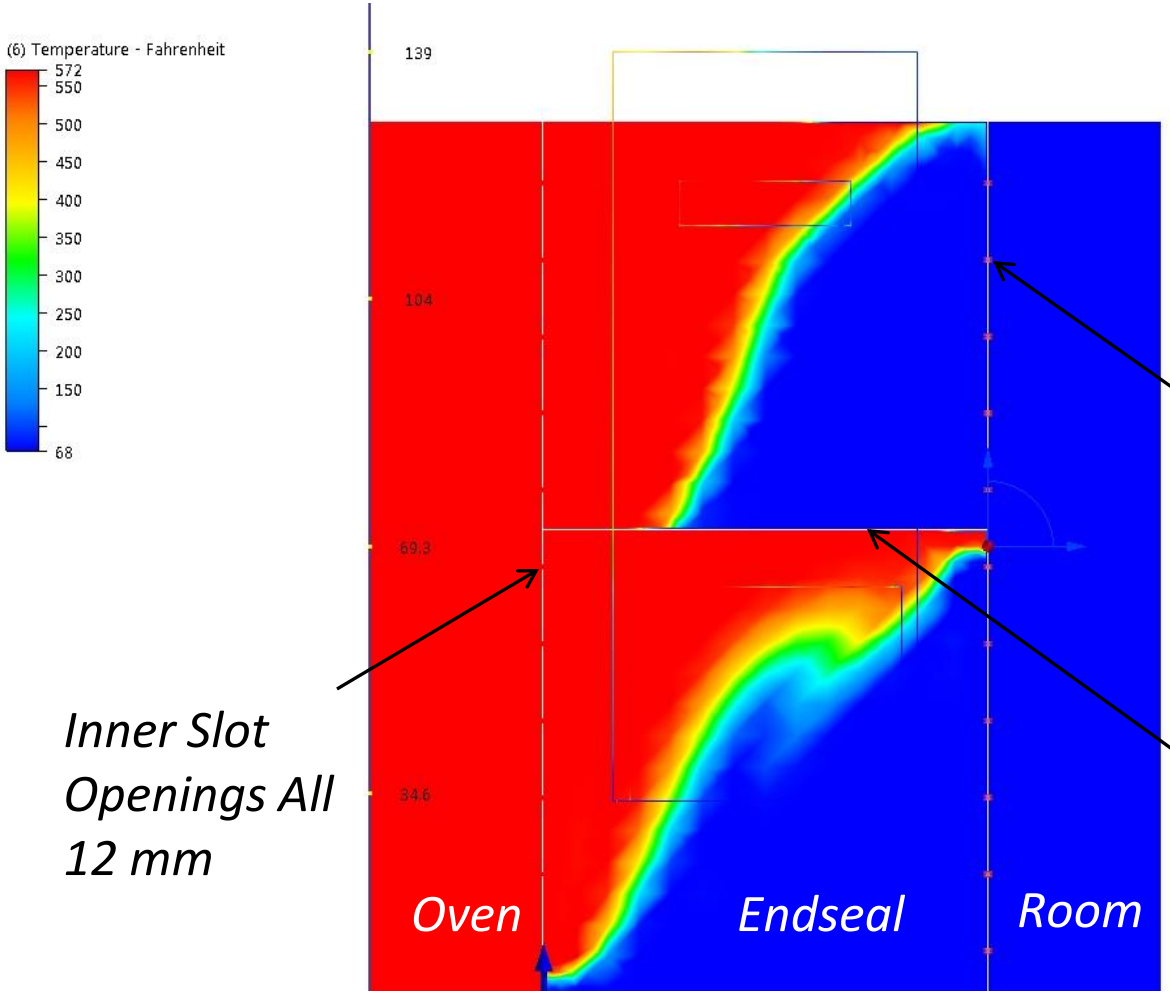
Oven Atmosphere Sealing – **Field Data**



Velocity and Temperature - Affect of Slot Height



Velocity and Temperature - Affect of Slot Height



Outer Slot Openings All 12 mm

Inner Slot Openings All 12 mm

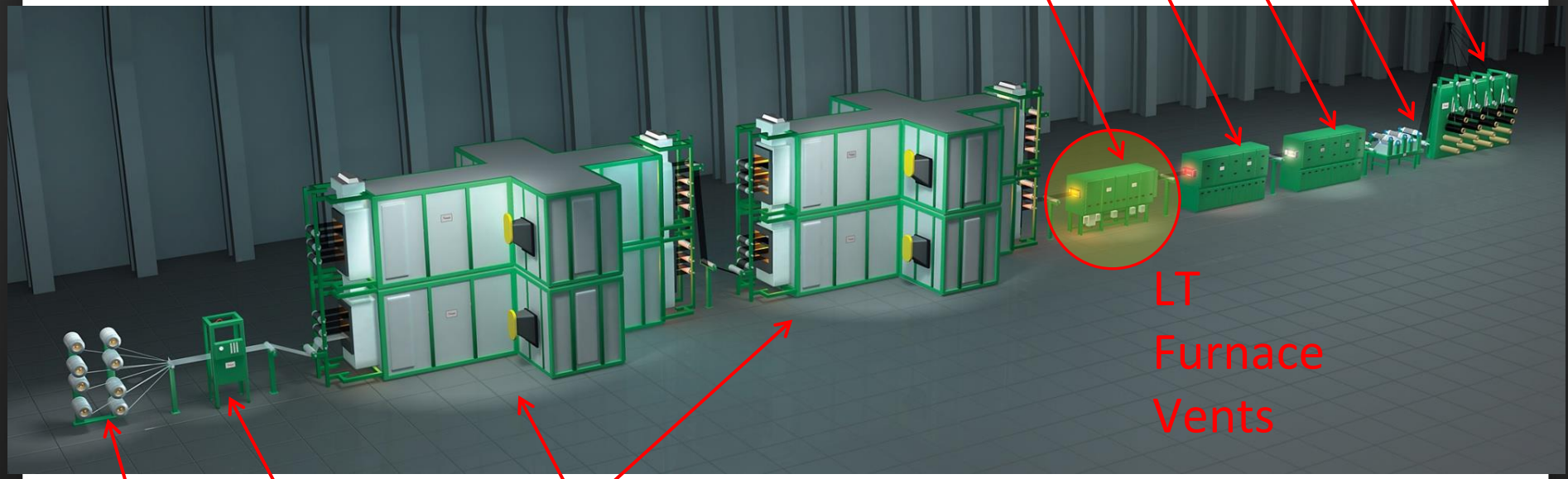
Separator Plate

Oven CFD Model – Results Overview

1. The chimney affect is influenced by the towband and by the presence of divider plates.

2. Slot opening heights have a major impact on the performance of the ovens, especially with respect to cold air infiltration.

