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Multiphysics and Multiscale Modeling of Heat Transfer during Fiber Drawing

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Fiber drawing modeling process is multiphysics and multiscale

- Fiber drawing process produces large plasticity
- Plastic work produces heat
- Cooled via immersion in water bath
- Water pumped and cooled
- Fiber bundle thickness small compared to tank geometry

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GEOMETRY

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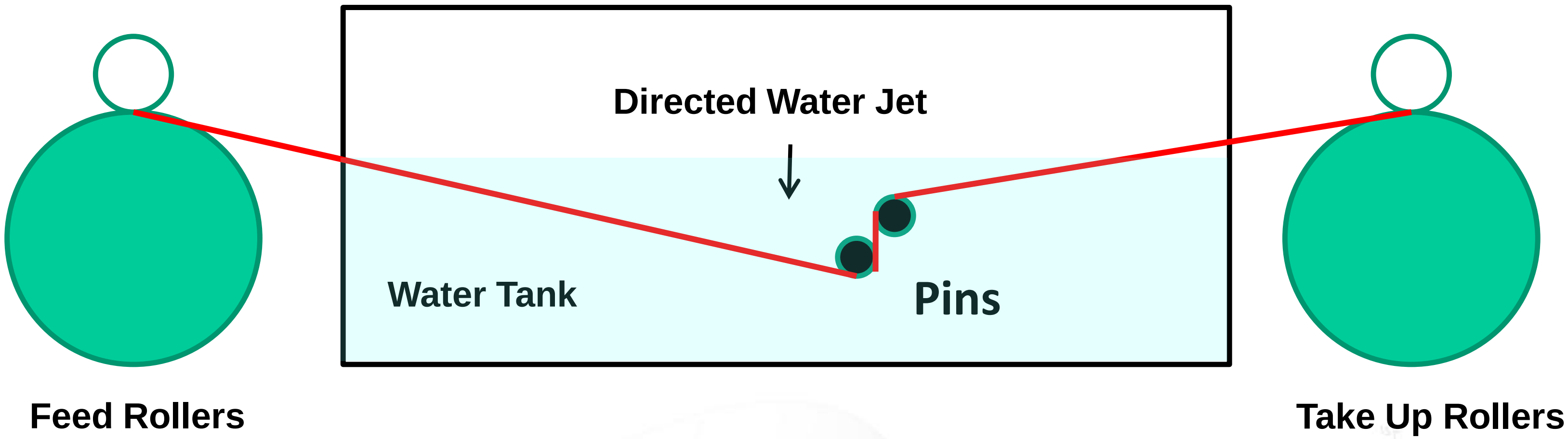
Process feeds fiber through tank and draws over pins



