# Dryer Computer Simulations

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USDA/CARD Drying Workshop
Worcester Polytechnic Institute in Worcester, Massachusetts

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# Agenda

- Why use CFD for dryer design/improvements?

- Case Studies
    - Gelatin dryer (improvements to dryer equipment)
    - Pistachio Roasting (assessment of operational conditions)

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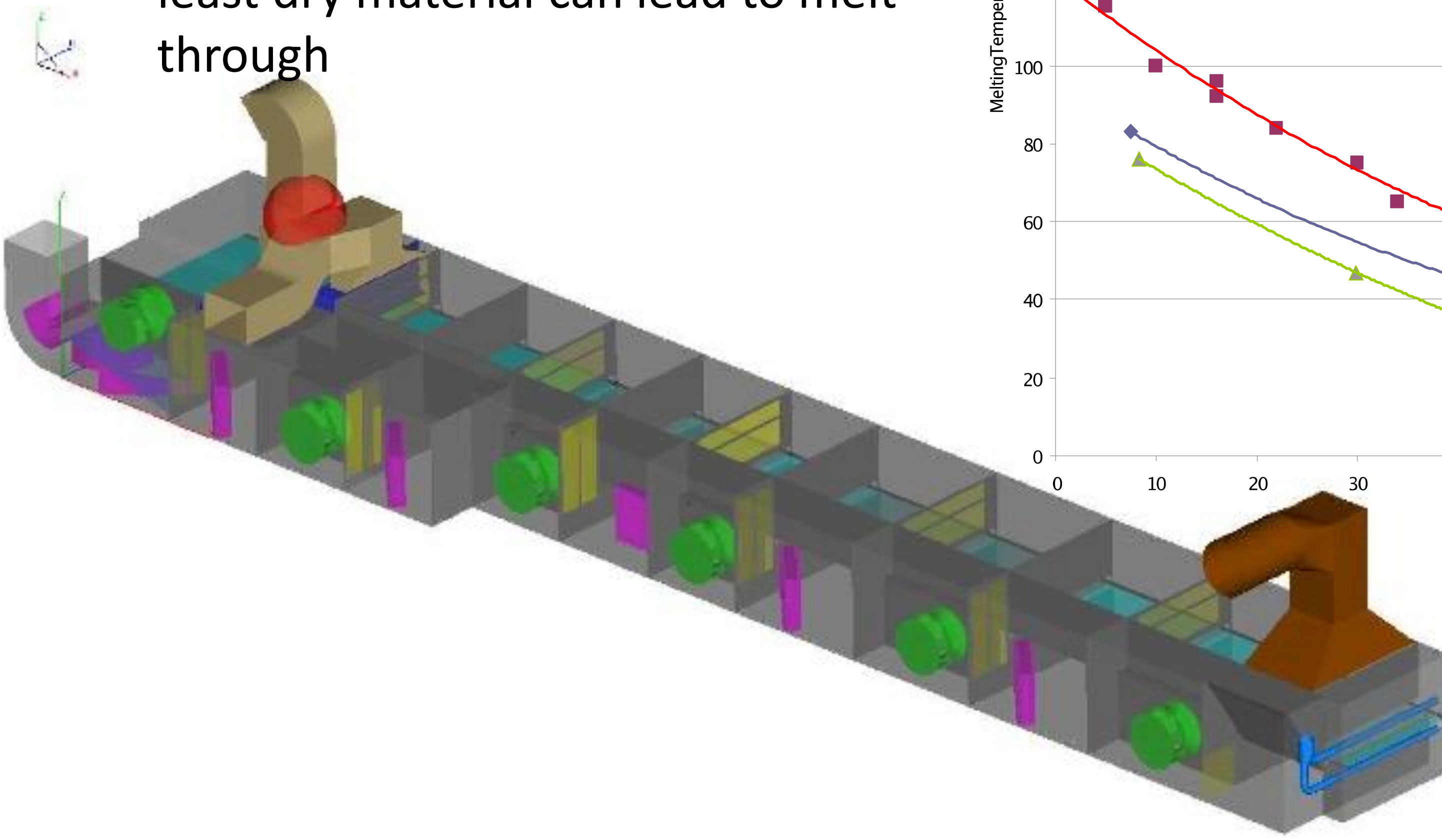
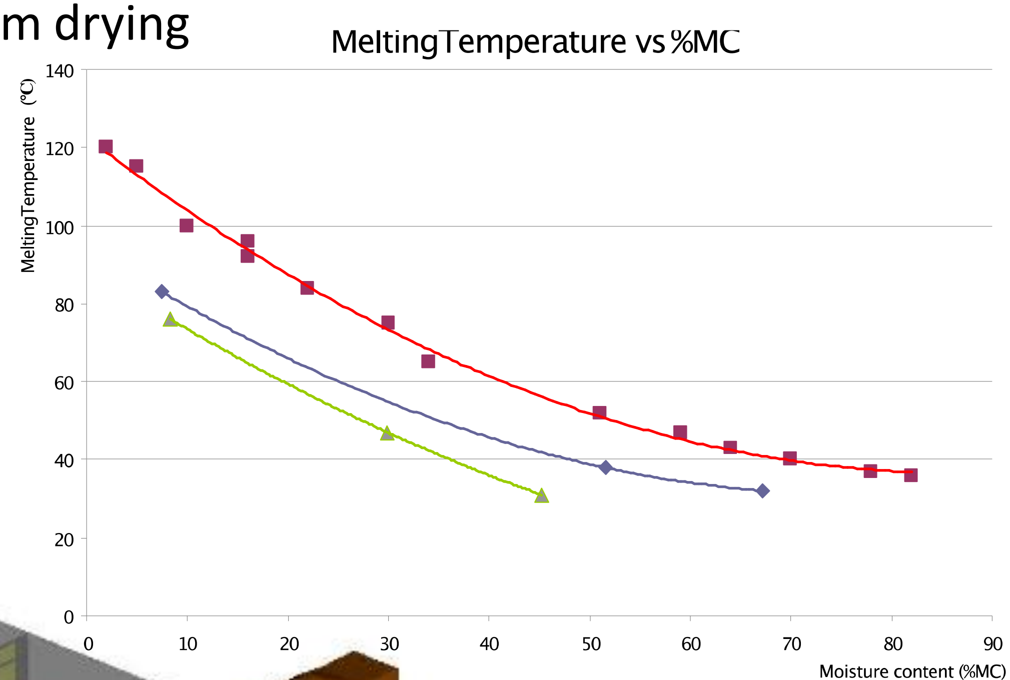
# Gelatin Drying Description/Challenges

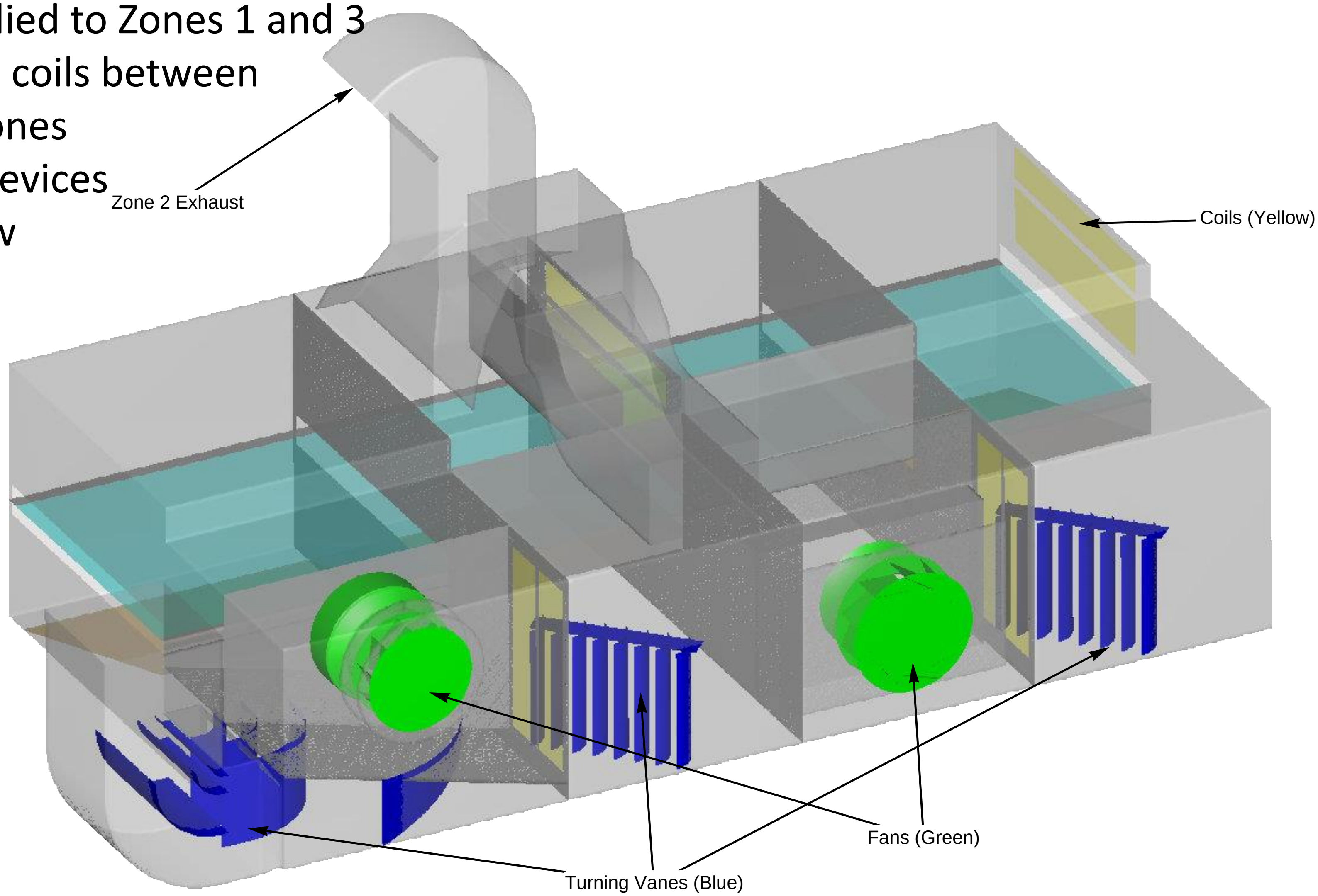
- Concentrated material extrude into "noodles" on dryer bed
- Melting temperature rises with falling moisture content
- 12 Zone dryer with cascading air flow
- Increased temperature in each successive zone
- Non-uniform flow leads to non-uniform drying
- Exceeding allowable temperature of least dry material can lead to melt through