Example Carbonization Line



Carbon Line Optimization and Growth Challenges

FURNACES

- Efficiency – Floor Space
  - 100% Uniformity of Product Across Width
- Efficiency – Improve utilization
  - Prevent tow damage
  - Prevent fiber material clogging of vents

LT Muffle Furnace– Design Objectives

- Uniform gas flow & temperature across furnace
- Vent process gas, for PAN precursor ~30% of the mass
- Prevent plugging (that can interrupt production)

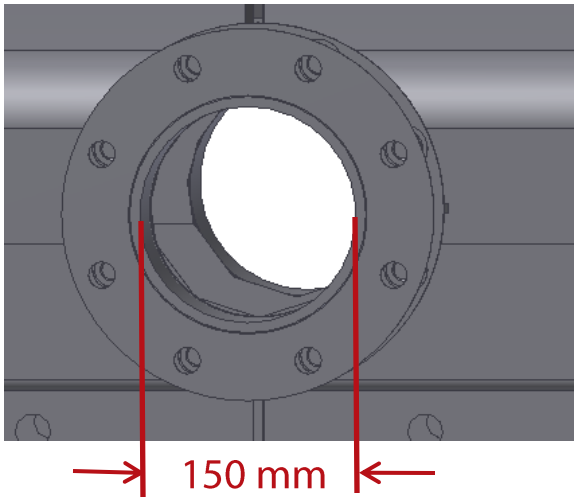
LT Muffle Furnace Features in CFD Model

1. Exhaust flow rate
2. Furnace width
3. Vent positions – sides or bottom of muffle
4. Vent geometry – restrictive bottom vs. open bottom

Vent Geometries

Side Vents –

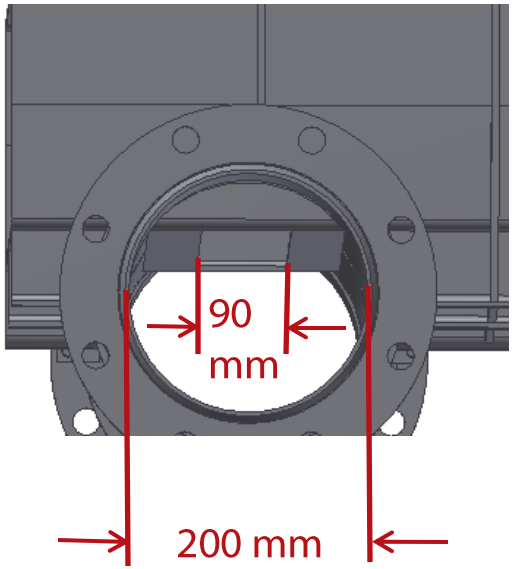
- No Opening Across Bottom
- At Muffle Mid-Height



