COMSOL
CONFERENCE
2015 BOSTON

Heat Transfer And Phase Change Simulation In COMSOL Multiphysics

Focus Session

COMSOL

Session Agenda

- Heat Transfer and Phase Change Simulation
  Nicolas Huc, COMSOL
- Microwave Heating of Initially Frozen Sandwiches
  Joyce Liao, Tyson Foods
- Cooling and Phase Change of a Melt-Cast Explosive
  Charles Dubois, École Polytechnique de Montréal, Department of Chemical Engineering
- Discussion

Talk Agenda

- Heat Transfer and Phase Change Simulation
  Nicolas Huc, COMSOL
  - Some orders of magnitude for water
  - Applications involving phase change
  - Heat Transfer with Phase Change and Moist Air features
  - COMSOL tutorials demonstrating phase change
  - Recommendations

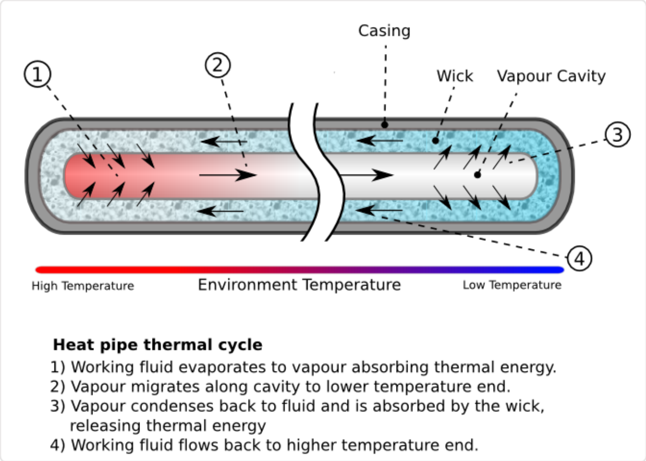
Latent Heat of Evaporation

- Latent Heat of Evaporation of evaporation for water at : L= ~2200kJ/kg

- Heat capacity Cp = ~4kJ/kg/K

=> Evaporating 100g of water requires more energy that rising the temperature of 1kg of water from 20 to 70°C

Heat Pipe



Heat pipe thermal cycle

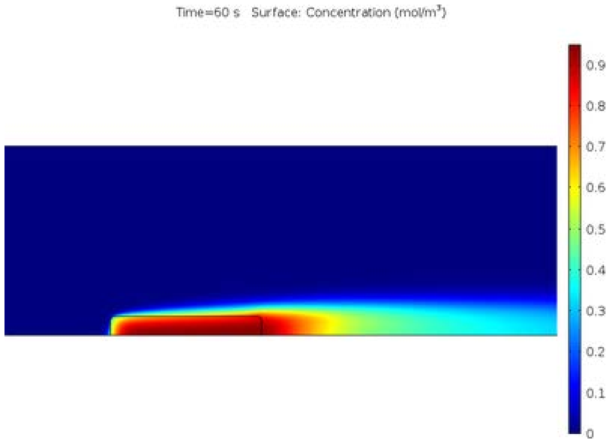
1) Working fluid evaporates to vapour absorbing thermal energy.
2) Vapour migrates along cavity to lower temperature end.
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy
4) Working fluid flows back to higher temperature end.

Illustration by from
https://commons.wikimedia.org/wiki/File:Heat_Pipe_Mechanism.png