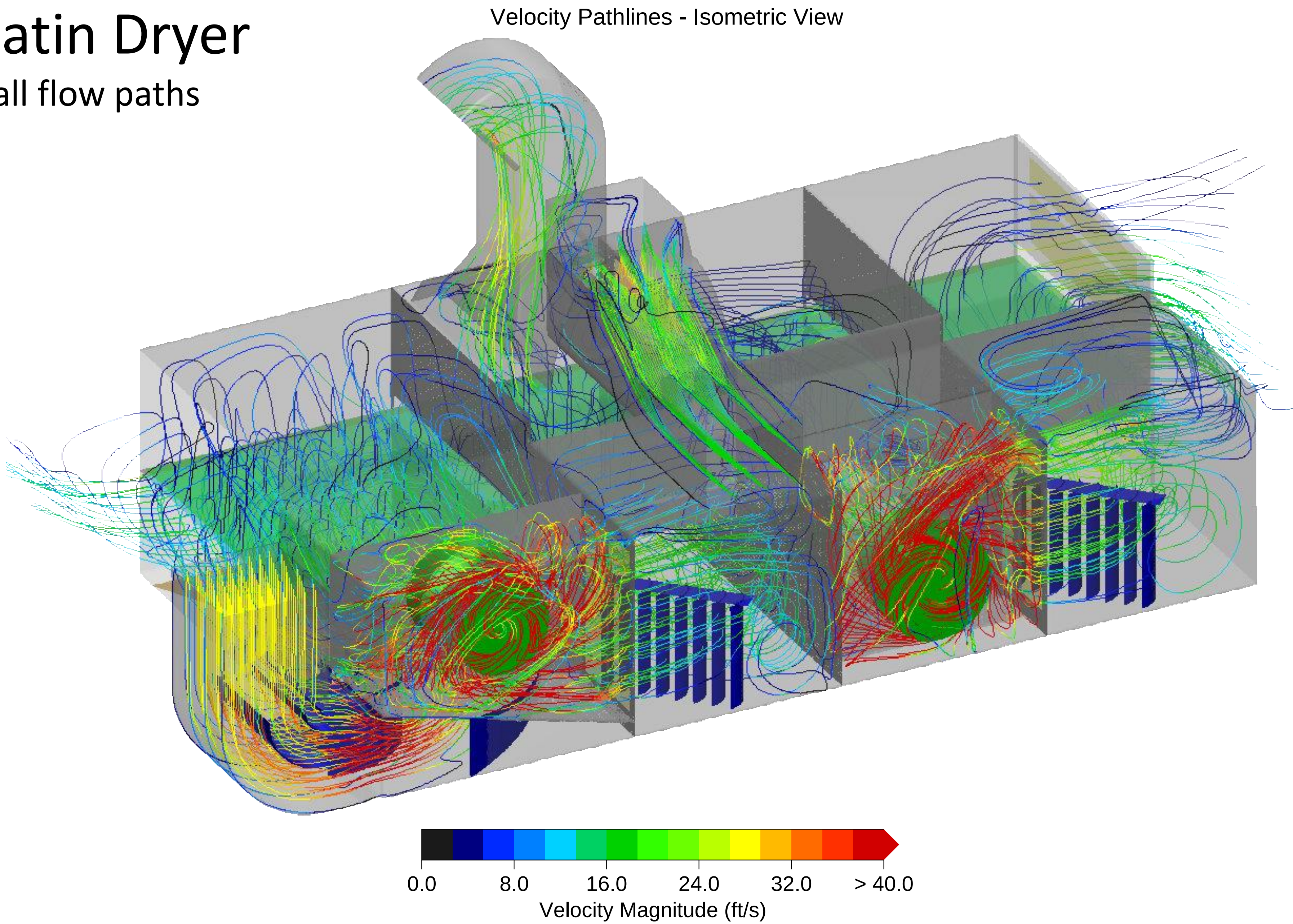
# Dryer Geometry (Zones 1-4)

- Upflow in Zones 1, 2, and 4
- Downflow in Zone 3
- Fresh air supplied to Zones 1 and 3
- Steam heating coils between each pair of zones
- Flow control devices to smooth flow



# Gelatin Dryer

## Overall flow paths

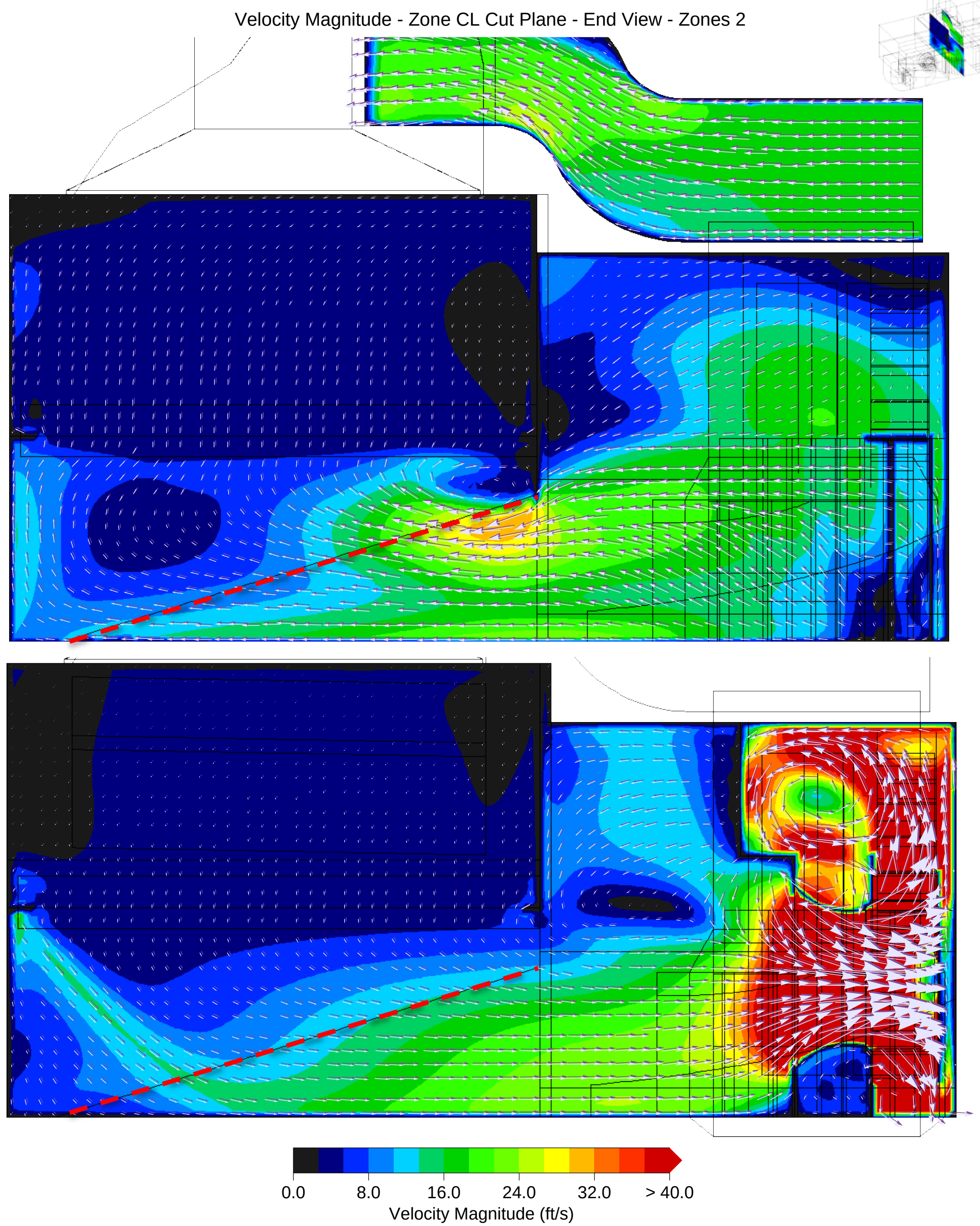


# Gelatin Dryer

In up flow zones, perforated plate is unable to smooth the flow, leading to flow non-uniformities through the gelatin

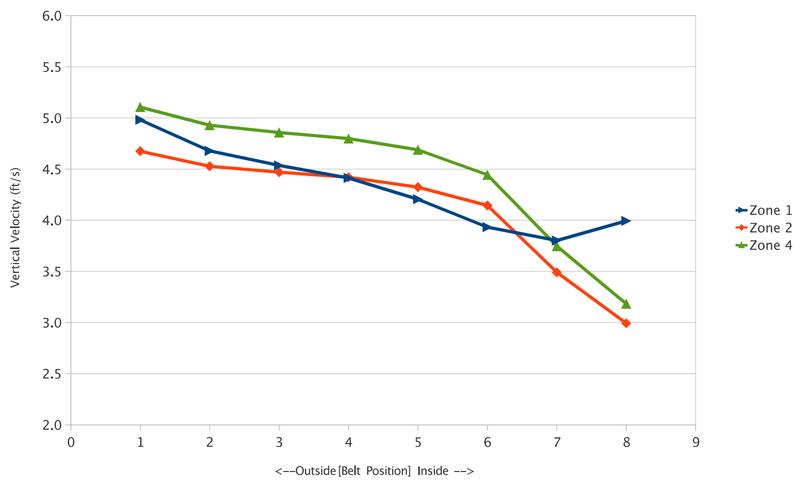
In downflow zones, the proximity of the fan causes flow to be skewed toward the fan side