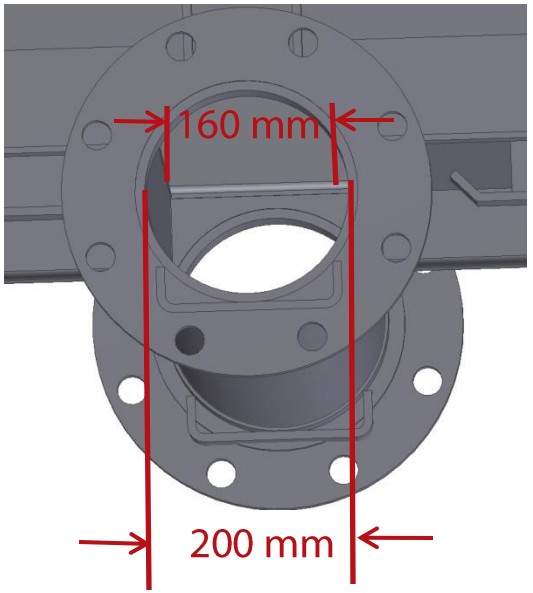
Bottom Vents –

- Below muffle
- Open Across Entire Width

Restrictive Type

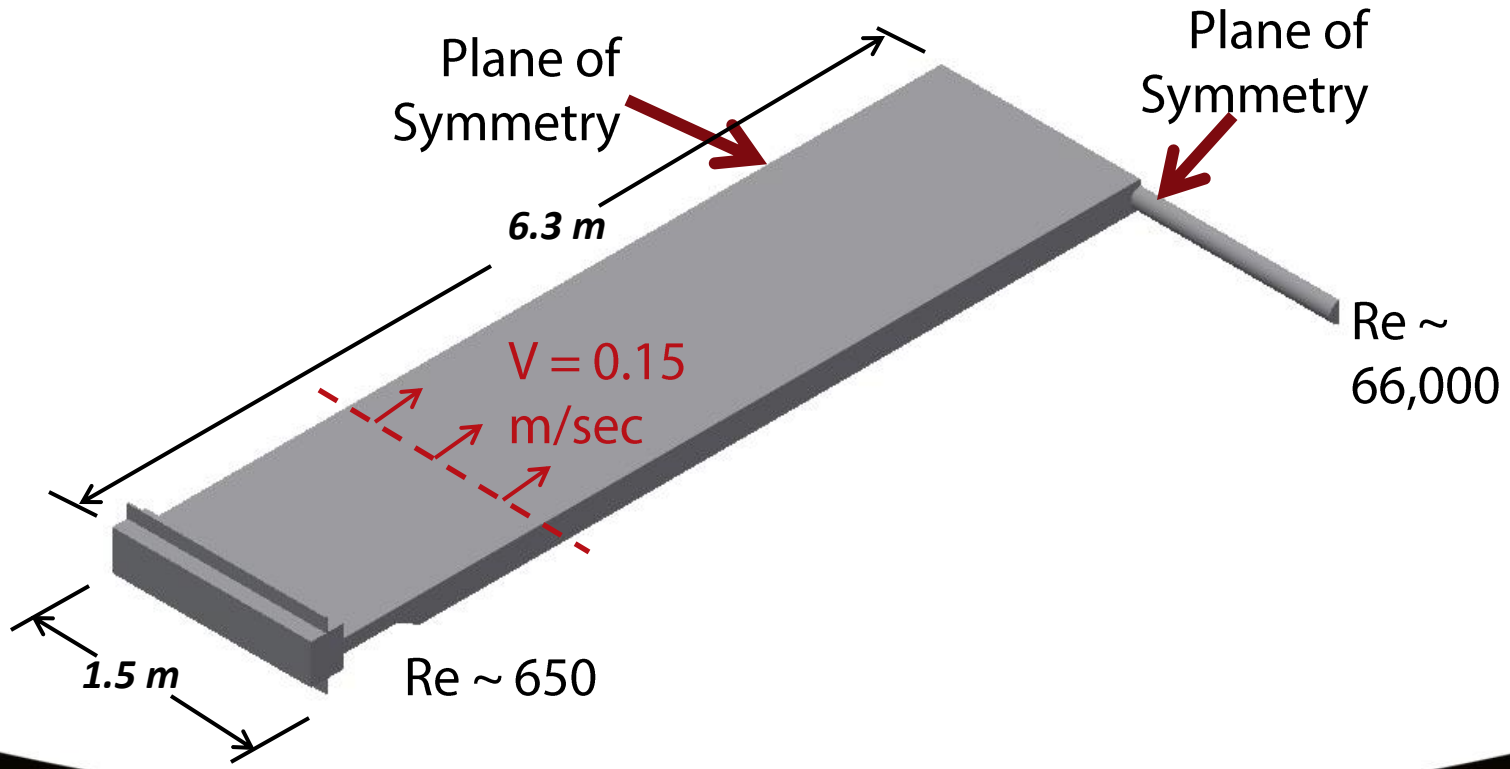


Non-Restrictive Type