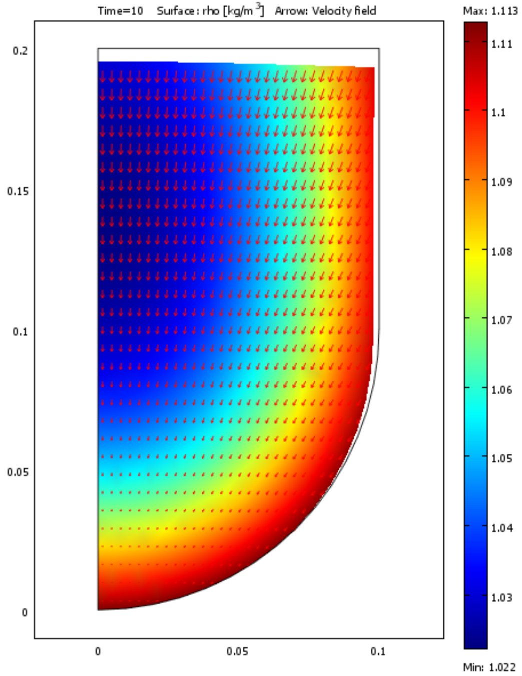
- Thermal conductivity
  - Ag = ~ 400 W/K/m
  - Cu = ~ 400 W/K/m
  - Diamond = ~1300W/K/m
  - Graphene= ~2000W/K/m
- Heat pipe: equivalent thermal conductivity from 4e3 to 40e6 W/K/m depending on the heat pipe size!

Drying, cooking

- In drying and cooking application the water evaporation can require most of the process energy



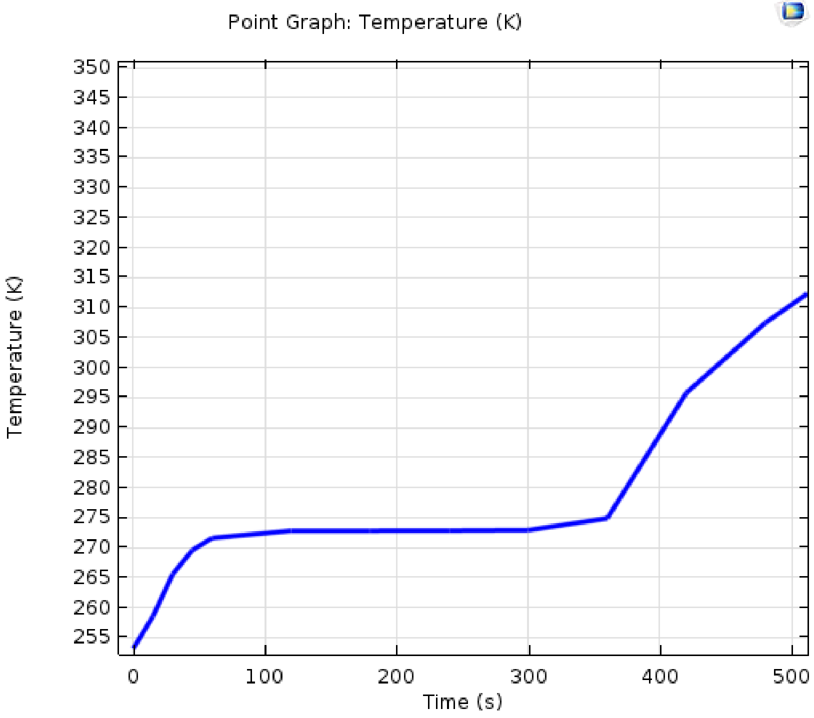
Material processing



- Molding
- Solidification
- Density change
- Bubbles and gaps formation

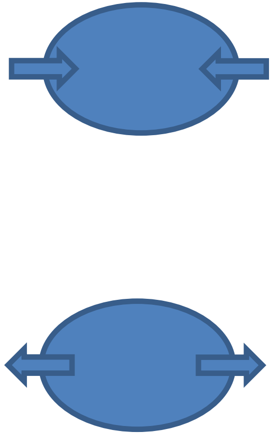
Thermal protection

- PCM offer a large choice of melting temperatures
- Maintain food or medecines at a give temperature