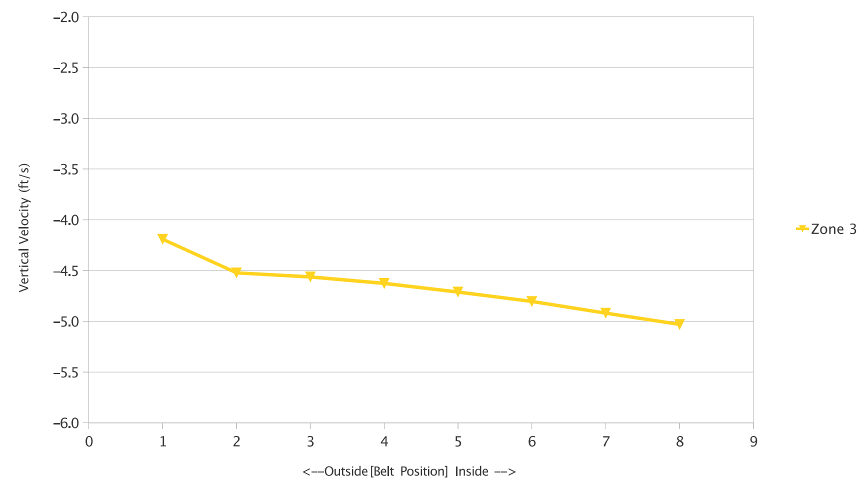
Both variations lead to non-uniform drying



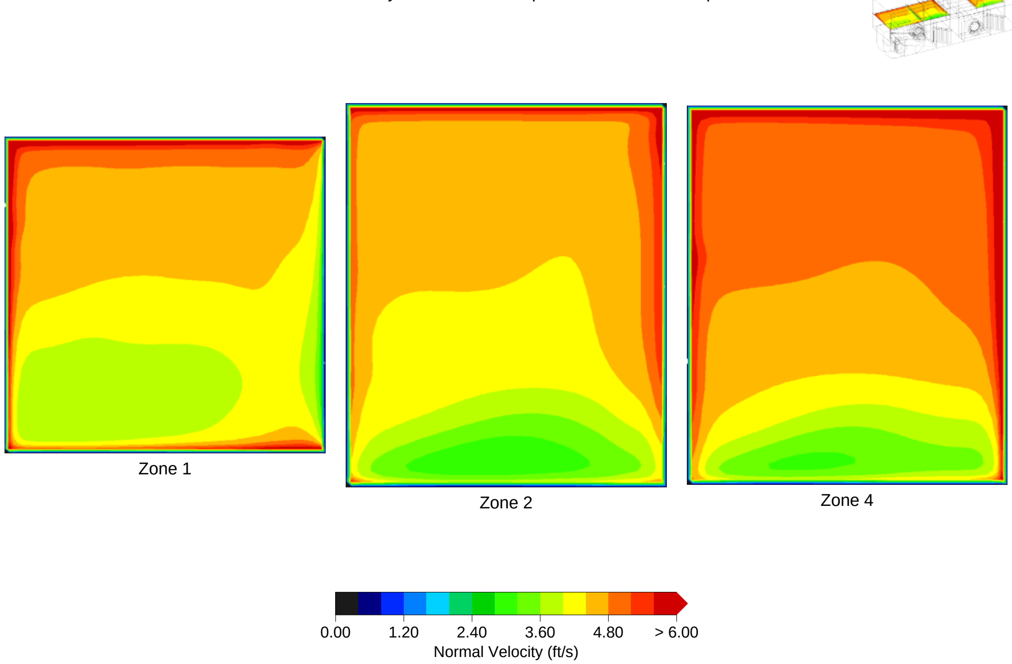
# Gelatin Dryer

## Variations in velocity through product bed

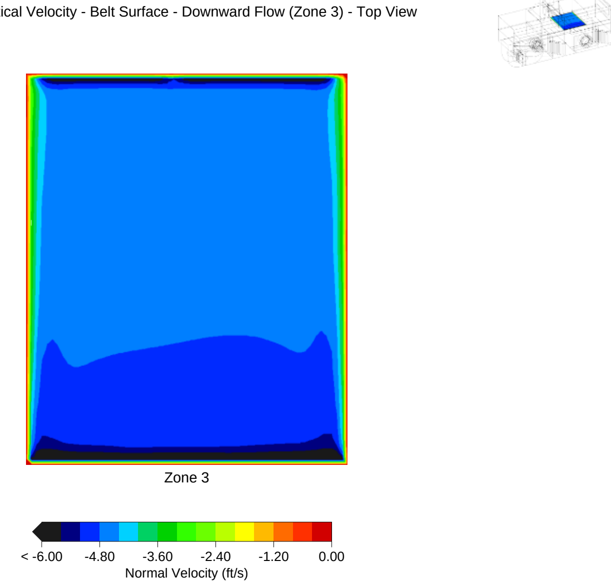



Vertical Velocity - Belt Surface - Upward Flow Zones - Top View




Vertical Velocity - Belt Surface - Downward Flow (Zone 3) - Top View

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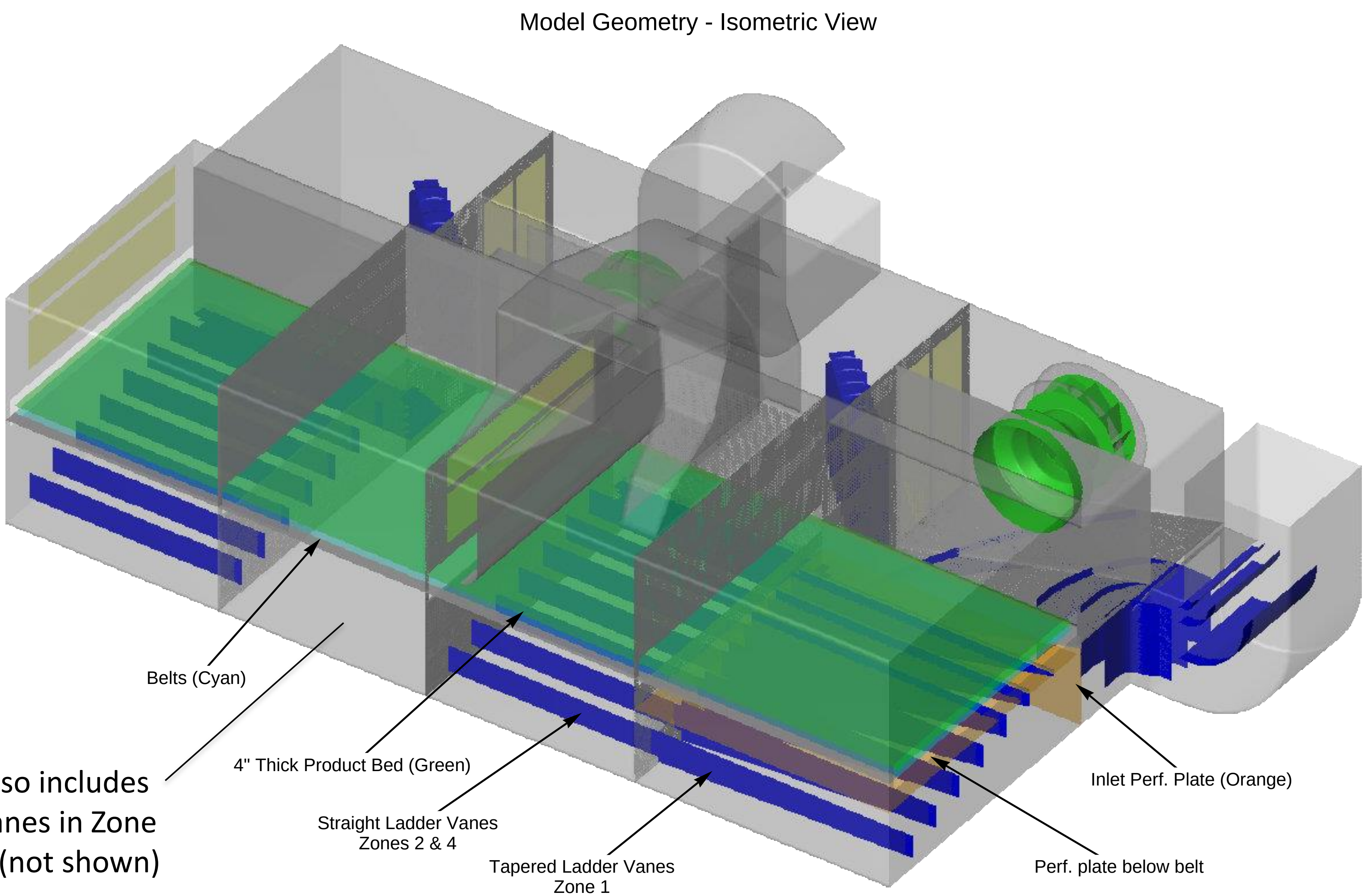
# Gelatin Dryer