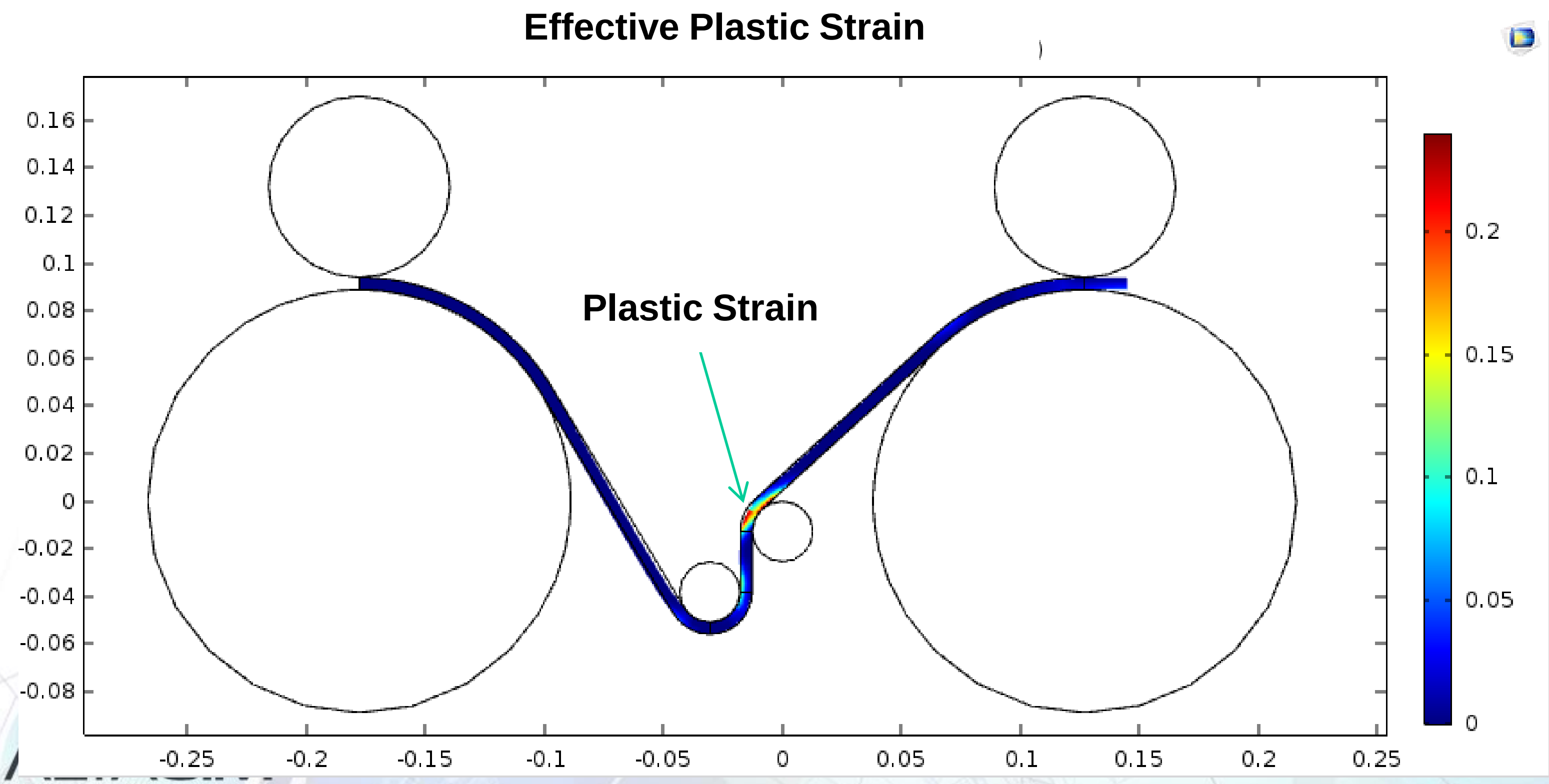
MULTIPHYSICS

Model includes 4 primary physics

- Fiber deformation / plasticity
- Fiber translation
- Heat transfer
  - Temperature-dependent plasticity
  - Heat source – plasticity
  - Cooling – forced convection
- Fluid dynamics
  - Pumping water
  - Flow induced by fiber translation

Solid mechanics calculates plastic strain

- Solved using plane strain model
- Contact between draw pins and fiber required for plasticity



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Heat transfer requires convection in fiber

- Solid mechanics solved quasi-statically
- Velocity required for
  - Heat transfer equations
  - Power generated by plasticity (J/s)
- Plastic deformation introduces change in velocity
- Equations added to solve for "flowing fiber"

$$0 = \nabla \cdot \left[-p\mathbf{I} + \mu\left(\nabla \mathbf{u2} + (\nabla \mathbf{u2})^T\right) \right] + \mathbf{F}$$

