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DALHOUSIE UNIVERSITY
mechanical engineering

Lab of Applied MultiPhase Thermal Engineering

Solid-Liquid Phase Change Simulation Applied to a Cylindrical Latent Heat Energy Storage System

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“Thermal energy storage (TES) is considered as *one of the most crucial energy technologies*”[§]

[§] I. Dincer, Thermal energy storage systems as a key technology in energy conversion, *Int. J. of Energy Res.*, **26**, 567–588 (2002)

Thermal Energy Storage

- **Sensible Heat Storage:**

  A heat storage system that uses a heat storage medium, and where the addition or removal of heat results in a change in temperature

- **Thermochemical Storage:**

  Storage of energy is the result of a chemical reaction

- **Latent Heat Storage:**

  The storage of energy is the result of the phase change (solid-liquid or solid-solid) of a phase change material (PCM). The process happening over a small temperature range.

Latent Heat Energy Storage Systems (LHESS)

- HVAC Systems
- Solar Thermal System
- Food Preservation
- Protection of Electronic Components

Problematic

- The main problem with using phase change materials in LHESS is their typical low thermal conductivity, which results in an increase in time for the charging (melting) and discharging (solidifying) process

- Example: $k_{PARAFFIN} = 0.21\ W/m \cdot K$
  $k_{COPPER} = 400\ W/m \cdot K$

  A factor of ~ 2000

Objectives

- Explore new ways of enhancing the apparent heat transfer properties of the PCM inside a LHESS from a geometric, or system, point of view; by properly designing the system so that it offers optimized surface areas for heat transfer;

  - Study the effects of the addition of fins in a cylindrical storage device:
    - on the overall rate of energy storage;
    - on the heat transfer rates in the system;

    in order to optimize the phase change process (melting) encountered in the phase change material (PCM);

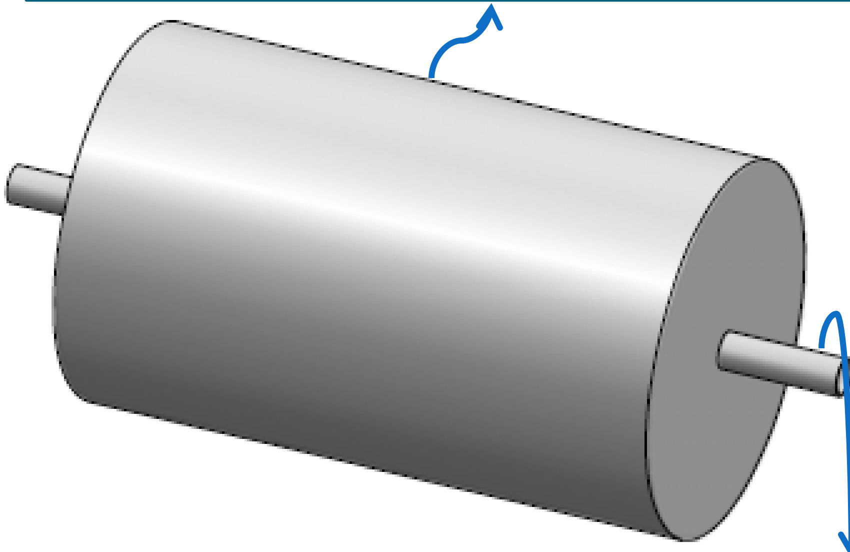
  - To use the finite element method to simulate the phase change process encountered in the PCM;

Geometry Studied

- Geometry & Fins

LHESS Geometry

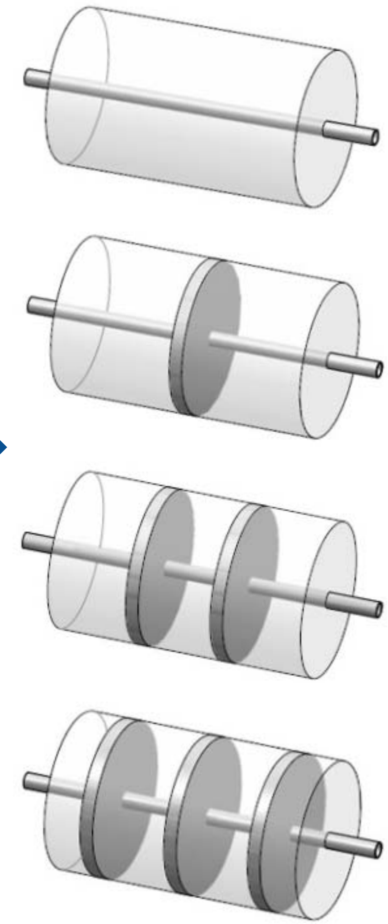
Cylindrical Storage Compartment
Length = 1 m
Outside Diameter = 0.6 m
Insulation Thickness = 10 mm



Copper Pipe:
Length = 1.4 m
Outside Diameter = 60 mm
Thickness = 3 mm

Introduction of fins

Fin thickness = 5 mm



Numerical Modeling

- Cylindrical LHESS

Modeling in COMSOL

- Problem type: Transient thermal fluid*

- Model used: Fluid-Thermal Incompressible Flow
  ↳ Transient Analysis

  This model encompasses:
    - Incompressible Navier-Stokes;
    - Heat transfer by conduction and convection.
      ↳ Convection is neglected in the liquid phase of the PCM