## Modified Design



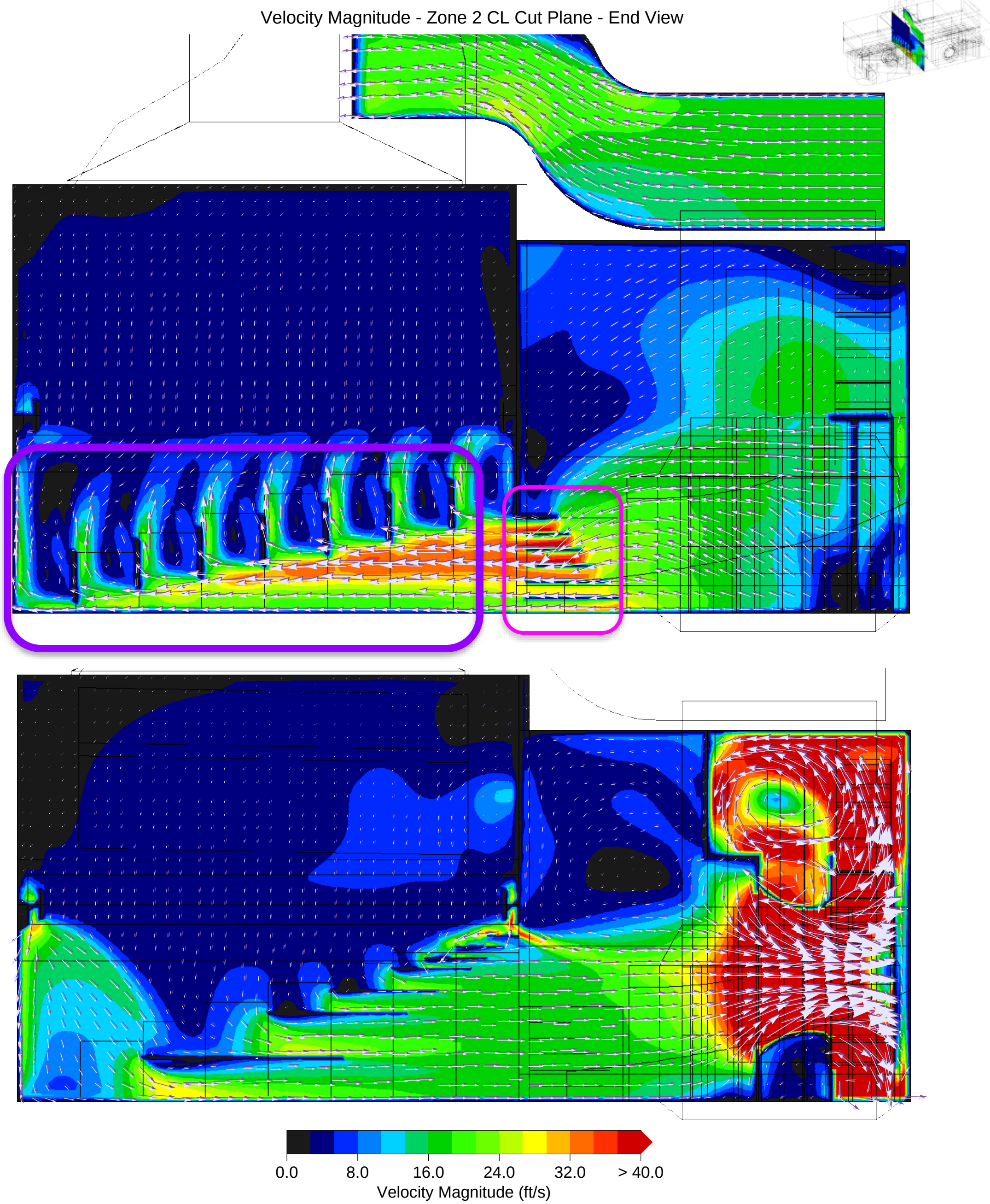

Also includes vanes in Zone 3 (not shown)

# Gelatin Dryer - Design

In upflow zones, two sets of vanes distribute the flow across the product bed:

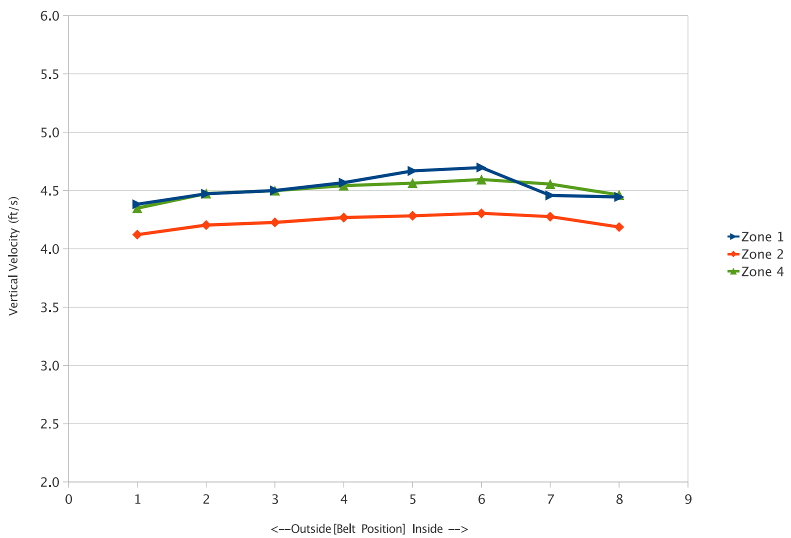
- At entrance to region under product belt
- Below product belt to turn flow upward

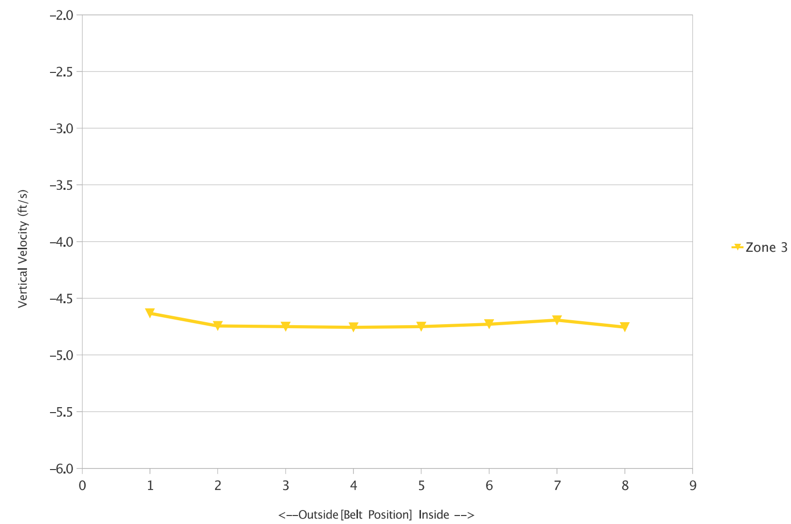
In downflow zone, one set of vanes below product belt decouples product belt from fan suction low pressure zone



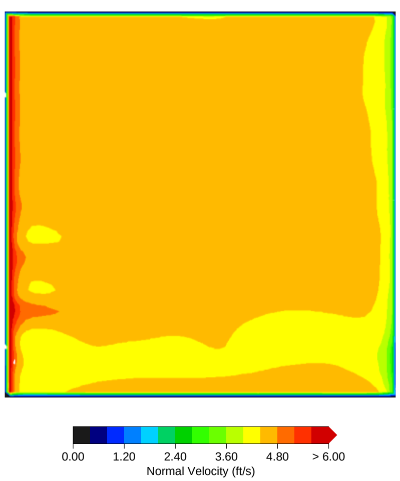
# Gelatin Dryer

## Uniformity of velocity through product bed greatly improved

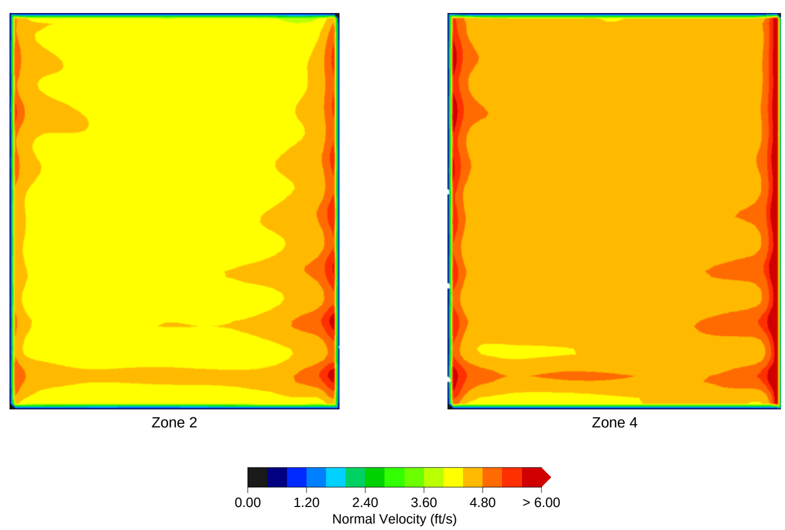


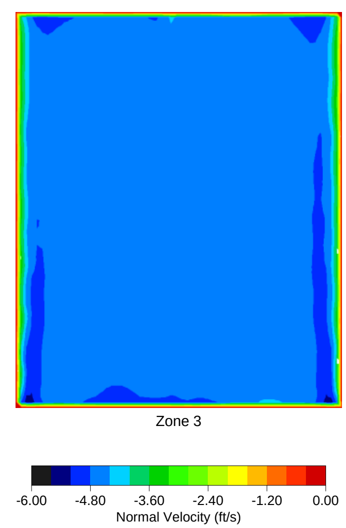

Vertical Velocity - Belt Surface - Zone 1 - Top View




Vertical Velocity - Belt Surface - Zones 2 & 4 - Top View




Vertical Velocity - Belt Surface - Downward Flow (Zone 3) - Top View



# Impact of Design Modifications

- Due to velocity variations and resultant drying variations, operational points had to be set to accommodate the *slowest* drying portion of the product bed.
- This led to the dryer being the slowest unit operation on the production line, limiting overall production rate.
- Following installation of the recommended modifications, the dryer became this fastest unit operation, increasing overall production.
- Other plant operations could then be improved to take advantage of the increased capacity of the dryer.