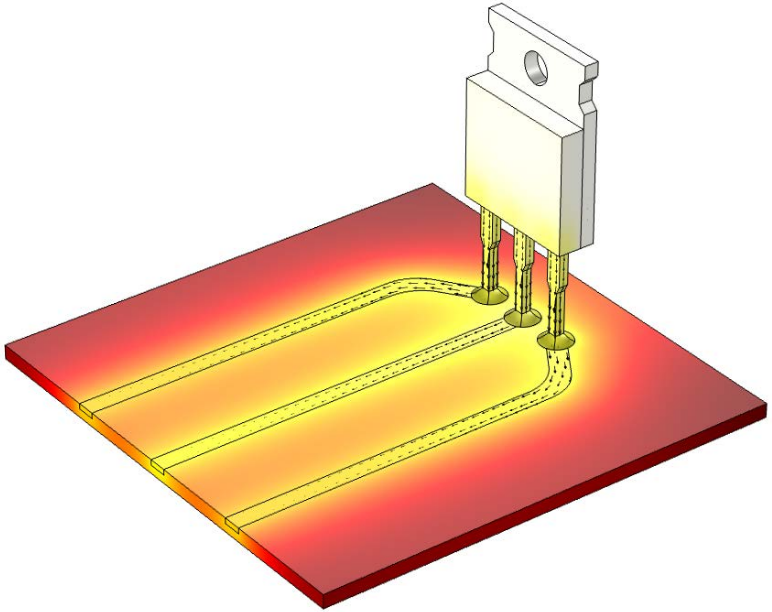
Thermal storage ans release

- Maintain building temperature
- High end clothes



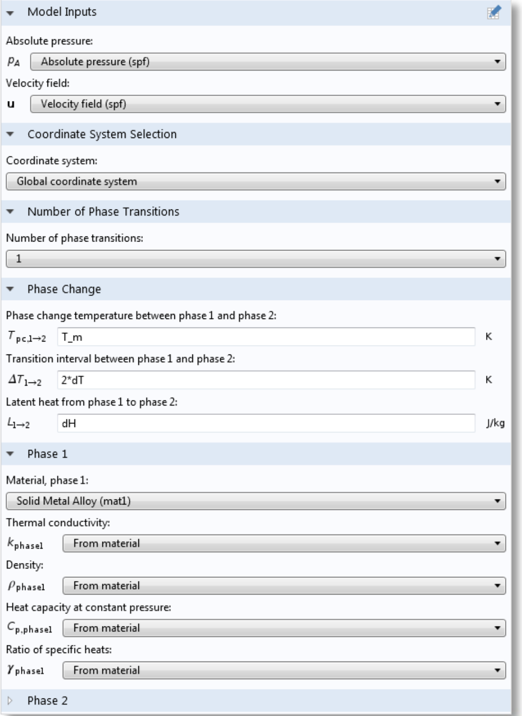
Condensation prevention

- Condensation can accelerate oxidation
- Condensation occurs when the partial vapor pressure reaches saturation pressure
- Saturation pressure increases when temperature increases



Heat Transfer with Phase Change feature

- Reliable implementation of the apparent heat capacity method
- Computes the material properties as a function of T
- Accounts for latent heat of phase change
- Requires a transition interval
- Supports up to 6 phases
- Redefines all heat transfer postprocessing variables



Model Inputs

Absolute pressure:

p_A Absolute pressure (spf)

Velocity field:

u Velocity field (spf)

Coordinate System Selection

Coordinate system:

Global coordinate system

Number of Phase Transitions

Number of phase transitions:

1

Phase Change

Phase change temperature between phase 1 and phase 2:

$T_{pc,1\to2}$ T_m K

Transition interval between phase 1 and phase 2:

$\Delta T_{1\to2}$ 2*dT K

Latent heat from phase 1 to phase 2:

$L_{1\to2}$ dH J/kg

Phase 1

Material, phase 1:

Solid Metal Alloy (mat1)

Thermal conductivity:

k_{phase1} From material

Density:

ρ_{phase1} From material

Heat capacity at constant pressure:

$C_{p,phase1}$ From material

Ratio of specific heats:

γ_{phase1} From material

Phase 2

Apparent Heat Capacity Method

Assumes a smooth transition over ΔT, with a phase mass fraction, θ

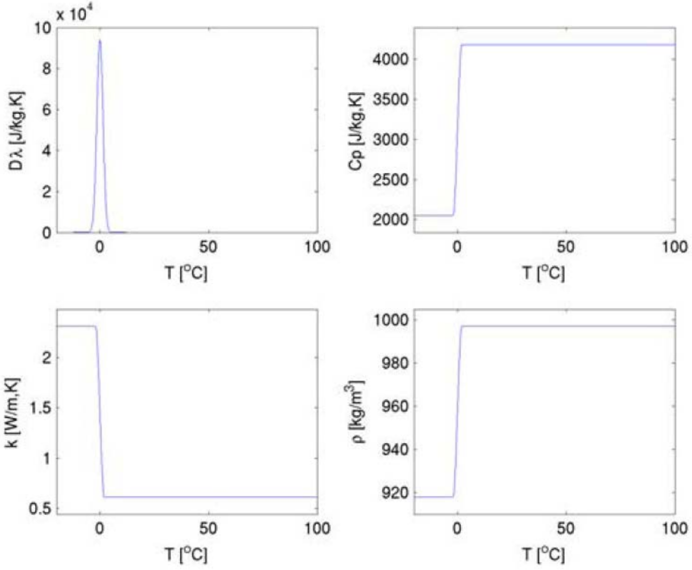
$$\rho = \theta\rho_{\text{phase1}} + (1-\theta)\rho_{\text{phase2}}$$

Based on the enthalpy of

C_p is modified to include the latent heat

$$C_p = \frac{1}{\rho}(\theta_1\rho_{\text{phase1}}C_{p,\,\text{phase1}} + \theta_2\rho_{\text{phase2}}C_{p,\,\text{phase2}}) + L\frac{d\alpha_{\text{m}}}{dT}$$

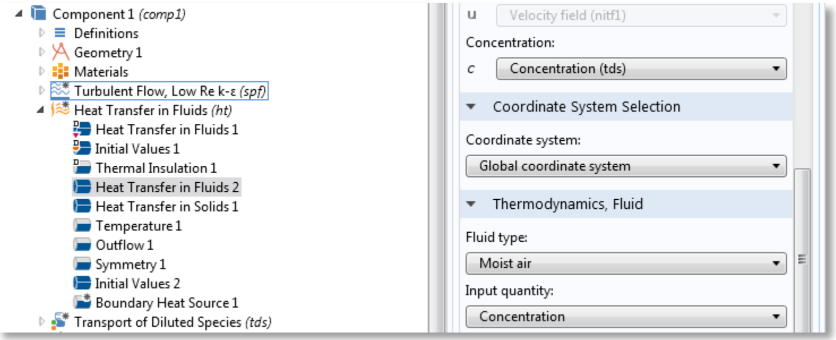
$$\alpha_{\text{m}} = \frac{1}{2}\frac{\theta_2\rho_{\text{phase2}} - \theta_1\rho_{\text{phase1}}}{\rho}$$



Moist Air Feature

- Located in Heat Transfer in fluids
- Moist air properties are automatically defined
- Vapor content can be prescribed or computed (multiphysics!)
- Input quantity can be
  - Moisture content
  - Vapor mass fraction
  - Vapor concentration
  - Relative humidity

(the interface provides functions to convert these quantities)



- Component 1 *(comp1)*
  - Definitions
  - Geometry 1
  - Materials
  - Turbulent Flow, Low Re k-ε *(spf)*
  - Heat Transfer in Fluids *(ht)*
    - Heat Transfer in Fluids 1
    - Initial Values 1
    - Thermal Insulation 1
    - Heat Transfer in Fluids 2
    - Heat Transfer in Solids 1
    - Temperature 1
    - Outflow 1
    - Symmetry 1
    - Initial Values 2
    - Boundary Heat Source 1
  - Transport of Diluted Species *(tds)*

u: Velocity field (nitf1)

Concentration:

c: Concentration (tds)