- Geometry is considered 2D axial symmetry

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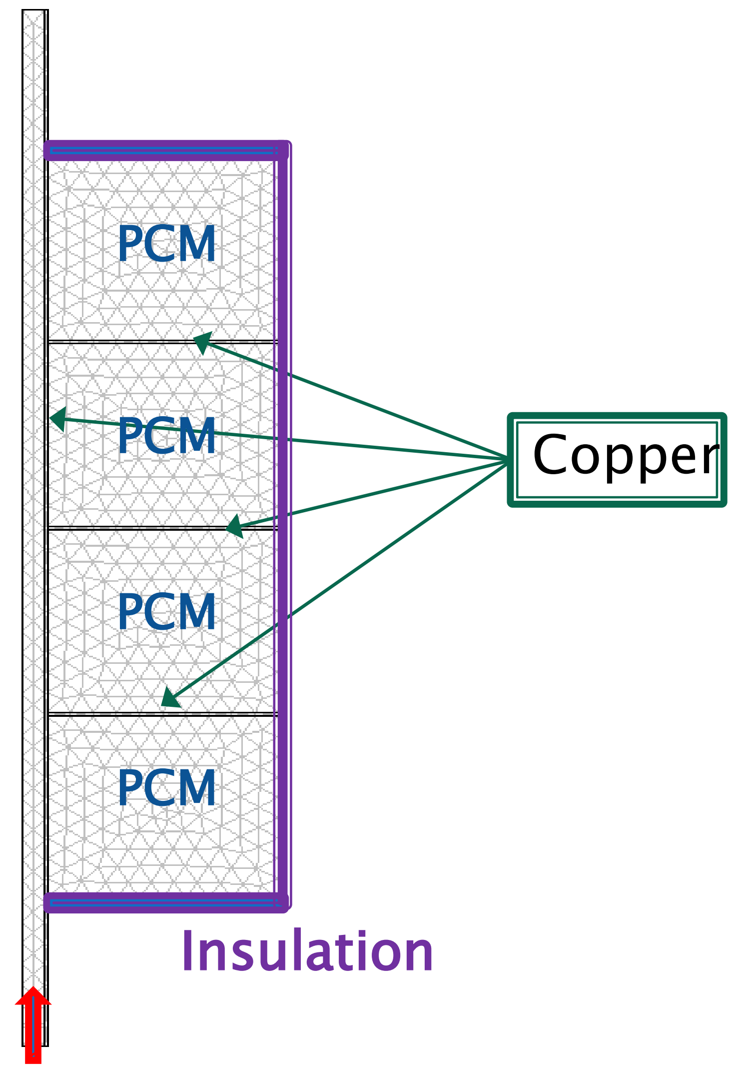
* The treatment of phase change renders the problem non-linear as well.

2D Axial Symmetry Model

Element size : 27mm
Element Type : Triangular

Simulation Time :
12hours

Maximum energy
storage capacity:
~ 44 MJ



Boundary Conditions

Fluid Flow	
Pipe Inlet Velocity	0.01 to 1 m/s
Pipe Outlet Condition	No viscous stress $P_0 = 0$
Pipe Wall Condition	No slip

Thermal	
Initial Temperature	293 K
Pipe Inlet Temperature	350 K
Pipe Outlet Condition	Convective heat flux
Interior Boundary Condition	Continuity
Outer Surface	Thermal Insulation

Phase Change

$$C_p = \begin{cases} C_{p,s} & T < 313\ K \\ C_{p,m} & 313\ K < T < 316\ K \\ C_{p,l} & T > 316\ K \end{cases}$$