# Pistachio Roasting Goals

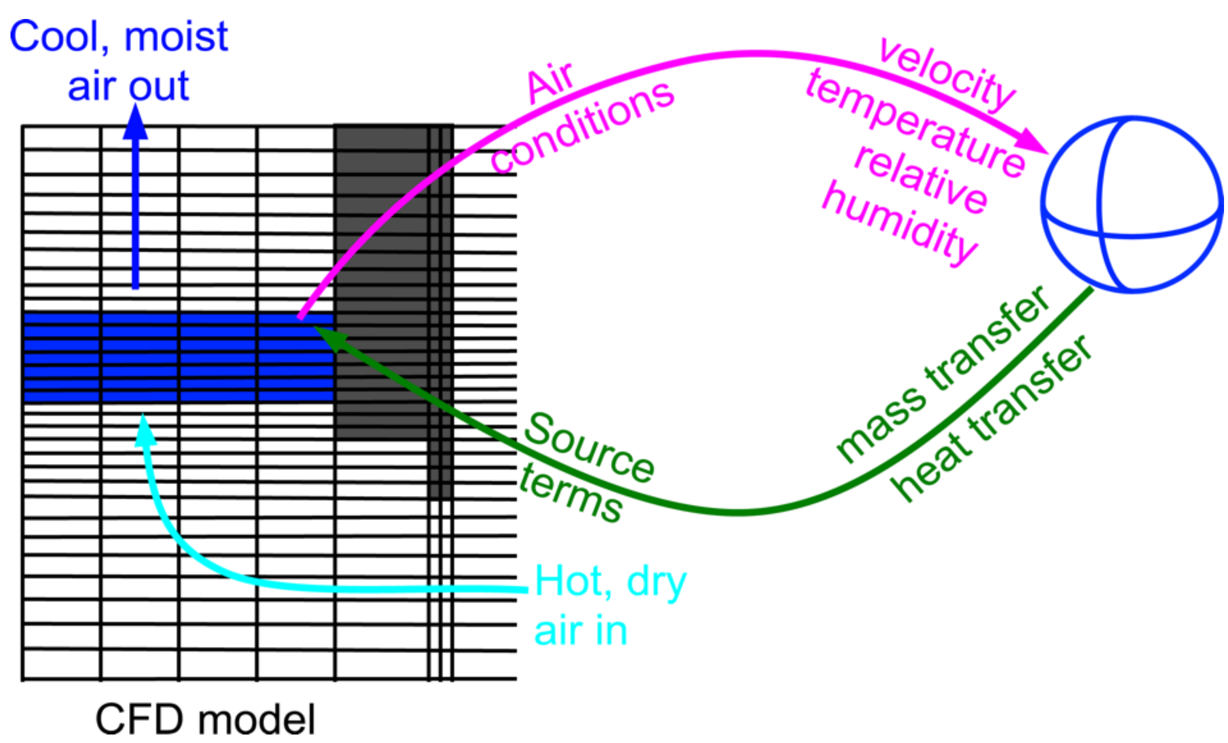
- Reduce moisture content
- Pasteurize nuts
- Maintain desirable color and texture

# Roasting Process

- Nuts are brined and the loaded into a bed dryer
- Three zones (downflow, upflow, upflow)
- Independent temperature control for Zones 1 and 2
- Zone three for cooling
- Deep bed
- Control over residence time

# Multi-Scale Modeling Approach

- Scale of process equipment is much larger than product being processed
- Information desired on both large and small scales
- Allows resolution of variations across equipment and within product
- Interaction between product and equipment is fully coupled

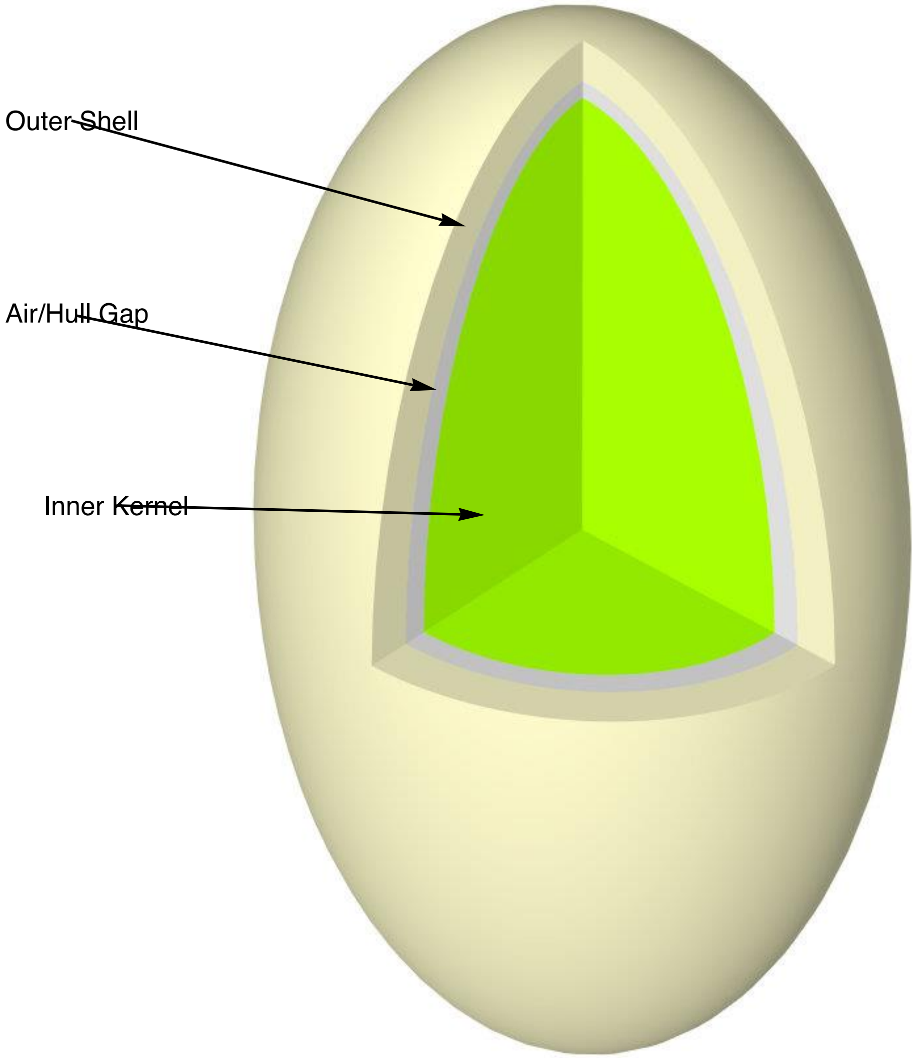



- Each cell in the CFD model that contains product includes a separate product model
- Heat and mass are exchanged between process air and product
- Product impacts air properties at downstream locations
- Motion of the product through dryer domain can be included

# Product Model

- Three basic geometries
  - Sphere
  - Rod
  - Plate
- 1-D shell model used (lumped capacity model also possible)
- Each shell has its own thermal properties
- Temperature, moisture content, and other parameters tracked for each shell layer

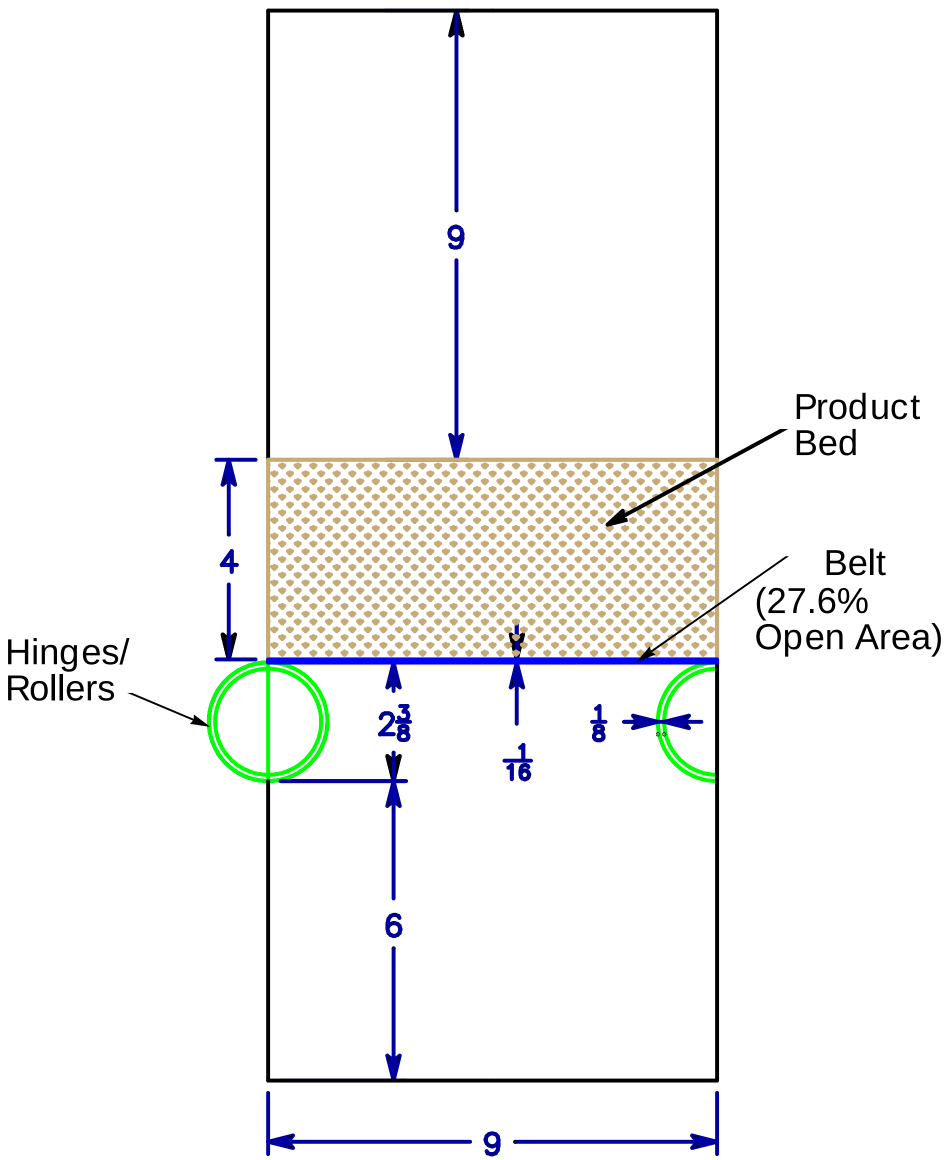
Pistachio Nut Conceptual Model



# Simulation Overview

- Deep product bed promotes flow uniformity
- Temperature/flow variations not considered/included
- Model reduced to one section of belt
- Follow product through dryer with transient simulation
- Product bed represented as porous zone