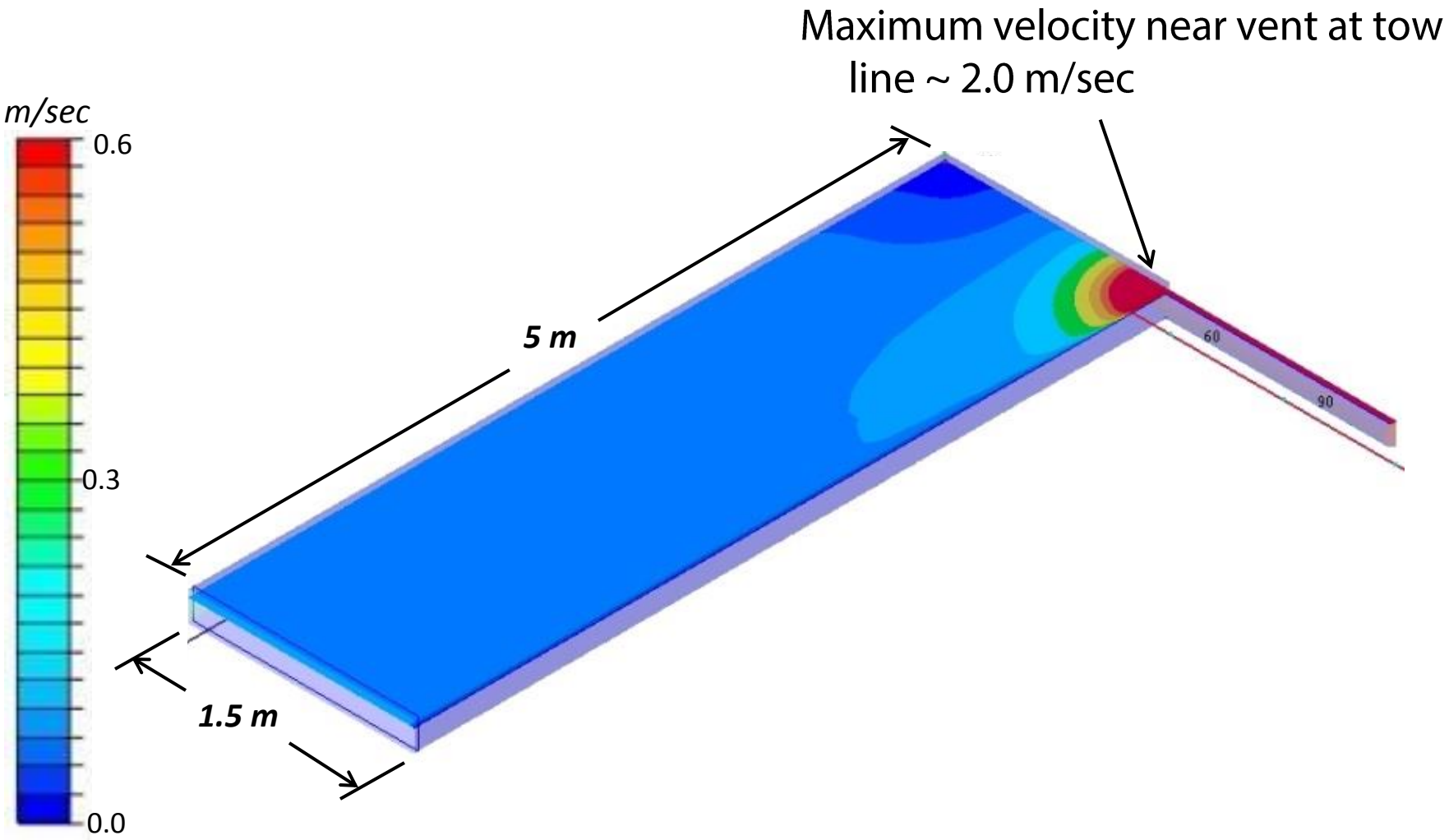


Model Geometries & Symmetries

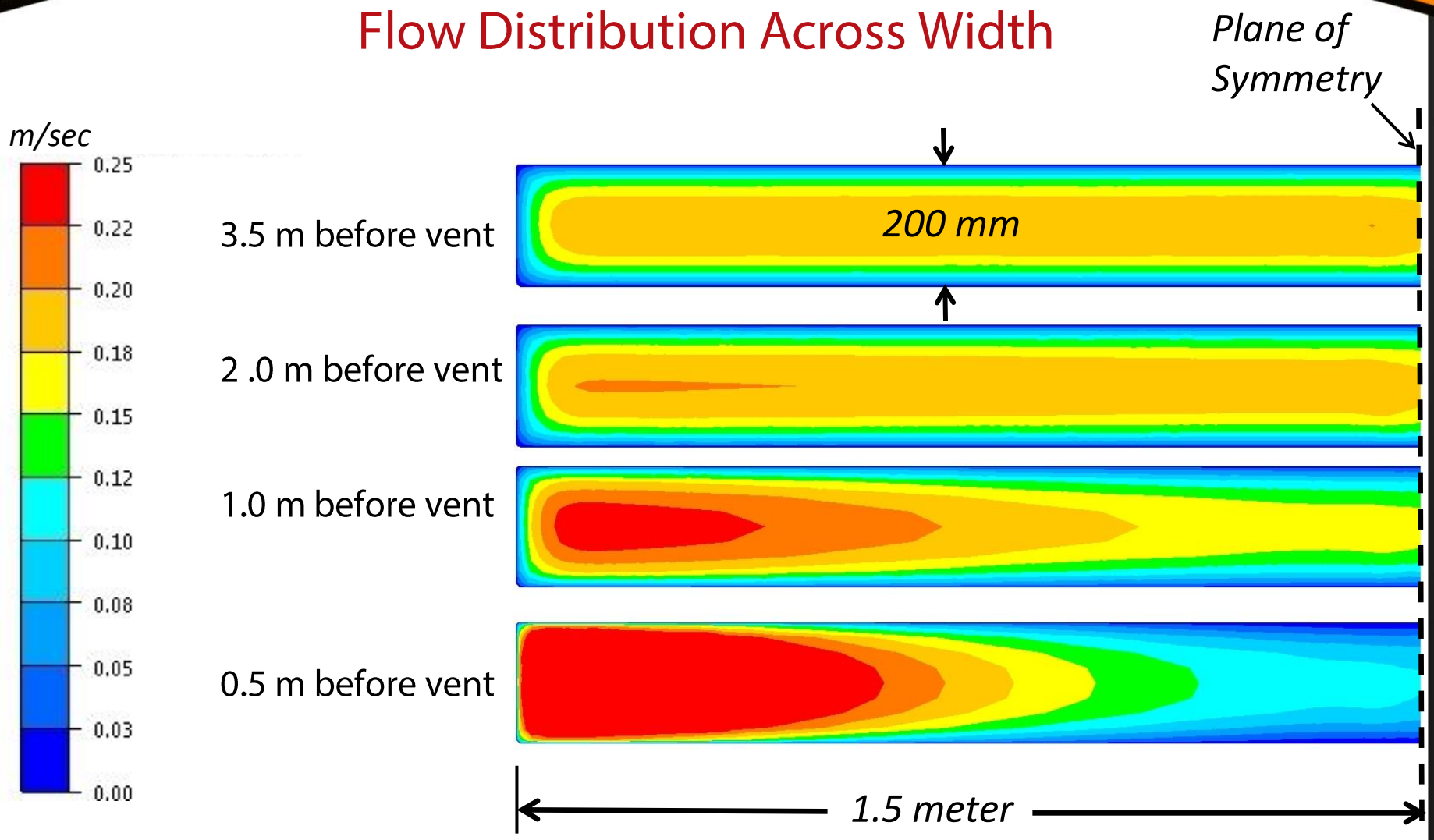
- Model is based on 3m wide furnace
- Uniform flow of nitrogen across width, totaling 200 kg/hr