Where

$$C_{p,m} = \frac{L}{(\Delta T_m)} + \frac{(C_{p,s} + C_{p,l})}{2}$$

$C_{p,m}$ = Effective C_P
= 60.5 kJ/kg

$C_{p,s}$ = Solid phase C_P
= 2.5 kJ/kg

$C_{p,l}$ = Liquid phase C_P
= 2.5 kJ/kg

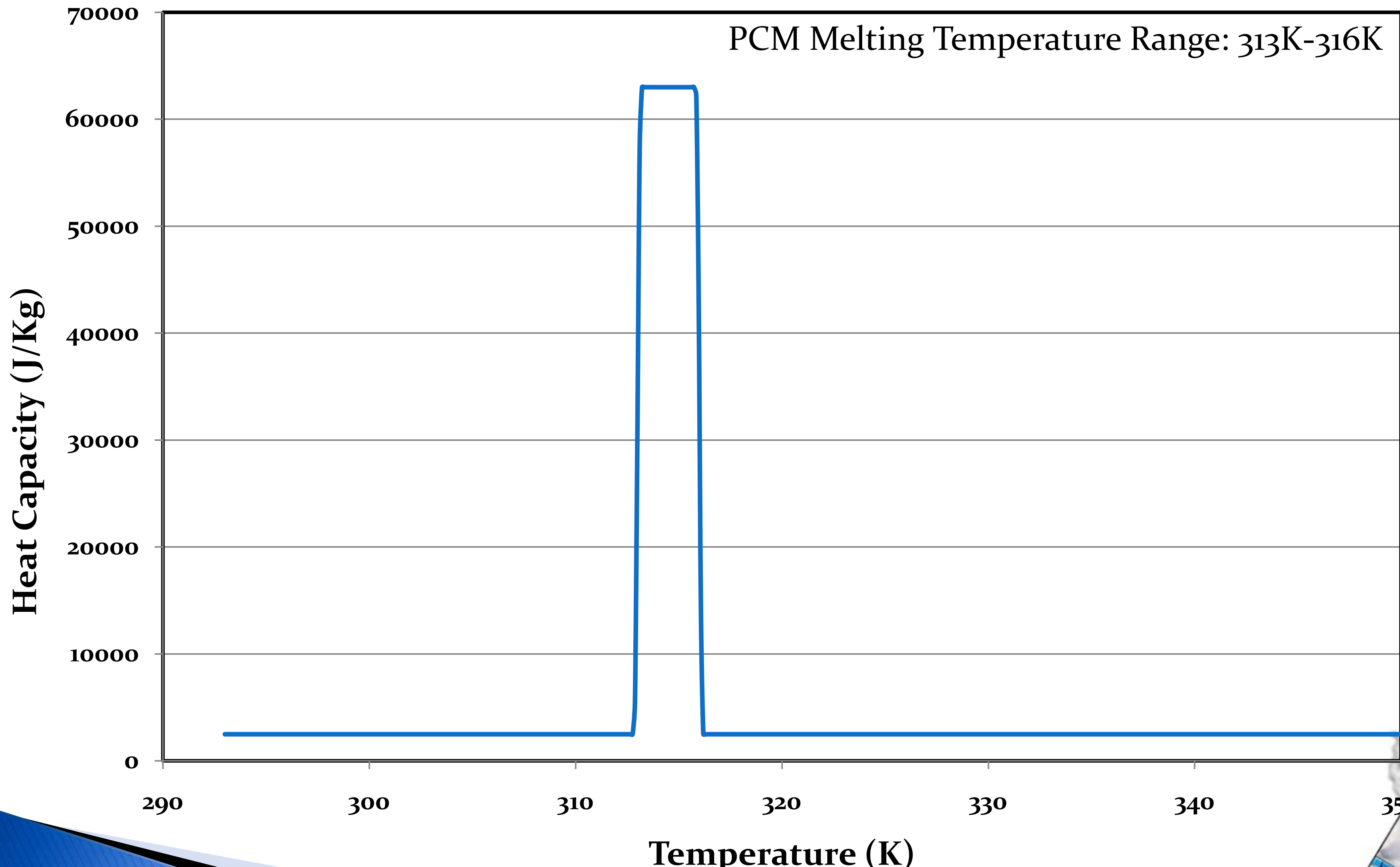
L = Latent heat of fusion
= 174 kJ/kg