$$\rho \nabla \cdot (\mathbf{u2}) = 0$$

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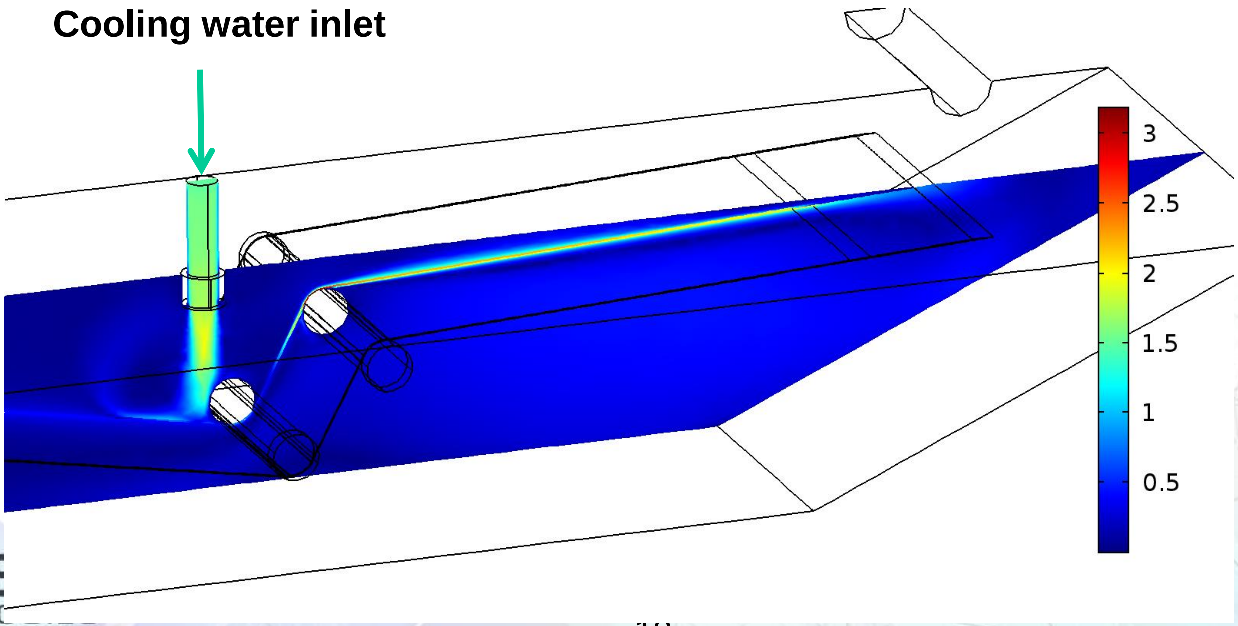
Heat produced by plasticity

- **Heat source due to plastic strain**
- **Initial solution assumed convection constant to represent fluid**
- **Work extended to include fluid flow in tank (3-D)**

Fluid dynamics

- Fluid flow for tank inlet and outlet included (3-D)
- Fluid flow induced by moving fiber included