Coordinate System Selection

Coordinate system: Global coordinate system

Thermodynamics, Fluid

Fluid type: Moist air

Input quantity: Concentration

Saturation pressure, p_{sat}

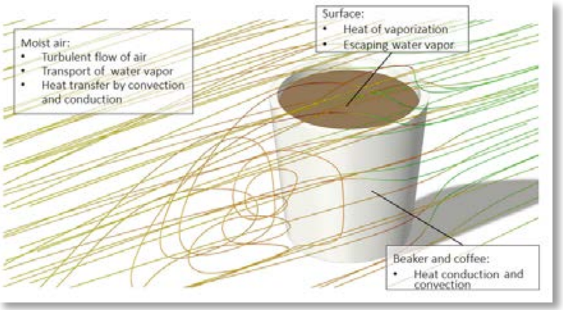
- Material properties are defined for moist air not for humid air
- Useful for applications where
  - condensation has to be avoided
  - condensation only occurs on walls

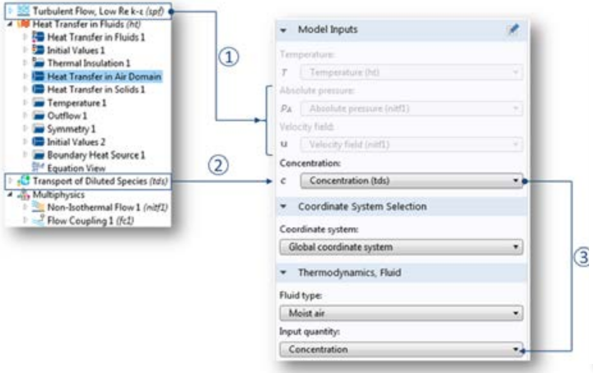
$$\phi = \frac{p_v}{p_{sat}}$$

$$p_{sat}(T) = 610.7[\mathrm{Pa}] \cdot 10^{7.5\frac{T - 273.15[\mathrm{K}]}{T - 35.85[\mathrm{K}]}}$$

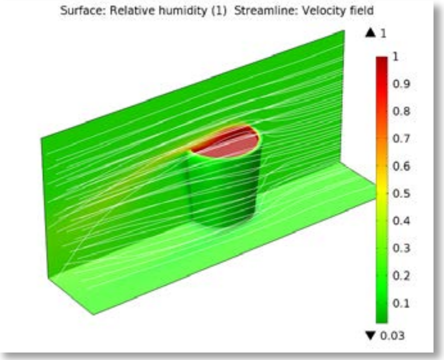
Evaporative Cooling

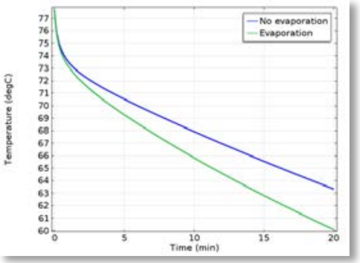
Evaporation is a process that occurs if some liquid vaporizes into a gaseous phase that is not saturated with the liquid. You need a physics that accounts for **water vapor transport**– add a 'transport of diluted species' interface.





Temperature:
T Temperature (ht)
Absolute pressure:
p_A Absolute pressure (nitf1)
Velocity field:
u Velocity field (nitf1)
Concentration:
c Concentration (tds)
Coordinate system:
Global coordinate system
Fluid type:
Moist air
Input quantity:
Concentration