ΔT_m = Melting Temperature range

Numerically

$$C_p = (2.5 + 60.5 * (313 < T) - 60.5 * (T > 316))$$

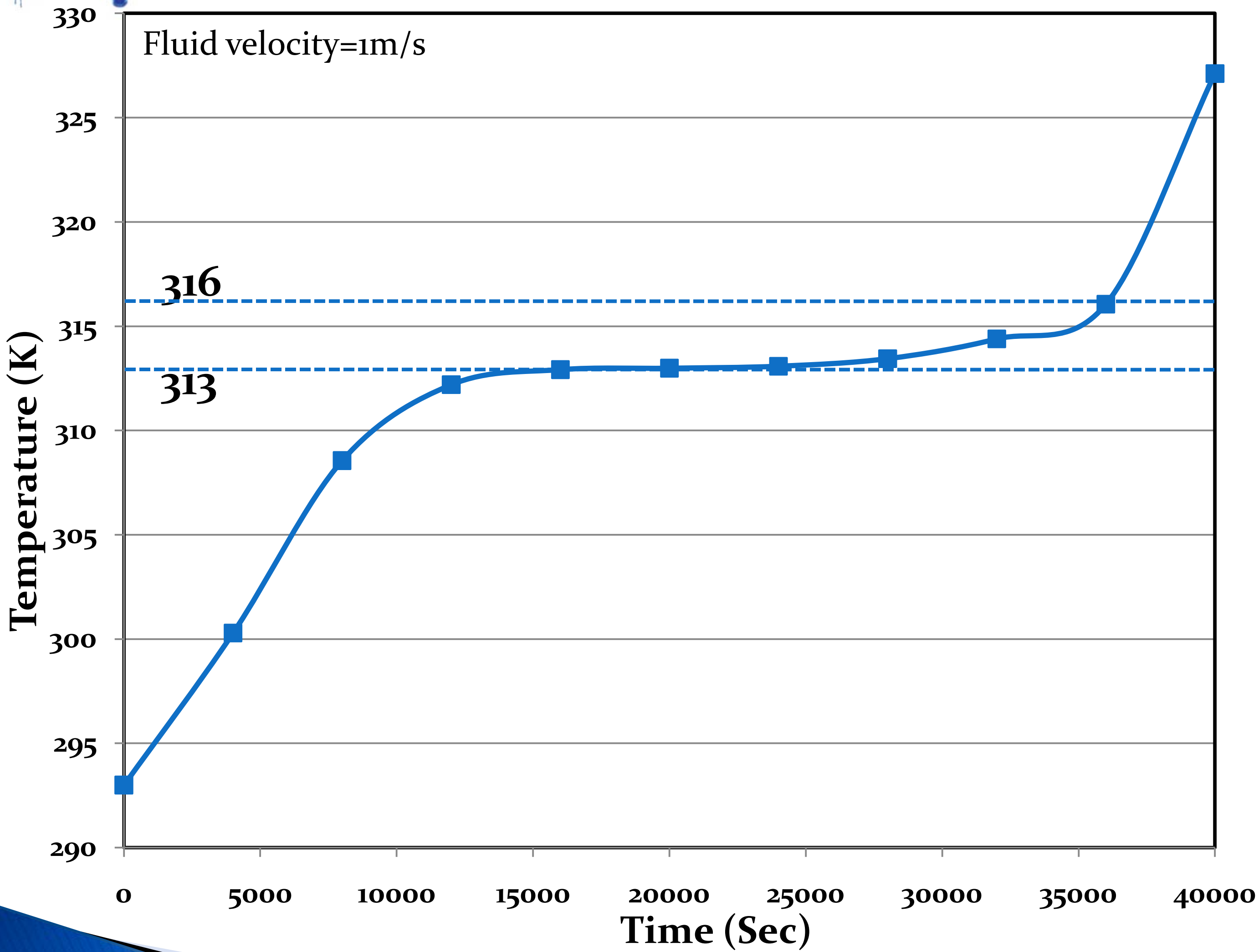
Modified Heat Capacity

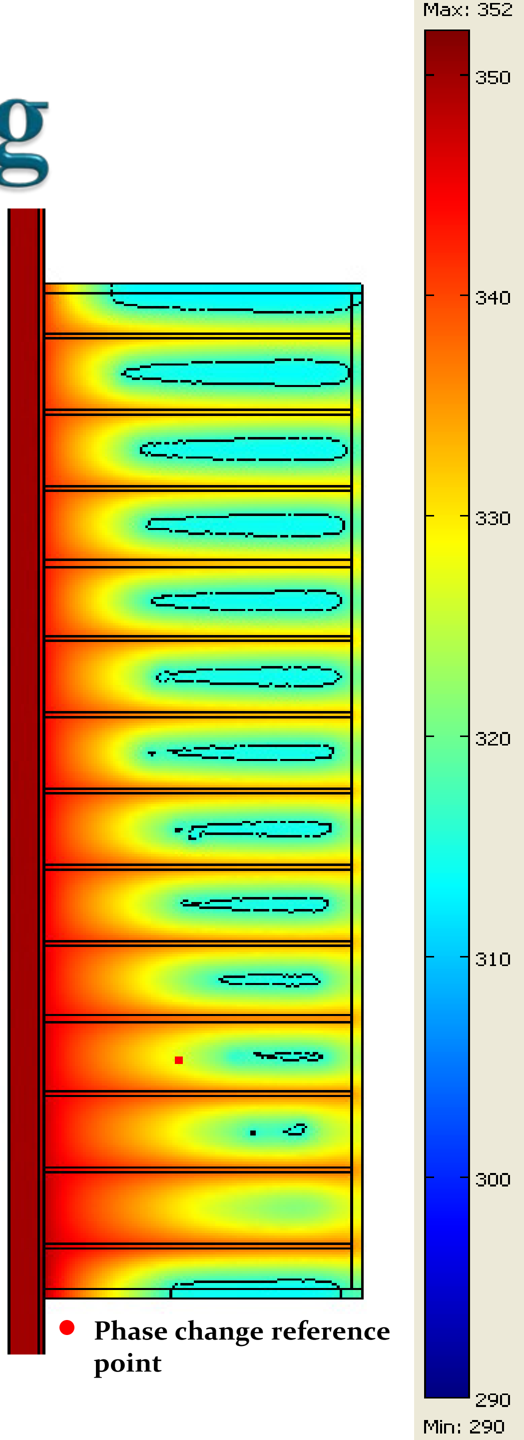


Numerical Results

- Cylindrical LHESS

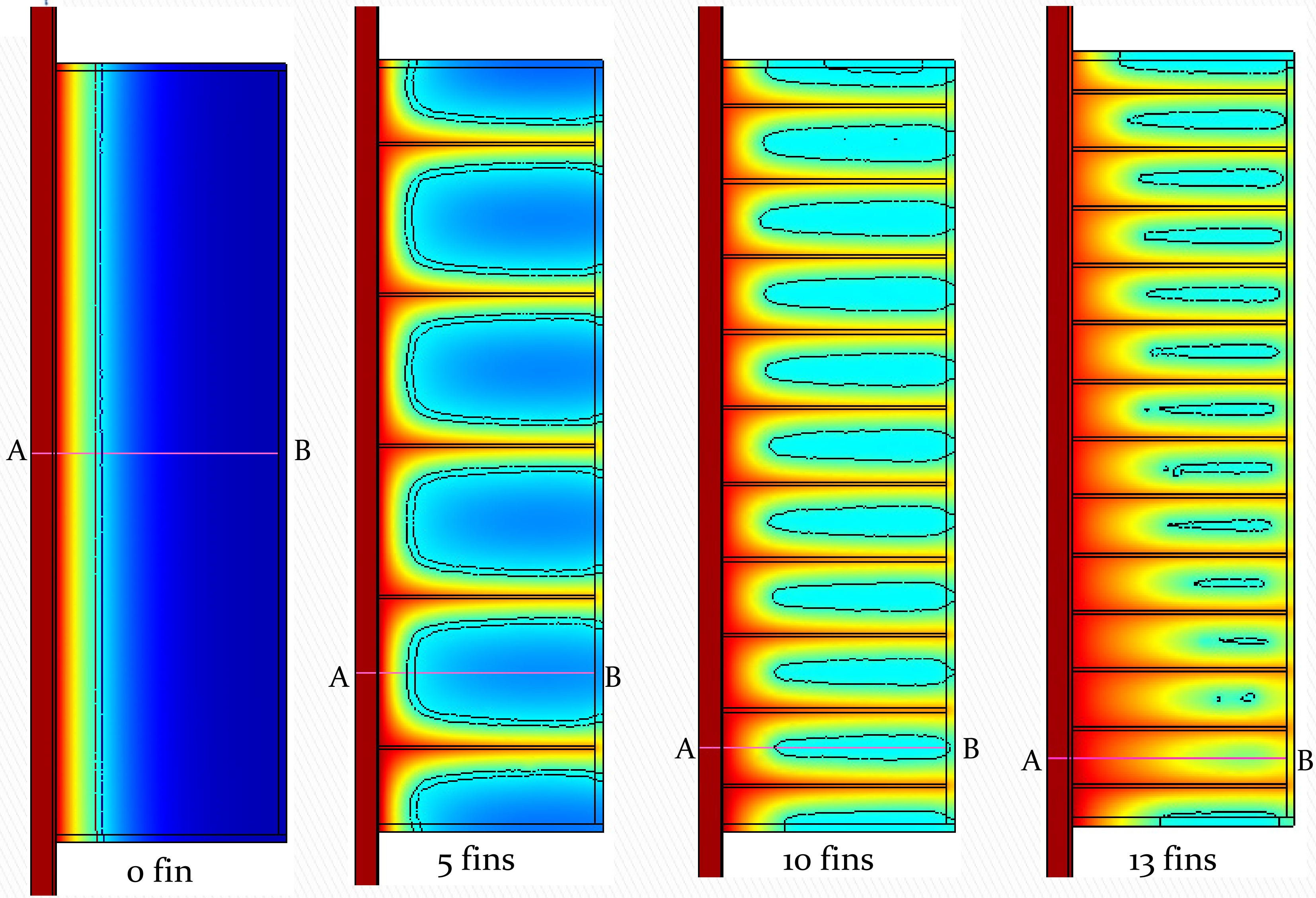
Observed Melting