MULTISCALE

Process includes range of length scales

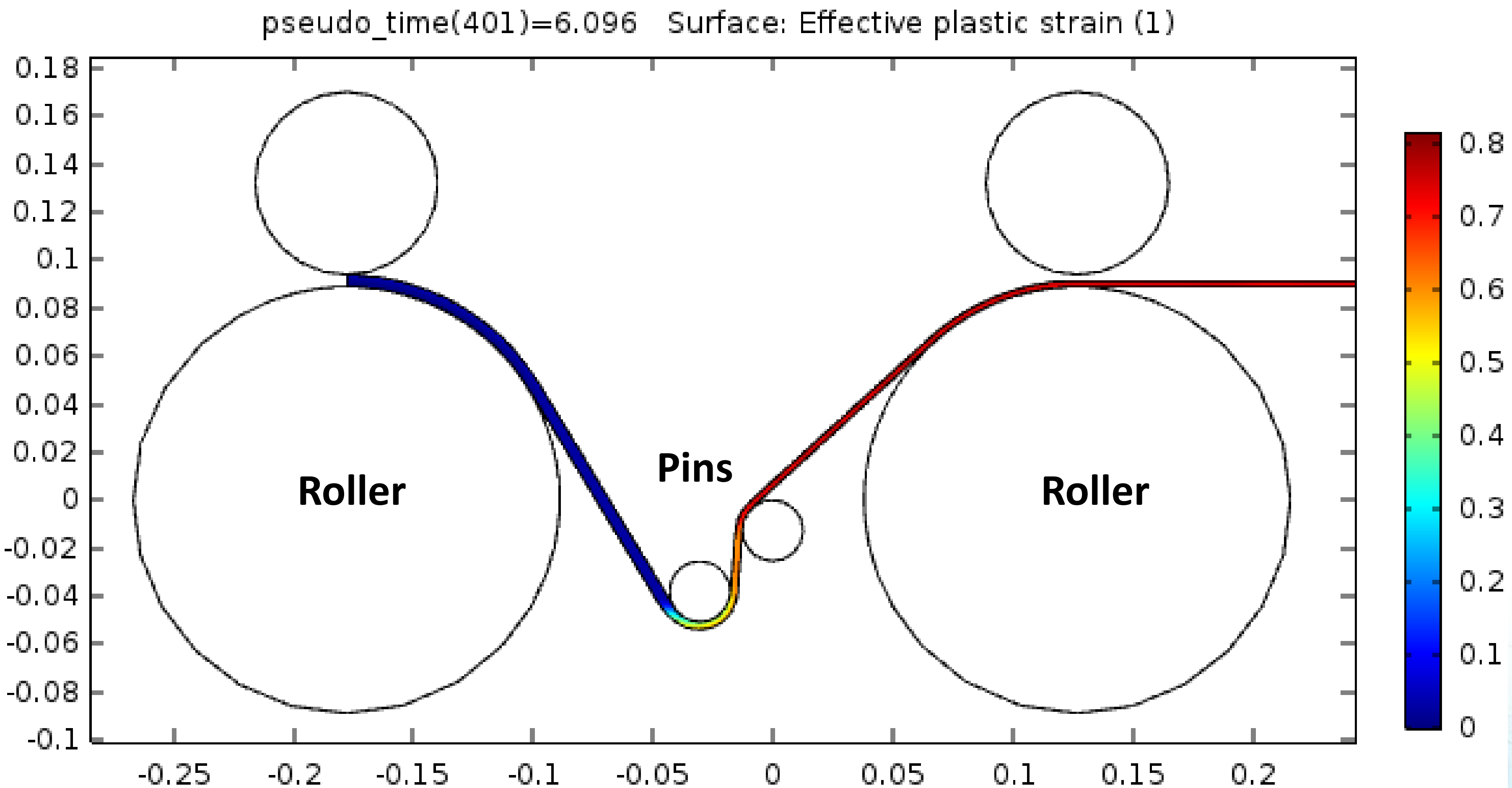
- **Fiber diameter: 60 μm**
- **Fiber bundle width: 150 mm**
- **Tank size: 1.5 m x 1.5 m x 1 m**

Multiple models required to solve

- **Mechanical analysis: plane strain**
- **Fluid dynamics analysis: three-dimensional**
- **Plane strain and 3-D models sequentially coupled via heat source and velocity**