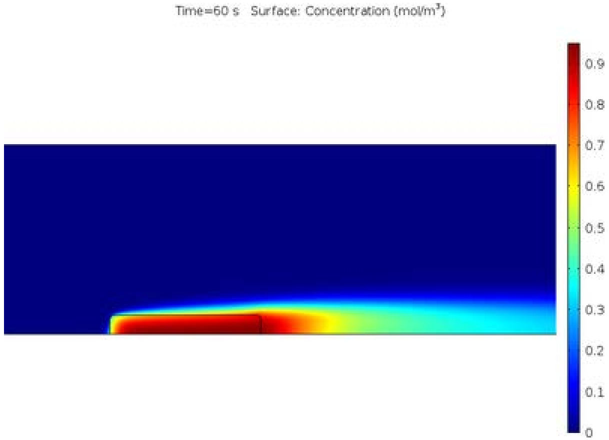


http://www.comsol.com/model/evaporative-cooling-of-water-6192

http://www.comsol.com/blogs/intro-to-modeling-evaporative-cooling/

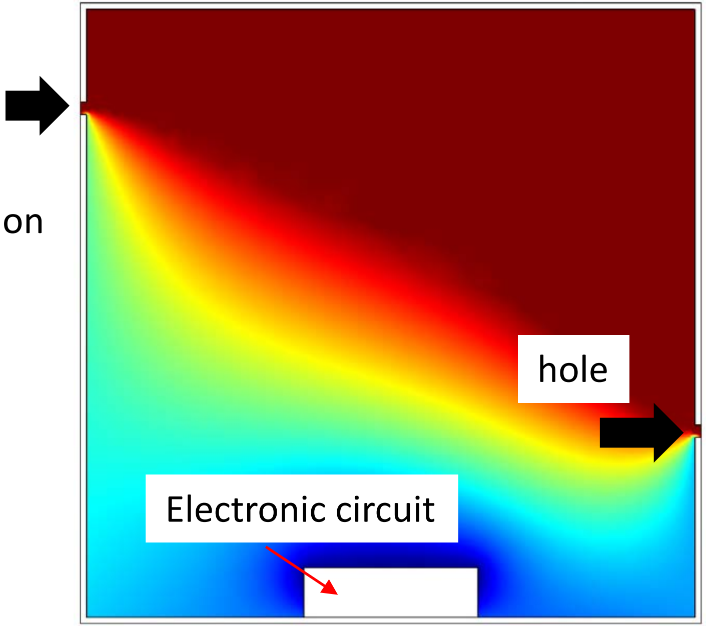
Evaporation in porous media

- Turbulent free flow and porous media flow are coupled
- Transport of vapor is made using transport of diluted species interface

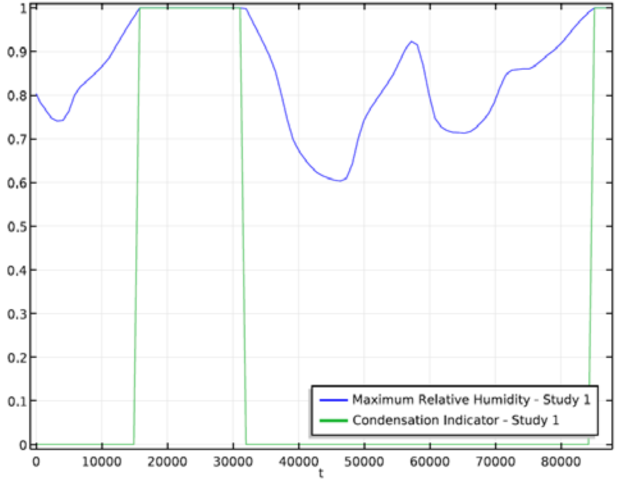


Condensation detection in an electronic box

hole at external temperature, pressure and humidity contidion



Relative humidity in the box



Maximum relative humidity in the box

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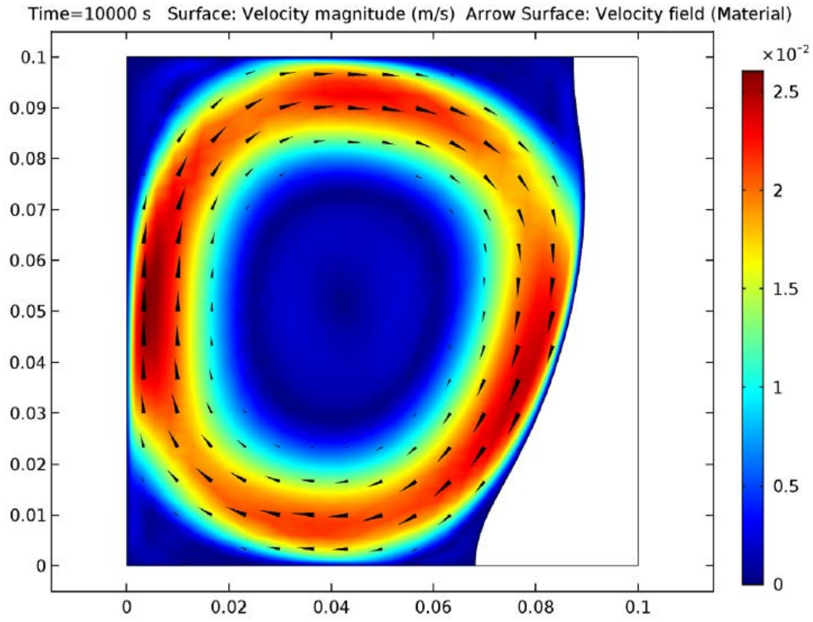
Tin melting front