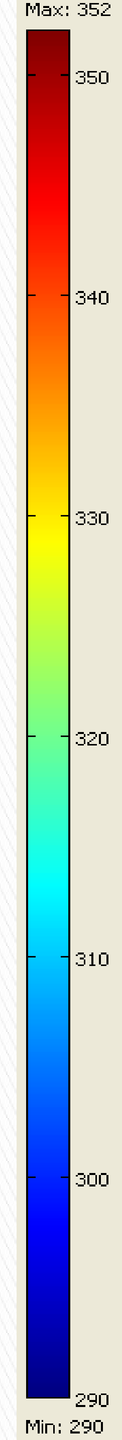




● Phase change reference point

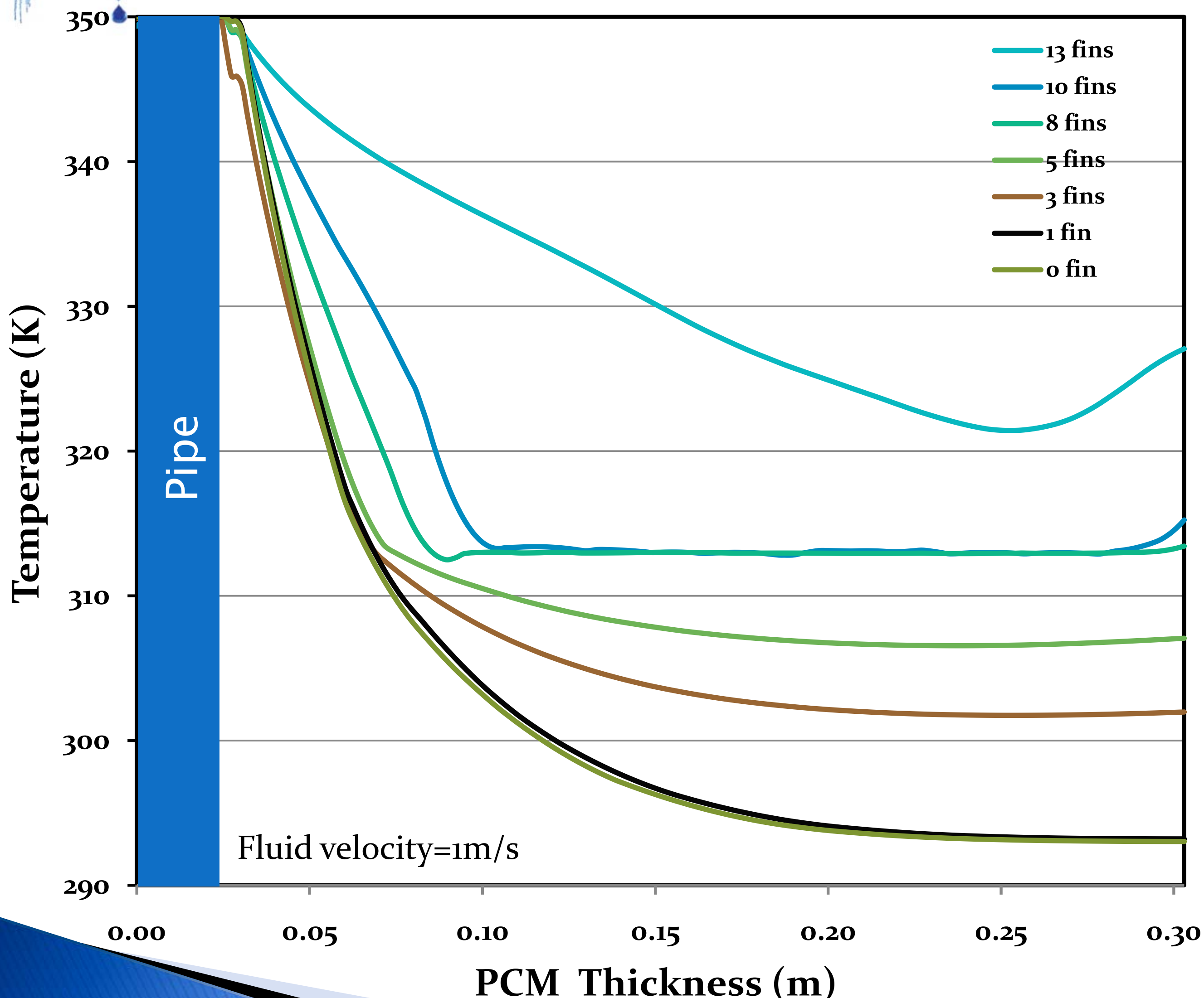
Effect of Fins

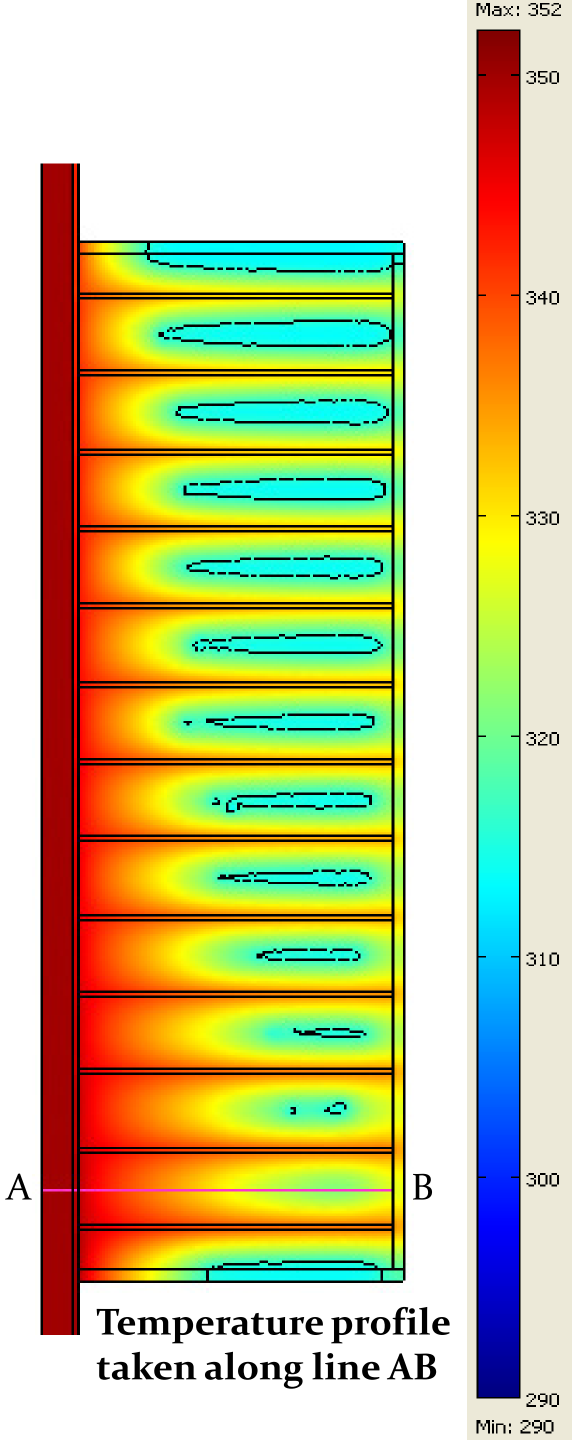




Fluid Velocity : 1 m/s
Simulated Period: 12hours

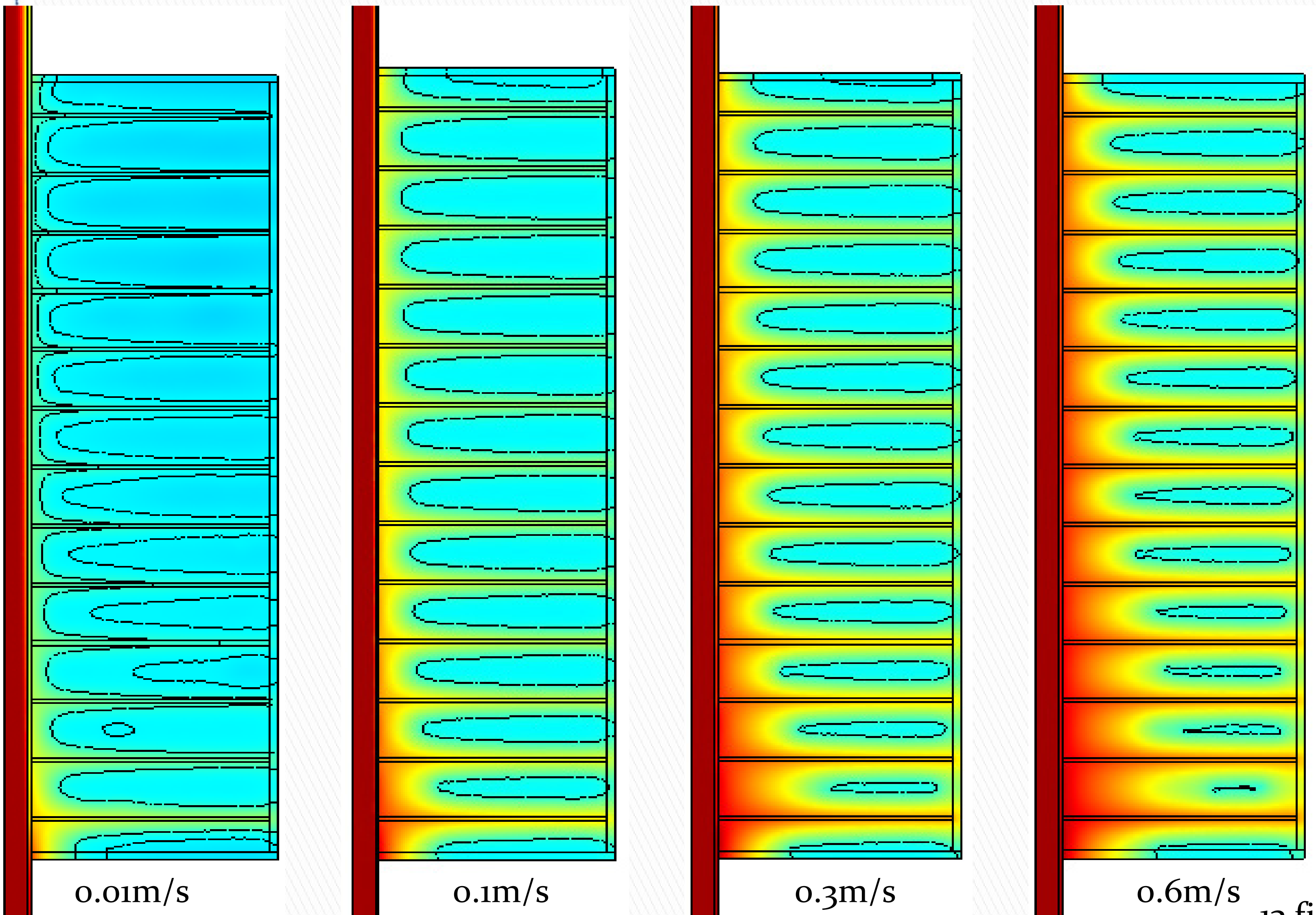
Effect of Fins