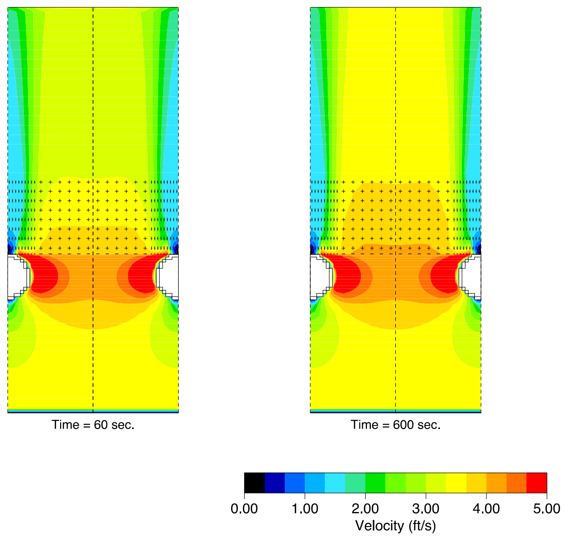
Model Geometry



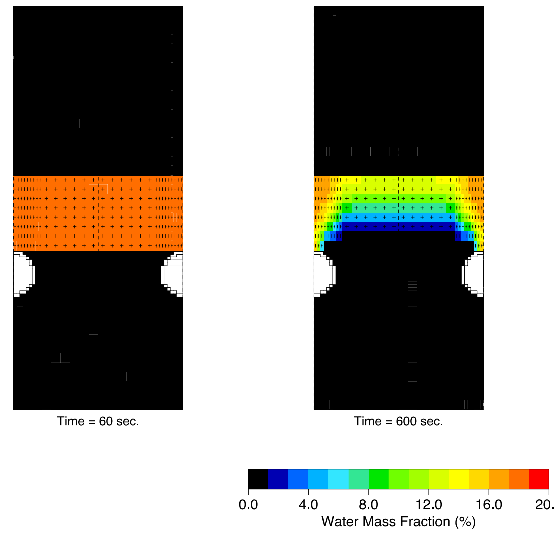
# Pistachio Roasting

## Test condition simulation results – Zone 1 (upflow)

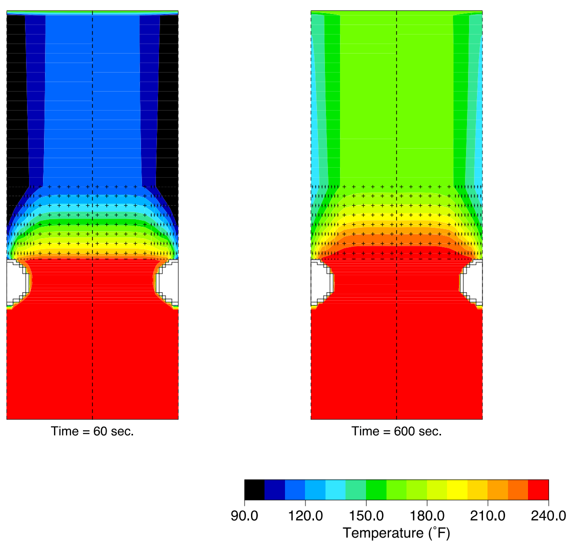
Velocity Magnitude - Zone 1



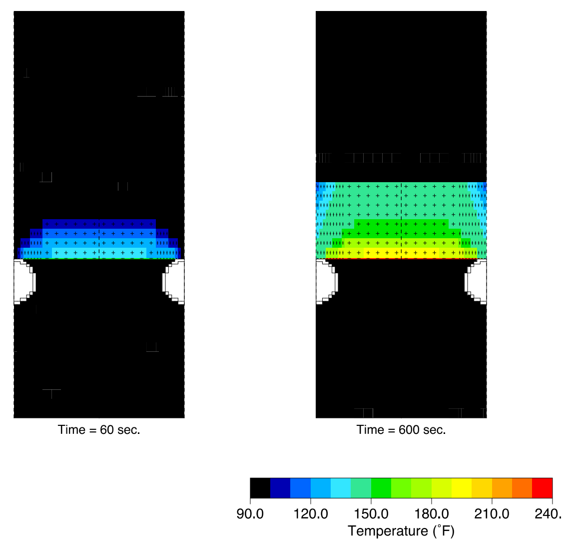

Average Nut Water Mass Fraction - Zone 1




Air Temperature - Zone 1



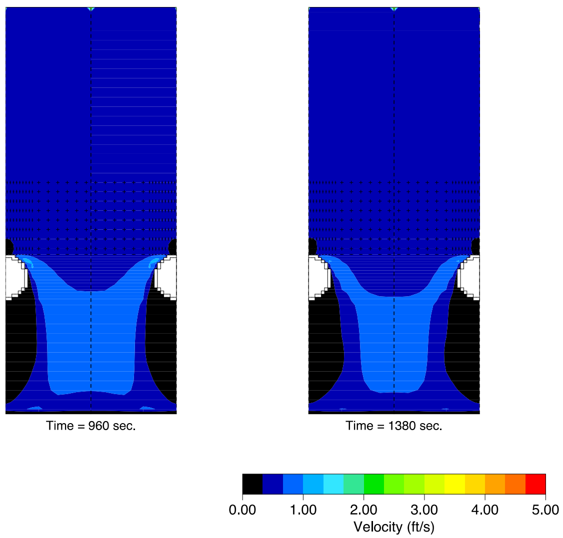

Average Nut Temperature - Zone 1



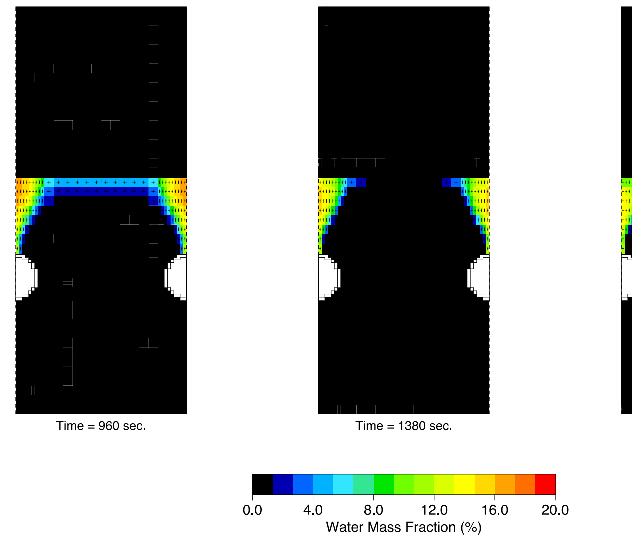
# Pistachio Roasting

## Test condition simulation results – Zone 2 (downflow)

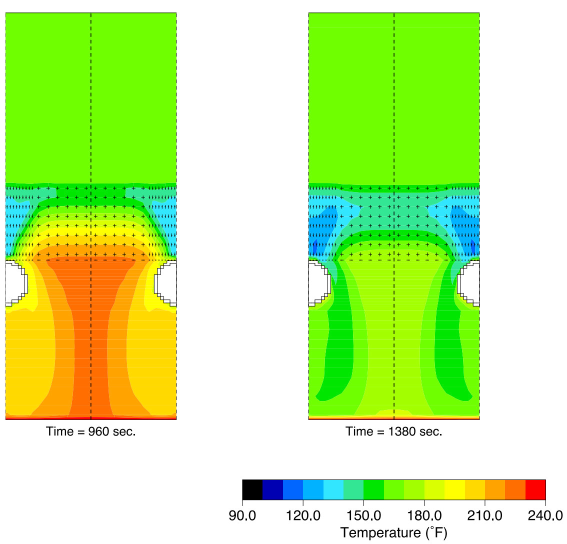
Velocity Magnitude - Zone 2



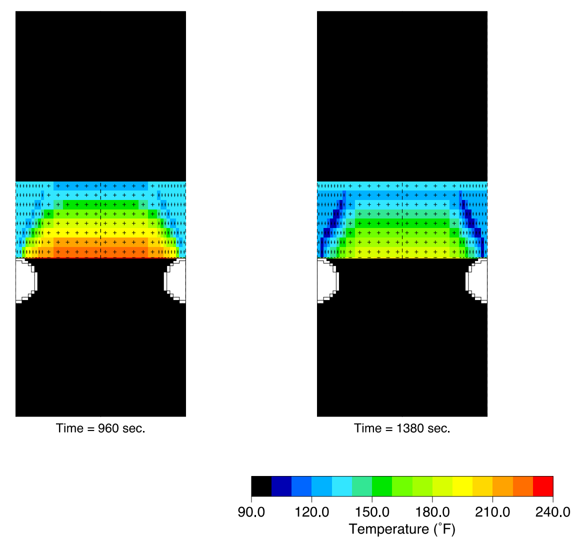

Average Nut Water Mass Fraction - Zone 2




Air Temperature - Zone 2

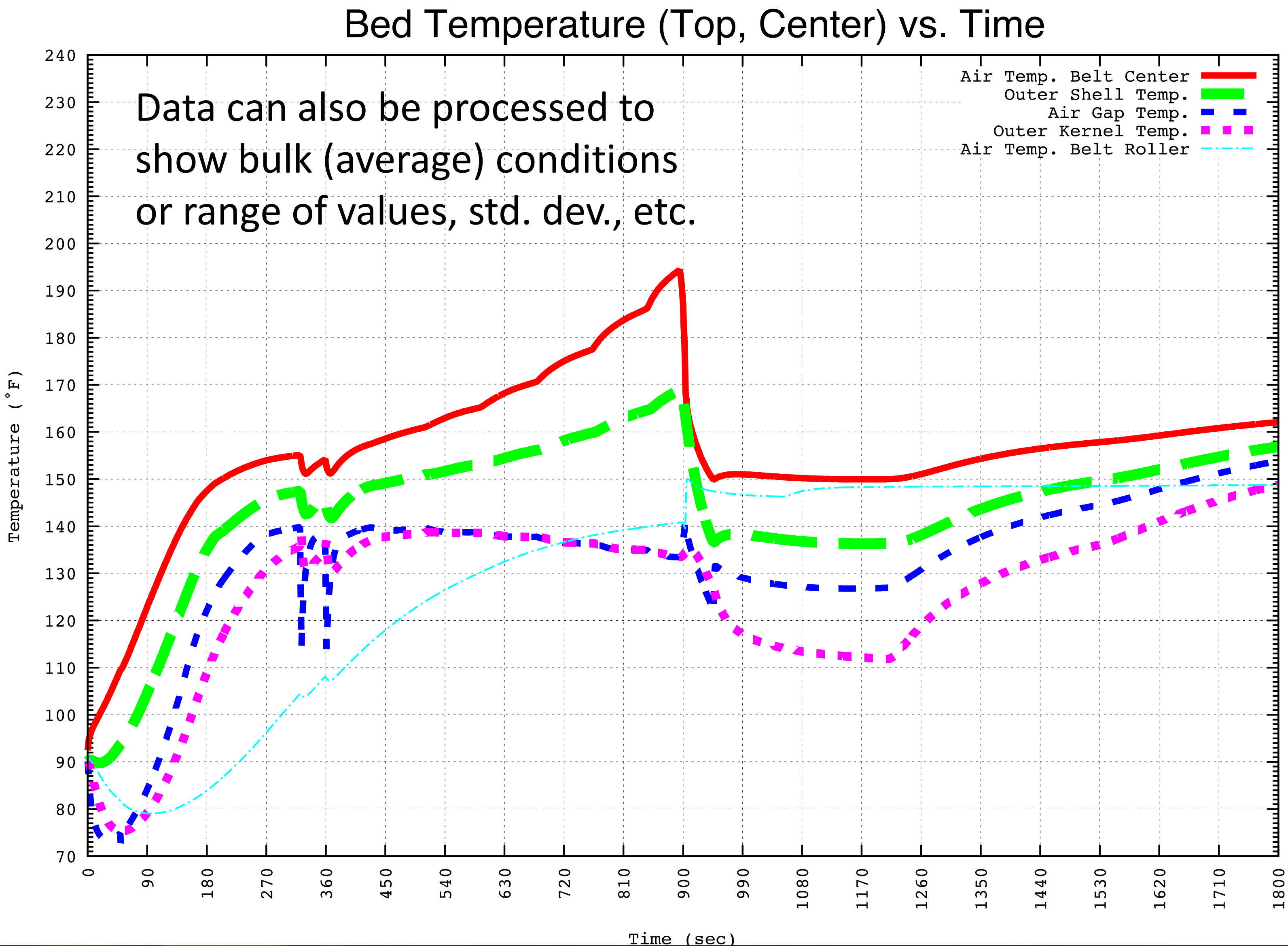