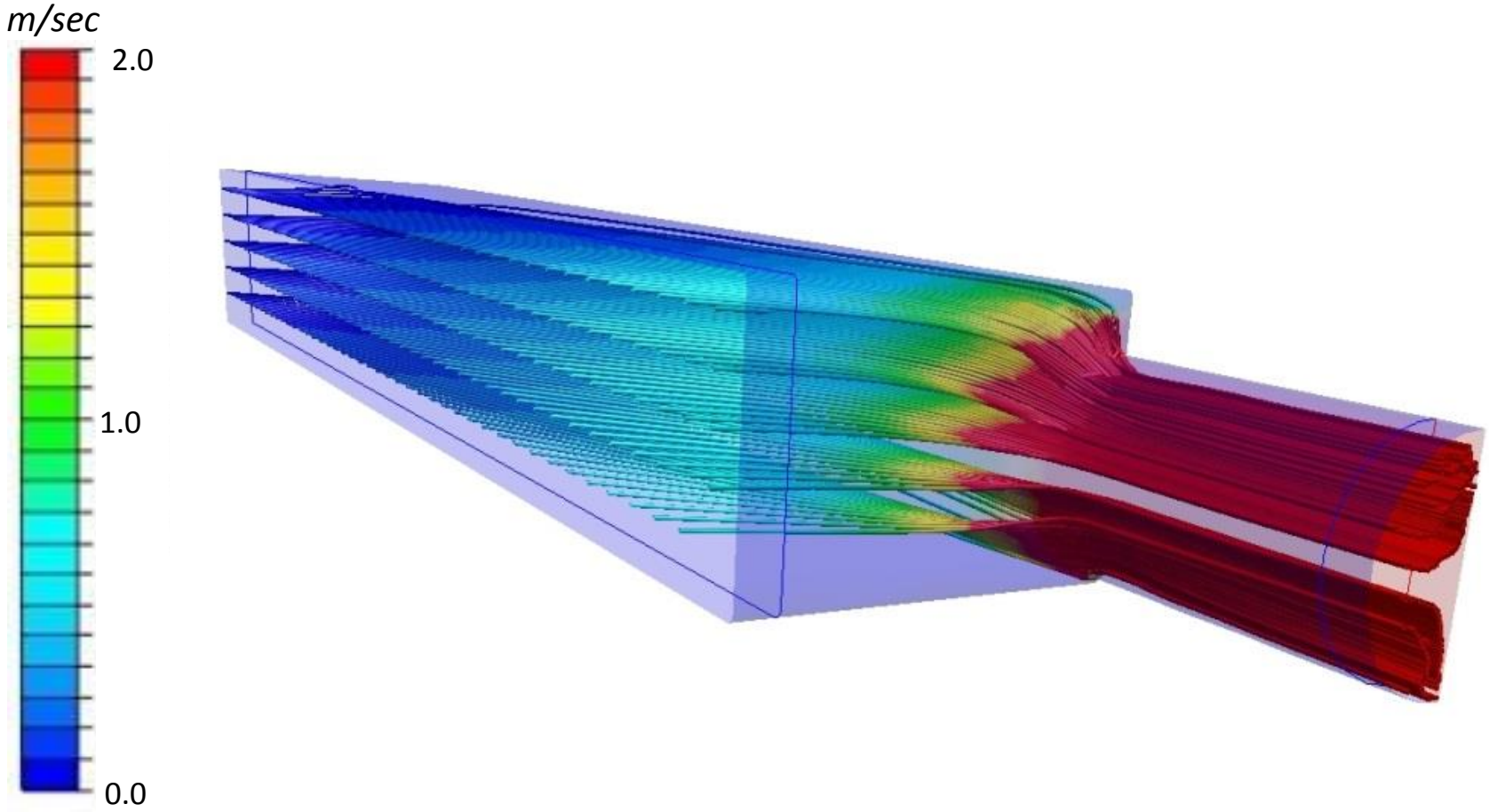
Side Vent Velocity



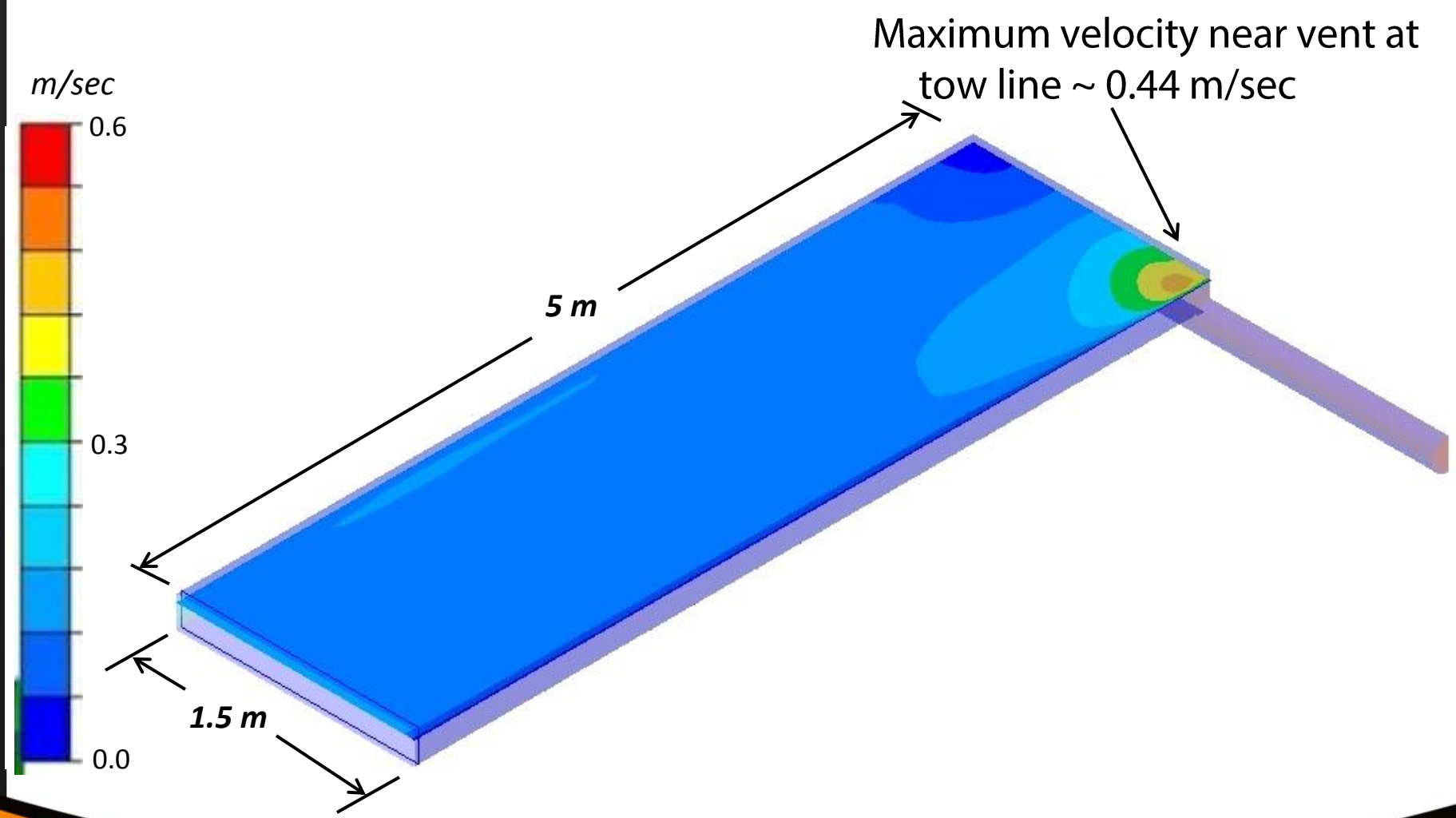
Side Vent
Flow Distribution Across Width