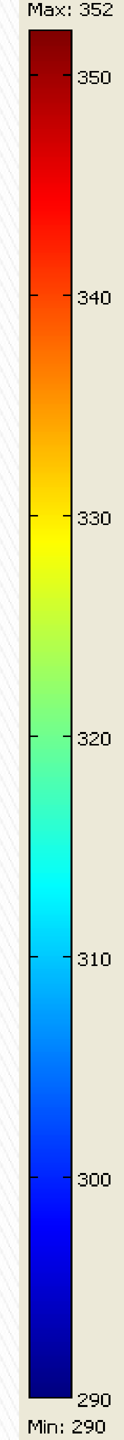




Temperature profile taken along line AB

Effect of Inlet Velocity

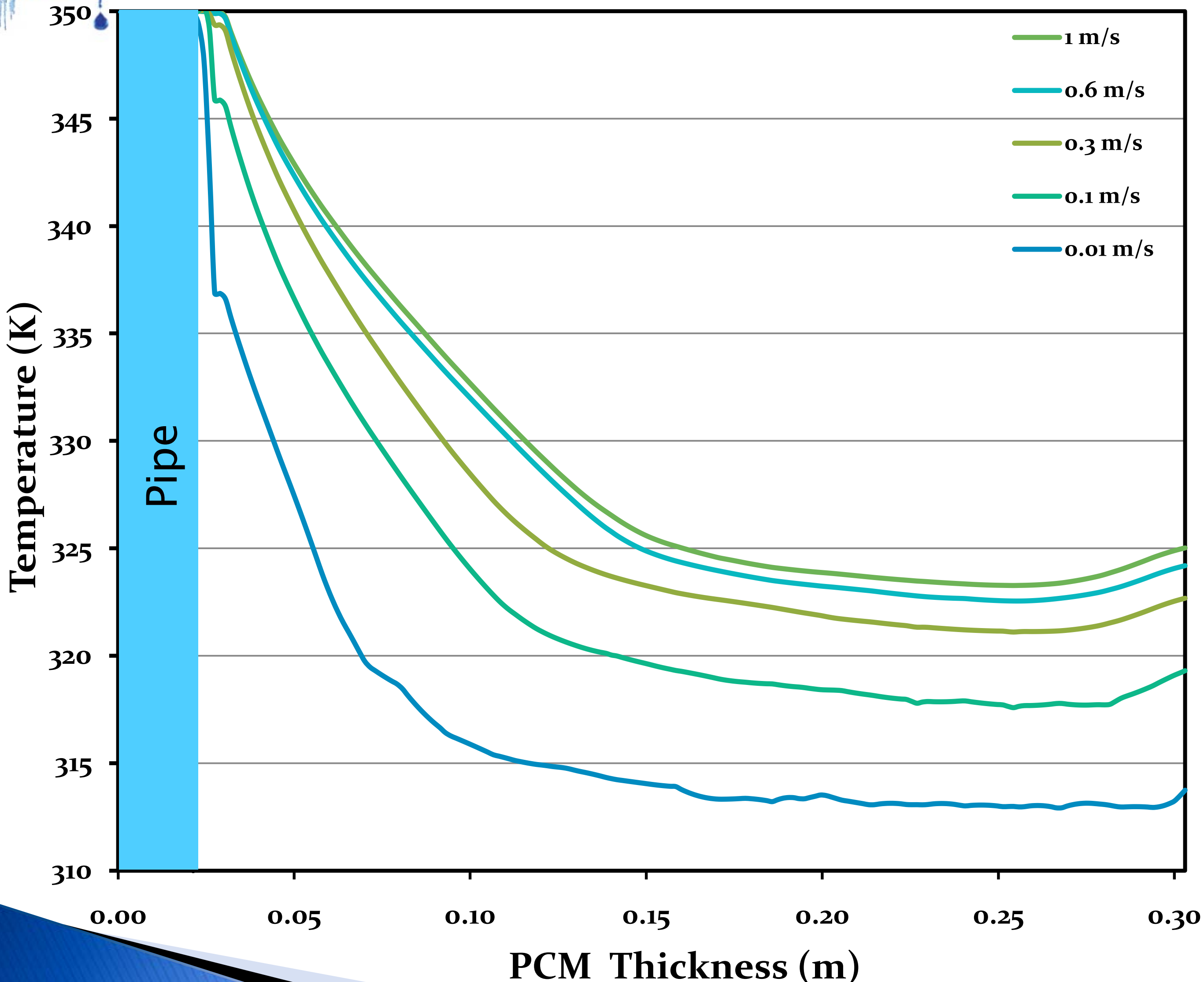


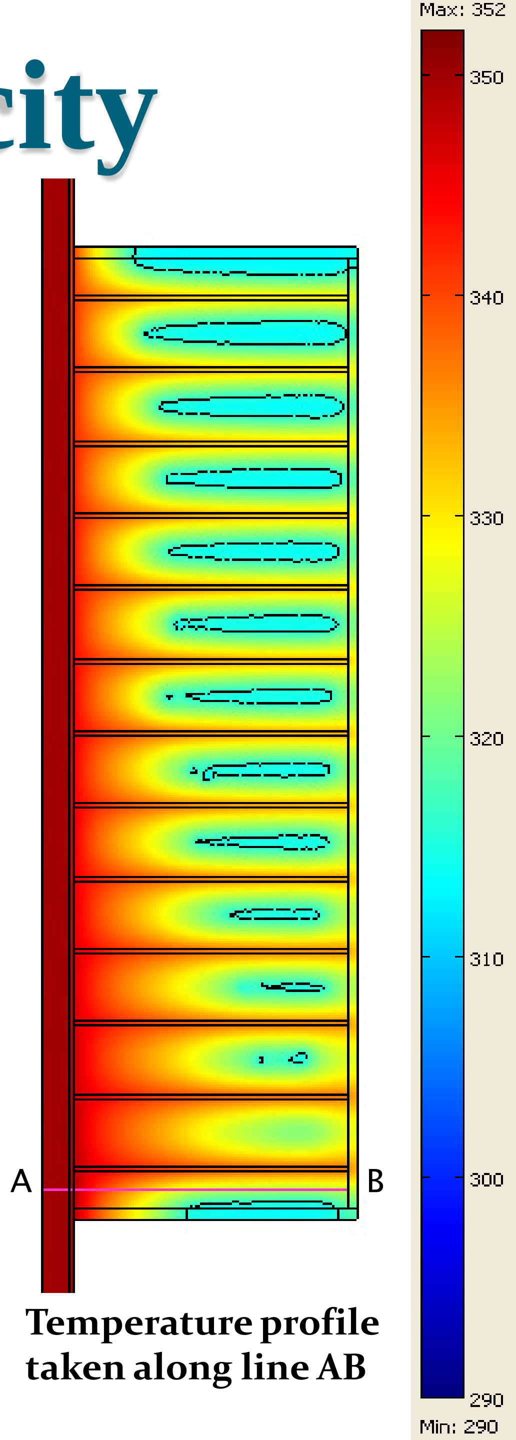


13 fins

Simulated Period: 12hours

Effect of Inlet Velocity





Temperature profile taken along line AB

Conclusion

- This preliminary work shows that the fluid flow, heat transfer and phase change processes can be numerically accounted using COMSOL Multiphysics;
- The phase change energy process and the melting front displacement can be simulated by modifying the specific heat of the PCM to account for the much larger value of the latent heat of fusion over the melting temperature range; however, this method is only useful so far if convection in the liquid PCM is neglected.

- An analytical validation is currently under way to quantify the accuracy of the phase change simulated results.