Average Nut Temperature - Zone 2



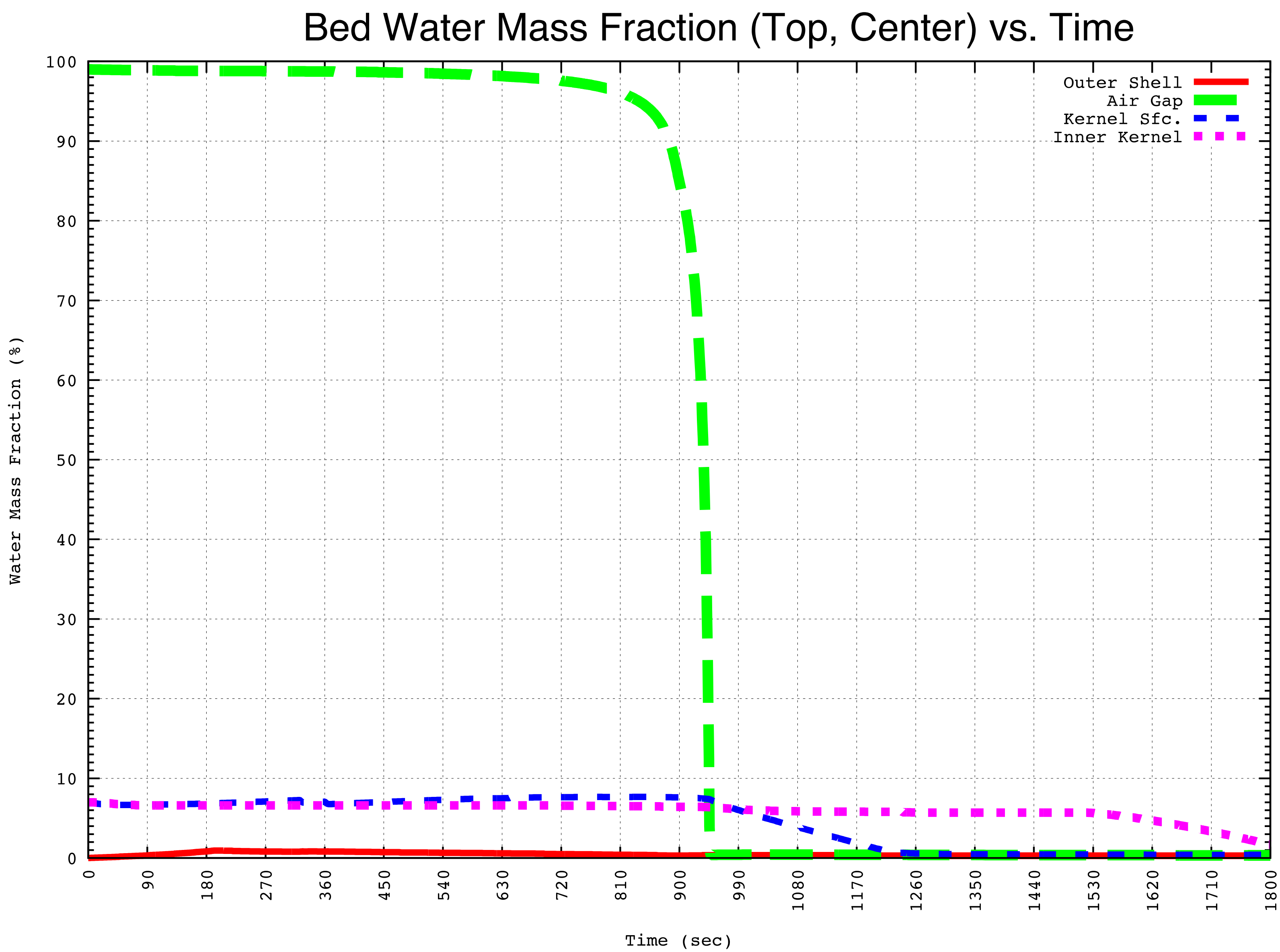
# Pistachio Roasting

Test condition simulation results



# Pistachio Roasting

## Test condition simulation results



# Modeling Pasteurization

*Journal of Applied Microbiology* 2005, **98,** 406–417 doi:10.1111/j.1365-2672.2004.02487.x

**Generating microbial survival curves during thermal processing in real time**

**M. Peleg, M.D. Normand and M.G. Corradini**

*Department of Food Science, Chenoweth Laboratory, University of Massachusetts, Amherst, MA, USA*

2004/0520: received 7 May 2004, revised 5 August 2004 and accepted 24 August 2004

$$\log_{10} S(t) = -b(T)\,t^{n(T)}$$

$$b(T) = \log\left[1 + e^{(T-90)/10}\right]$$

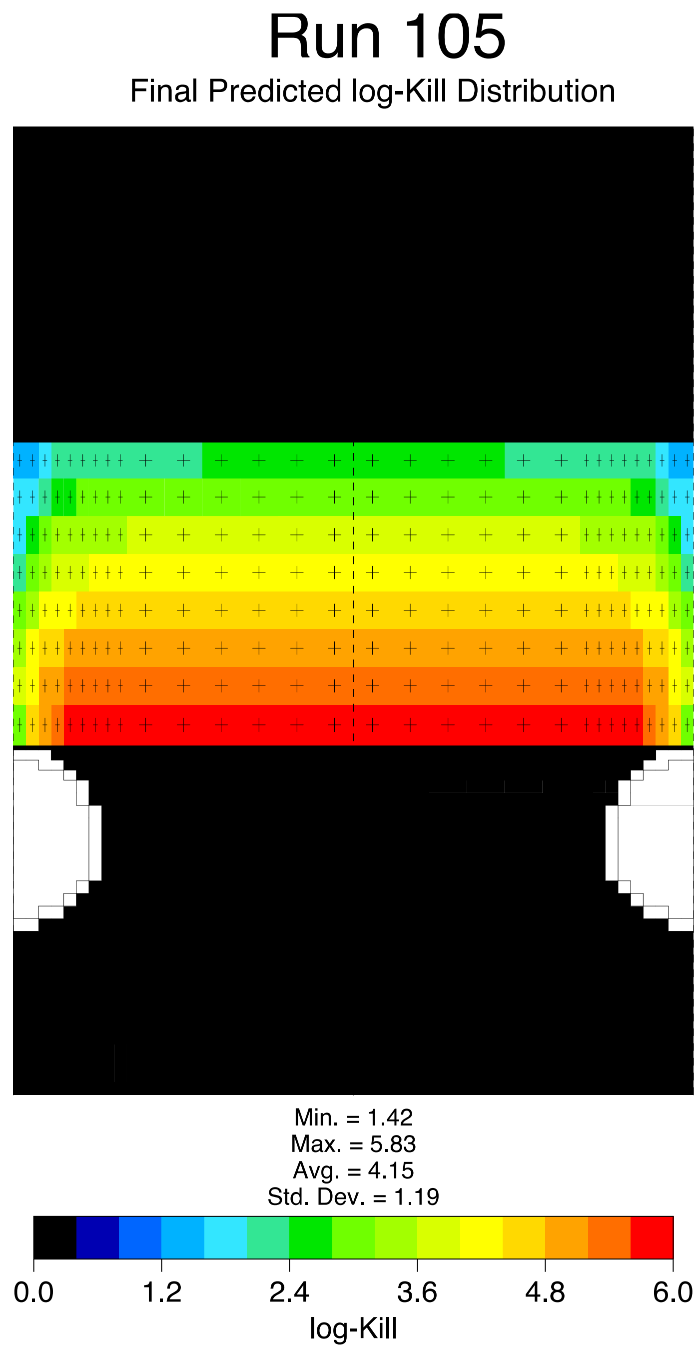
$$n(T) = 0.7/\left[1 + e^{(T-100)/10}\right]$$