- Moving mesh for the interface
- The interface temperature is the phase change temperature
- The front velocity depends on the heat flux at the interface



Best practices - density

Make sure that your model is consistent: density changes implies volume changes if mass is conserved !

With Lagrangian description, density should be constant unless matter is created or disappears.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

Best practices – averaged properties

- An averaged property is not always obtained using a linear relation…
- Check and use predefined quantities when available!

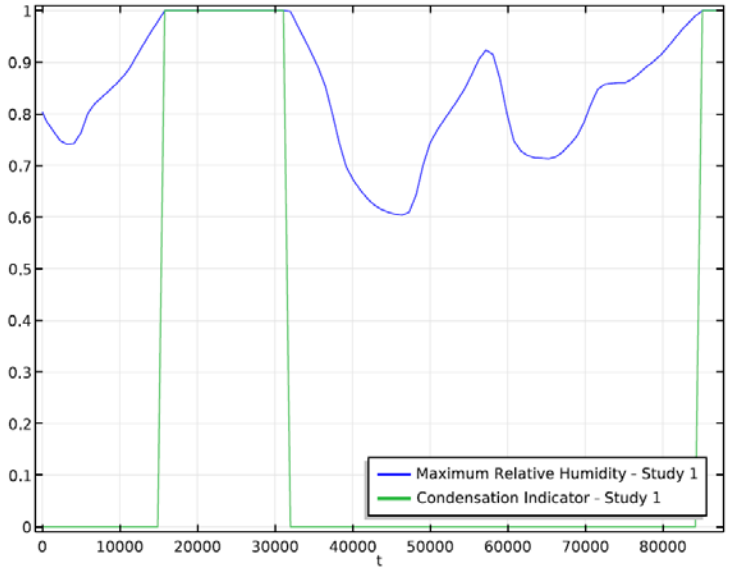
$$\rho = \theta\rho_1 + (1-\theta)\rho_2$$

$$\rho C_p = \theta\rho_1 C_{p,1} + (1-\theta)\rho_2 C_{p,2}$$

$$C_p = ???$$

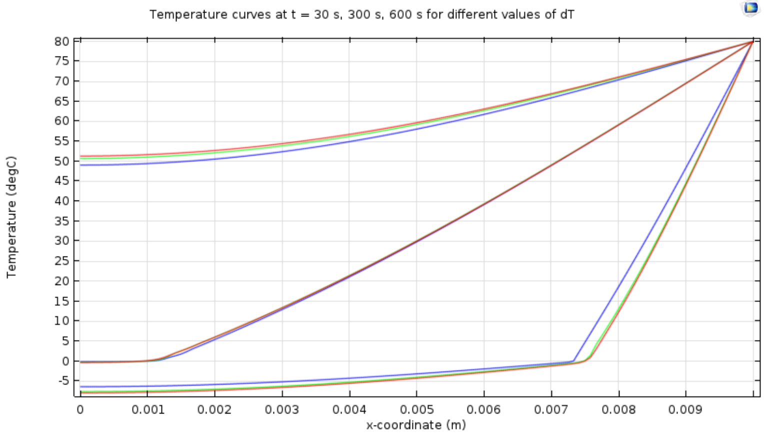
Best practices – size of the time step (dt)

- Make sure that the time step used for the simulation is consistent with the expected accuracy



Best practices – size of the phase change transition (ΔT)

- ΔT determines how sharp is the Cp peak and the material transition
- Check the “thermal accuracy” of the model
- ΔT should correspond to a couple of mesh elements in the transition area
- A too large value may lead to unwanted phase change in initial conditions!



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