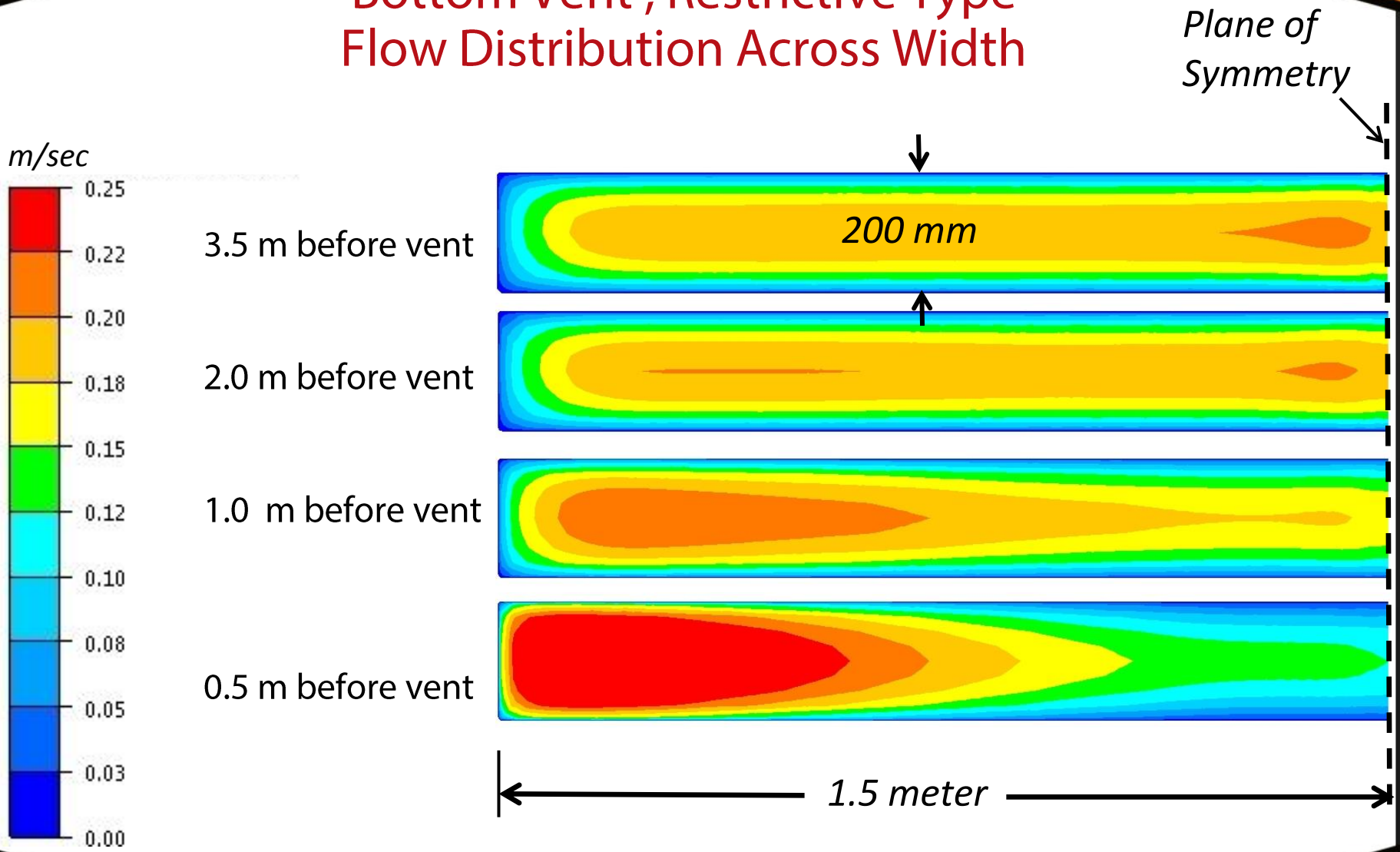
Side Vent Streamlines



Bottom Vent , Restrictive Type – Velocity

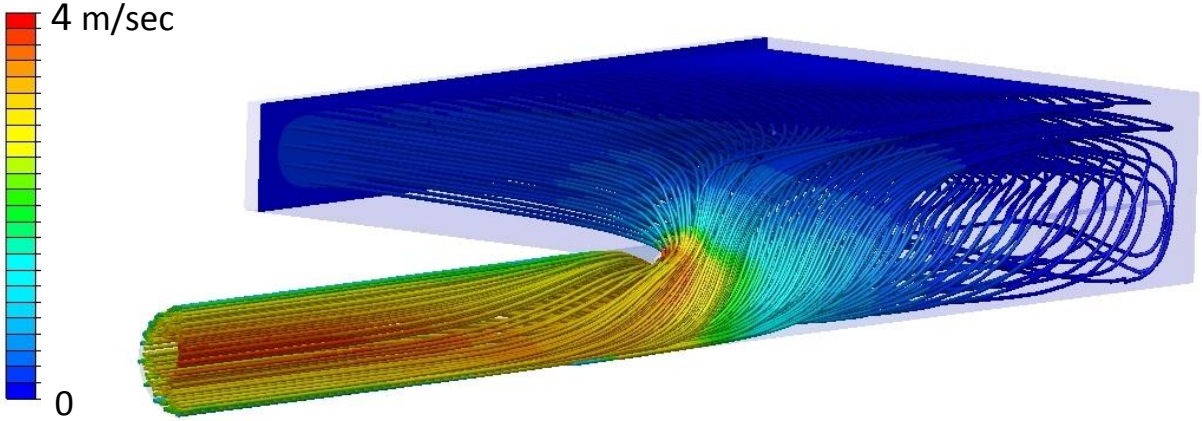


Bottom Vent , Restrictive Type
Flow Distribution Across Width