RESULTS

Plastic strain produced by drawing



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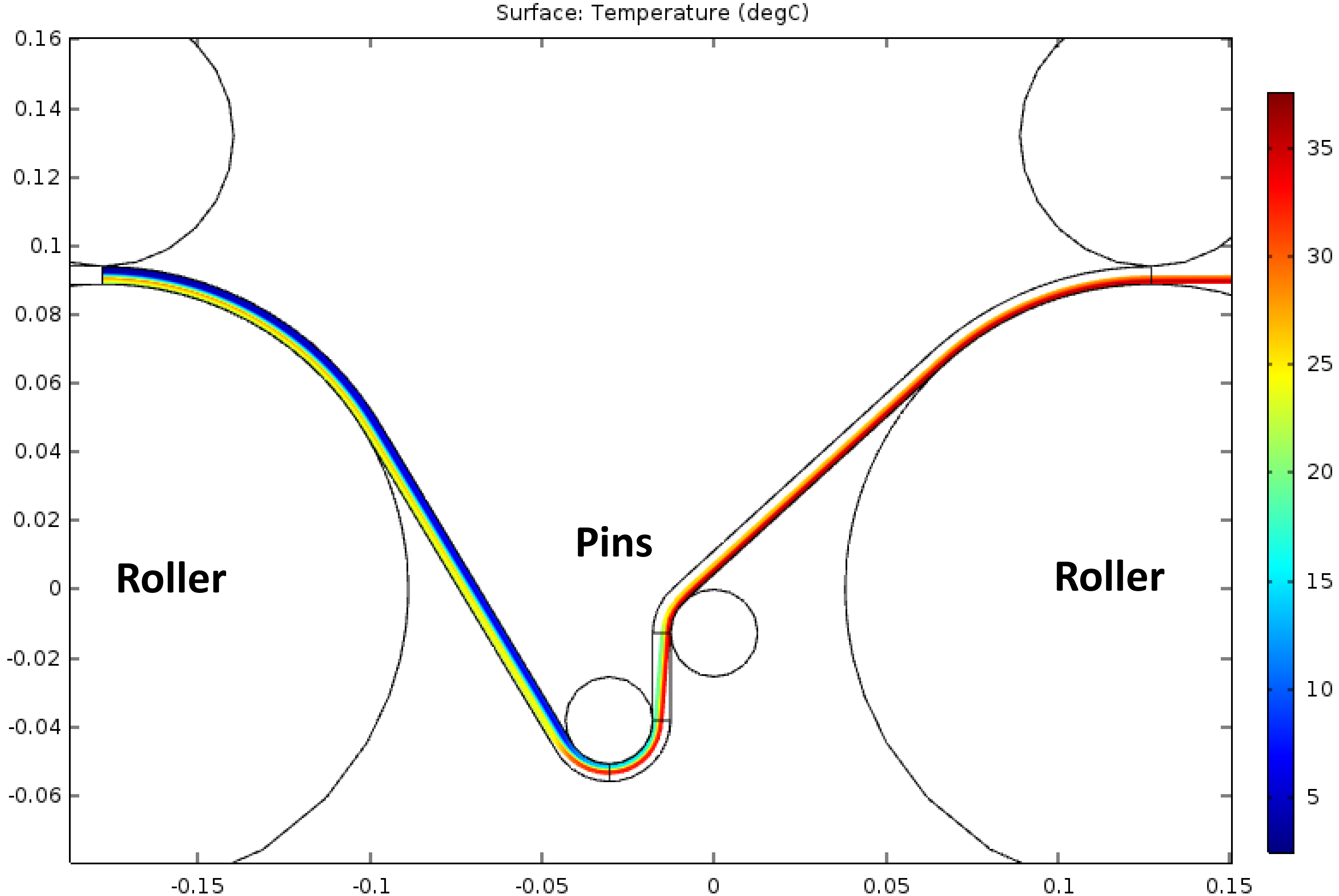
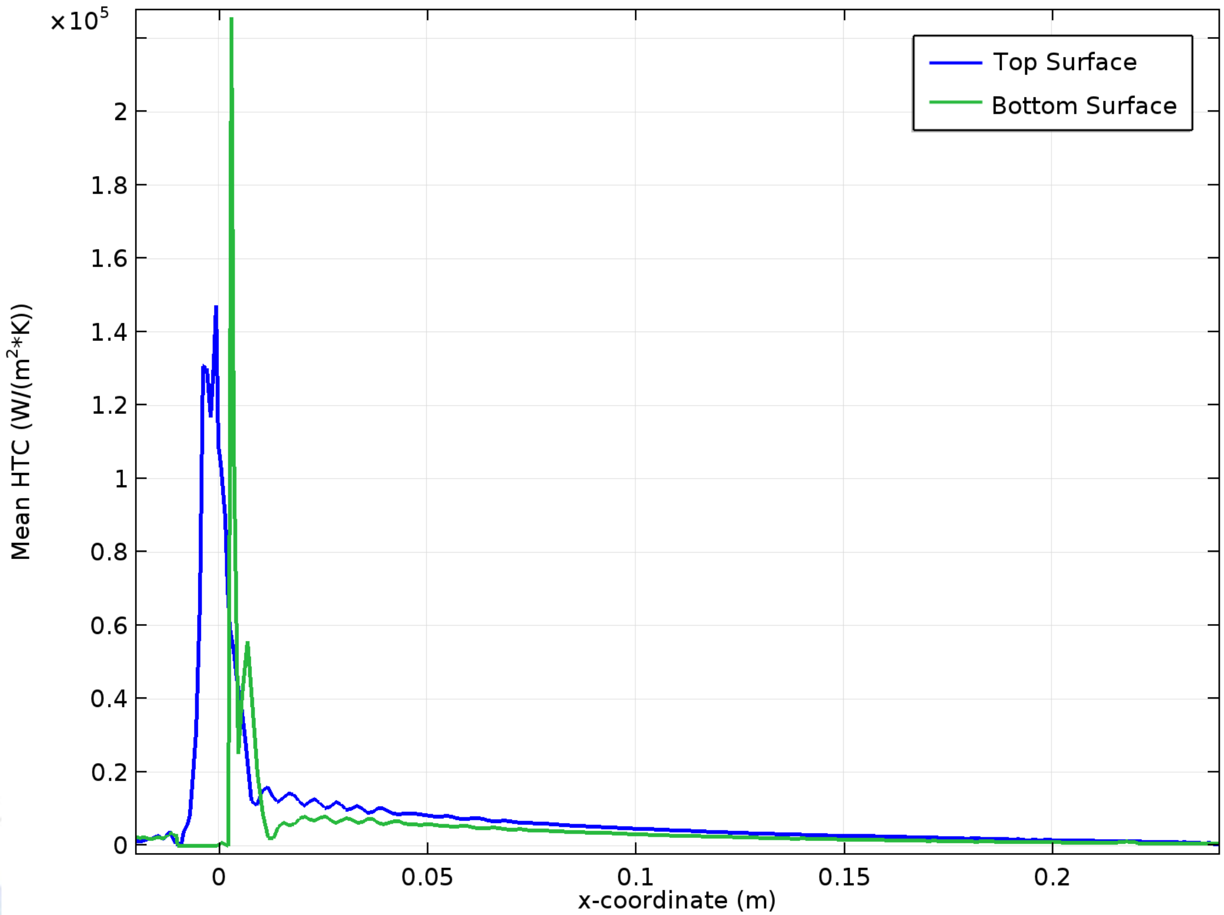
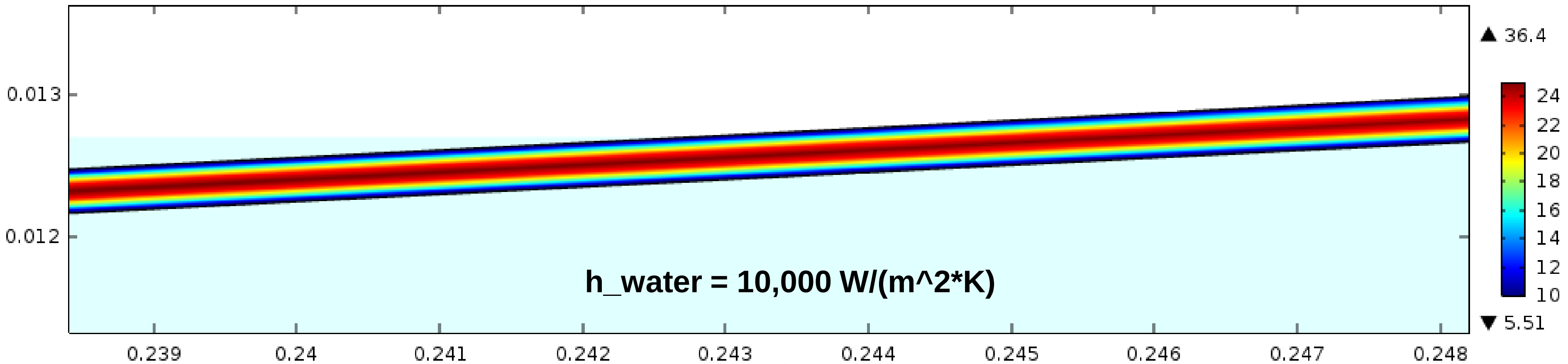
Fiber heats due to plastic deformation



Convection HTC – Fluid Flow Analysis



Fiber Temperature (°C)- Thickness



Difficult to remove heat from low thermal conductivity materials

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Summary

- Multiphysics and multiscale problem solved
- Heating of fiber due to plastic deformation calculated (w/ temp dep mat props)
- Design identified to cool fiber to desired temperature
- Temperature of outlet water calculated to size chiller

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