Using research of Peleg, the simulation results are used to estimate the log-kill for pathogens

Equations for b(T) and n(T) fit based on challenge test data

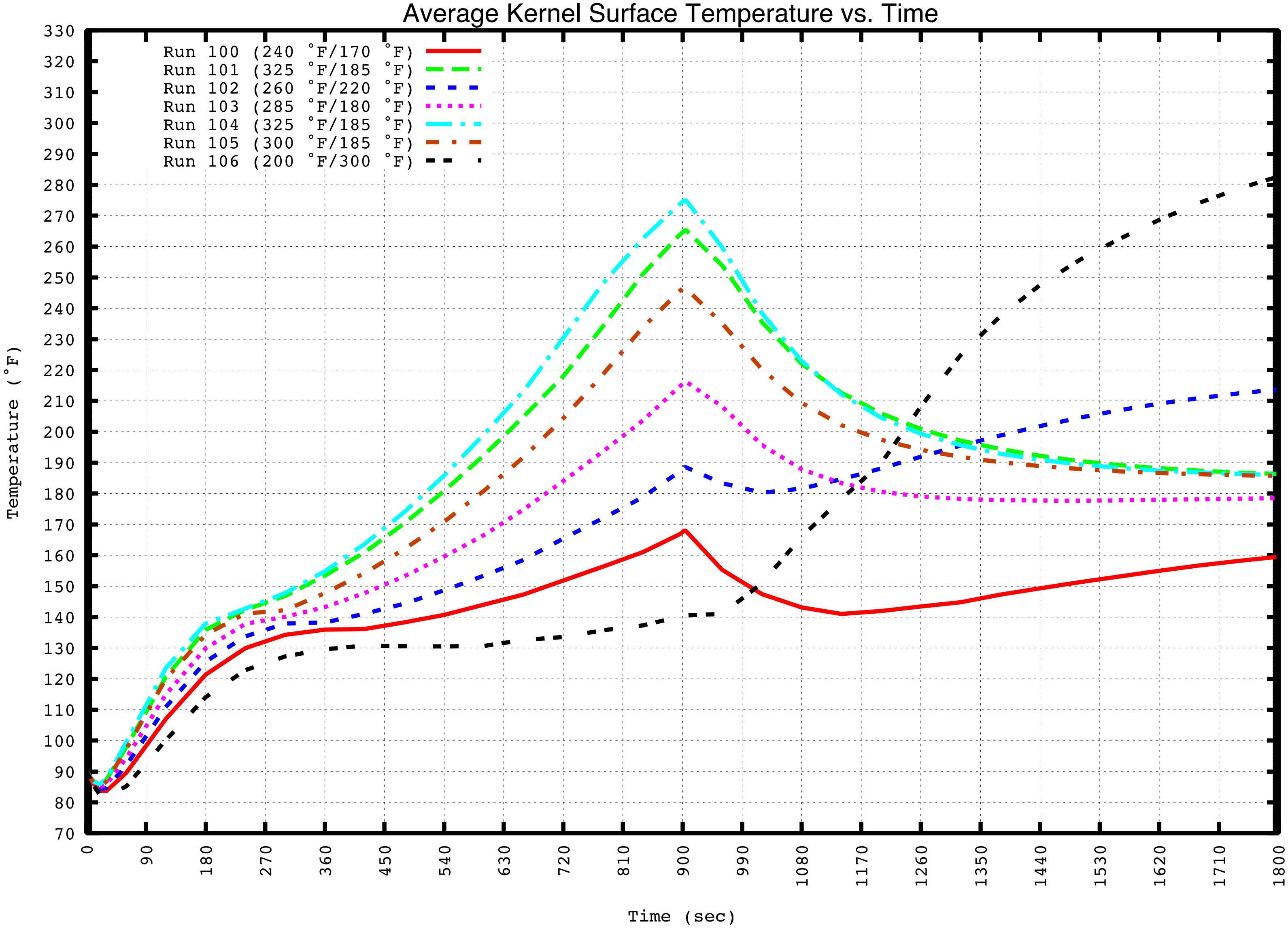
# Pasteurization Results

- Time temperature history of each location within dryer applied to equation to determine log-kill
- Due to variation in processing conditions, effectiveness varies
- Model can be used to assess different operating conditions

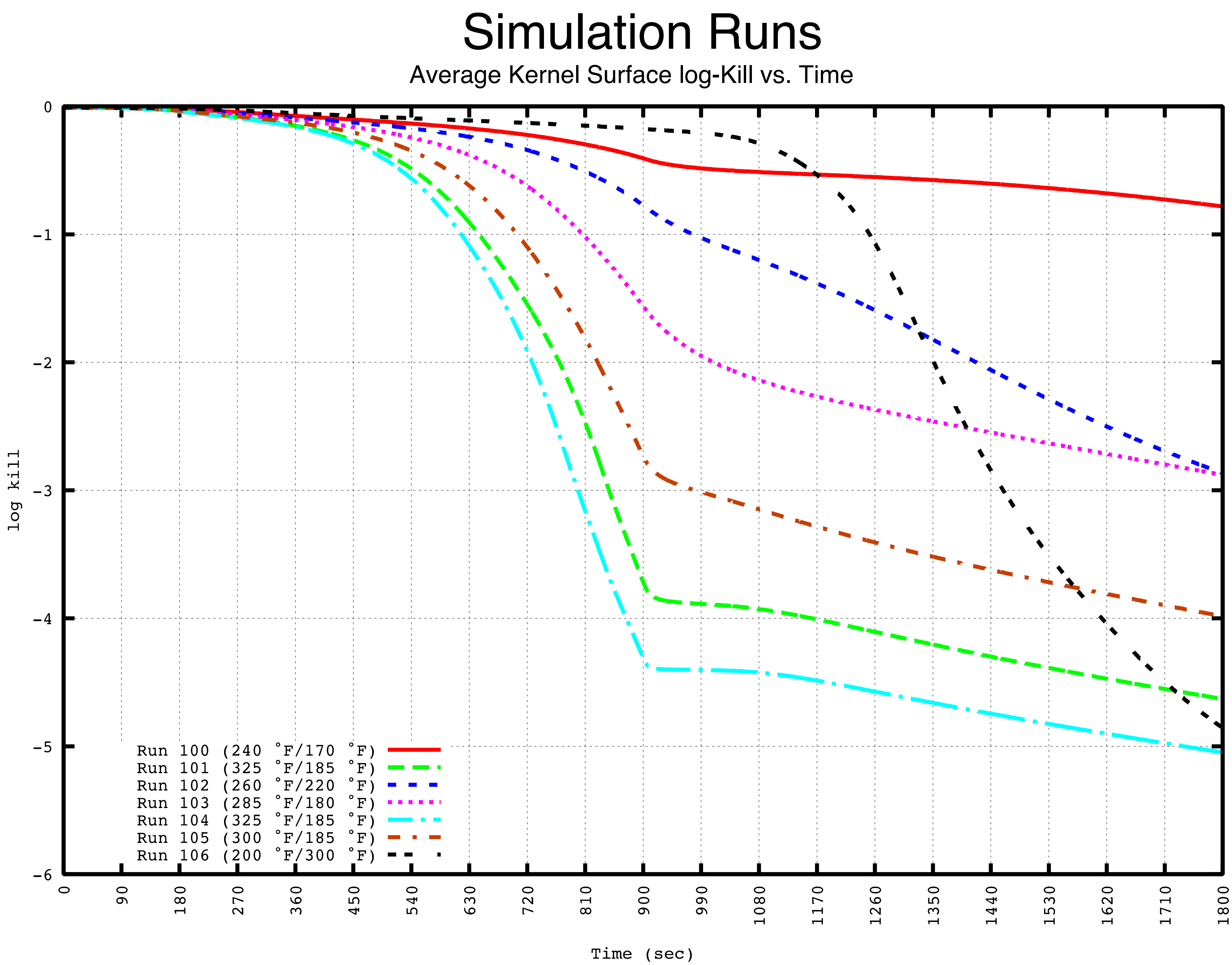


# Effect of Zone Temperatures on Pasteurization

## Simulation Runs



# Effect of Zone Temperatures on Pasteurization



# Multi-Scale Modeling Summary

There are several advantages combining models of both product and equipment into one simulation

- The interactions between the equipment and the product are revealed (real world conditions)
- Product variations that result from equipment design are identified and quantified
- The effect of changes to operating conditions can be evaluated
- The product model can be expanded to assess changes beyond temperature and moisture (pasteurization, browning, case-hardening, etc.)

# Questions?

For more information contact:

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