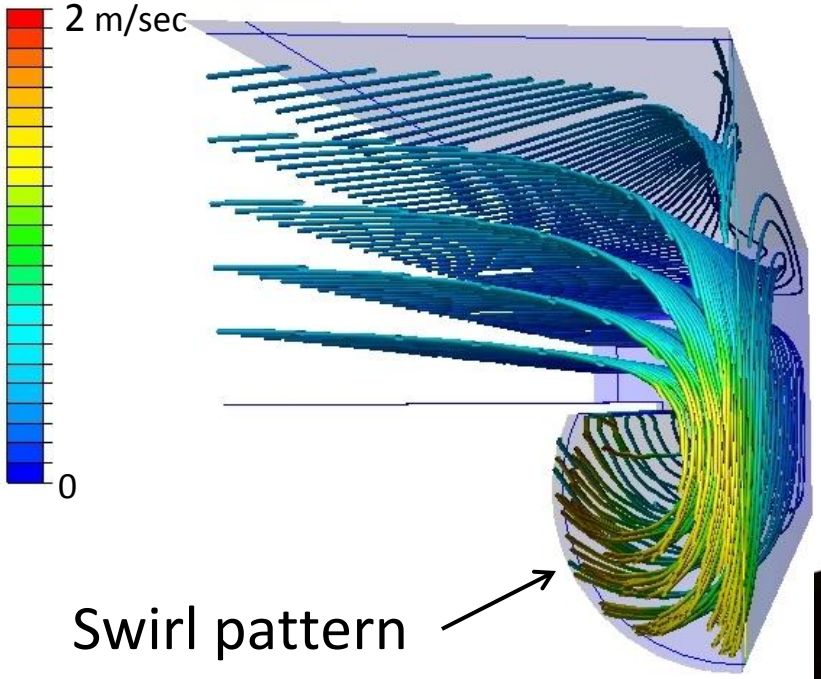


Bottom Vent Results – Restrictive Vent - Streamlines

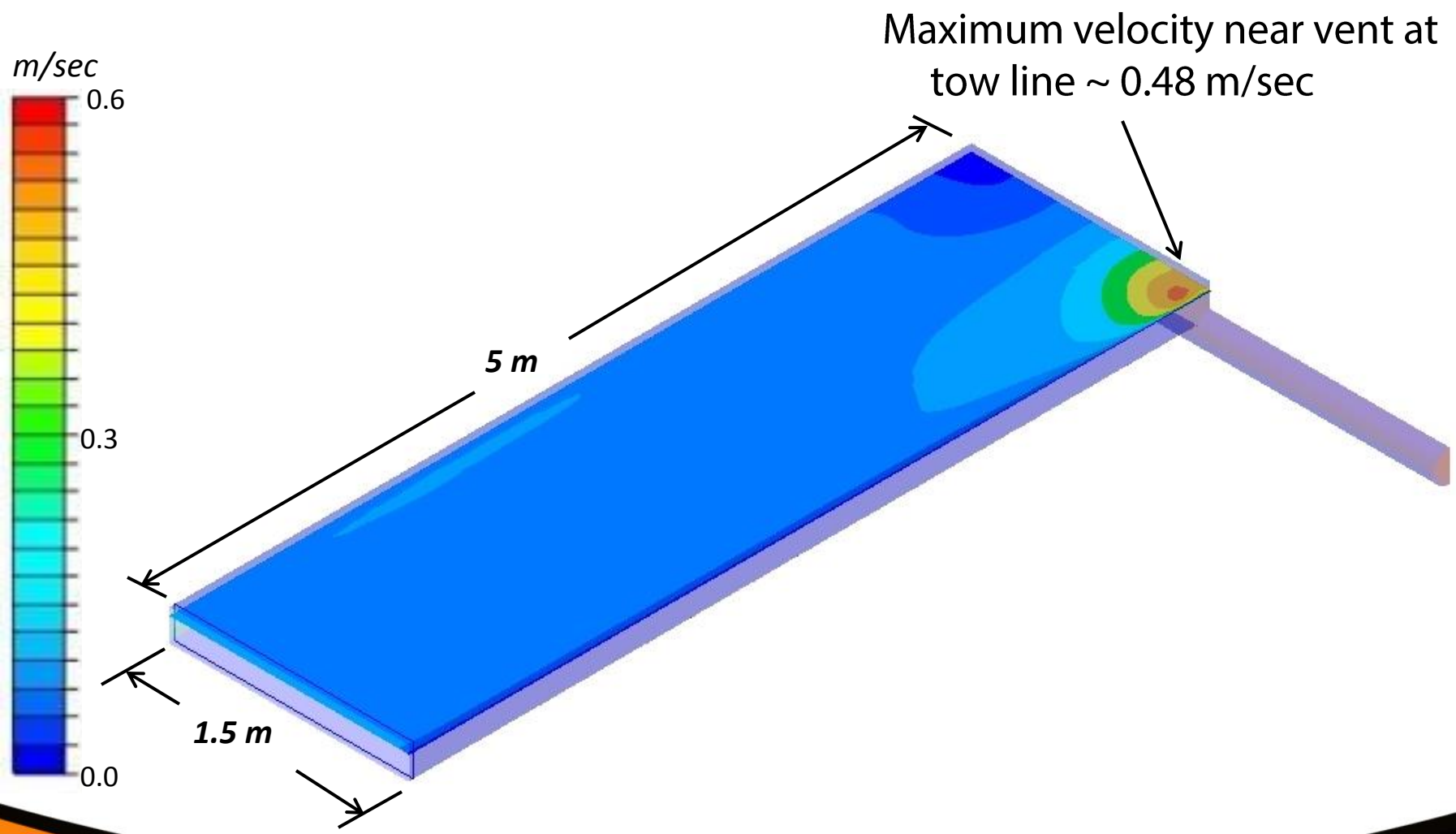
- The Restrictive Bottom Vent provides a more even draw across the muffle.



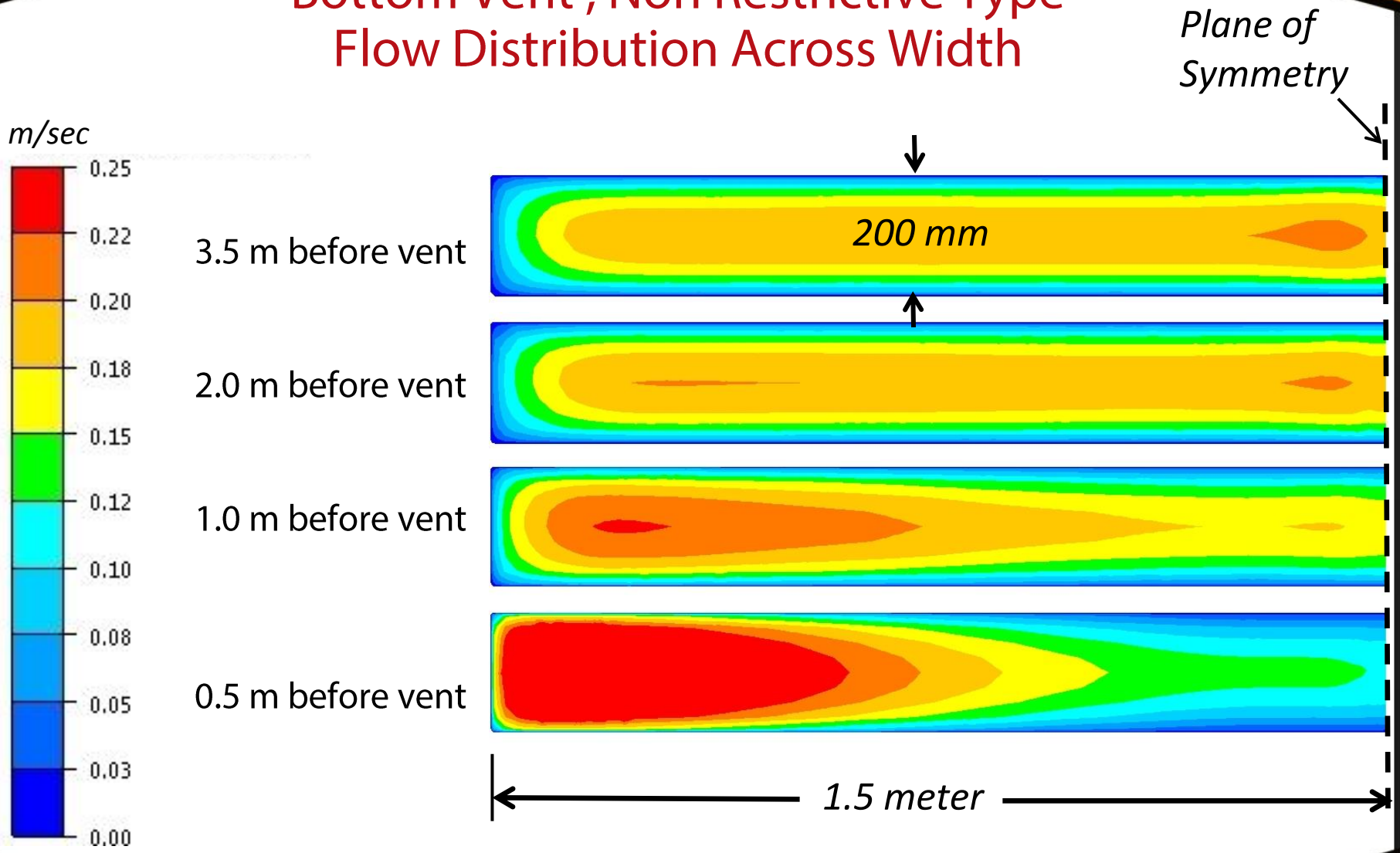
- The restriction creates a swirl pattern in the vent.



Bottom Vent, Non Restrictive Type - Velocity

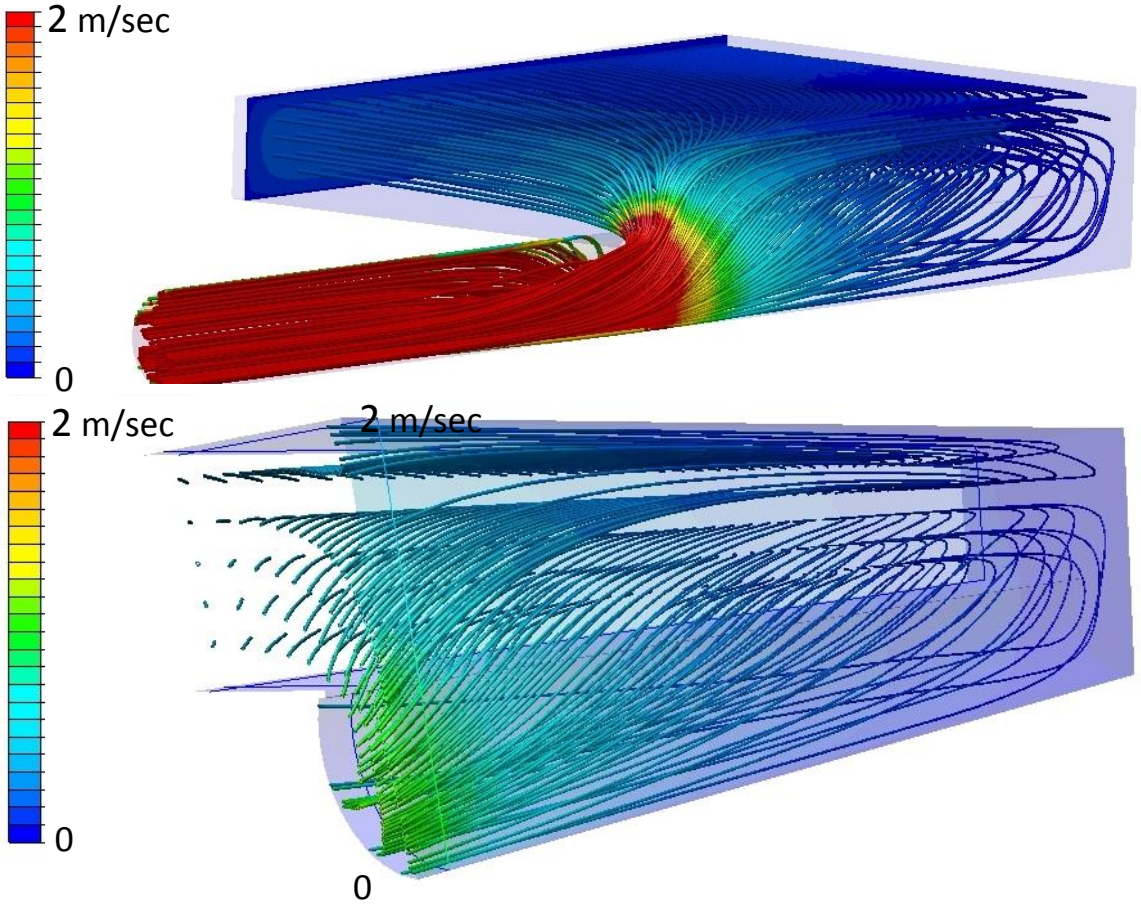


Bottom Vent , Non Restrictive Type
Flow Distribution Across Width



Bottom Vent, Non Restrictive Type - Streamlines

The Non-Restrictive Bottom Vent creates less swirl compared to the Restrictive Bottom Vent, and also has lower maximum velocity.



LT Muffle CFD Model – Results Overview

1. Flow disturbance is only significant within 1 meter of the vent position, regardless if vents draw from sides only or across the entire bottom.

2. Side vents show maximum gas velocity at the tow line of 2 m/sec that is 4X higher than either type of bottom vent.

3. Restrictive bottom vents introduce significant swirl into flow that could trap and entangle tows. This swirl is not evident in side or non-restrictive bottom vents.

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