Created in COMSOL Multiphysics 6.2

Drying of a Potato Sample

Introduction

Drying of porous media is an important process in the food and paper industry among others. Many physical effects must be considered: fluid flow, heat transfer with phase change, and transport of participating liquids and gases. All of these effects are strongly coupled, and predefined interfaces can be used to model these effects in an hygroscopic porous medium with COMSOL Multiphysics.

In this model, the liquid and gaseous phases are assumed to be in equilibrium inside a potato sample modeled as a porous medium, and the changing water saturation is computed over time, to model the heat and moisture transport by a two-phase flow.

Model Definition

This model describes a laminar dry airflow through a potato sample, modeled as a porous medium containing moist air and liquid water. The geometry and principle is shown in Figure 1.

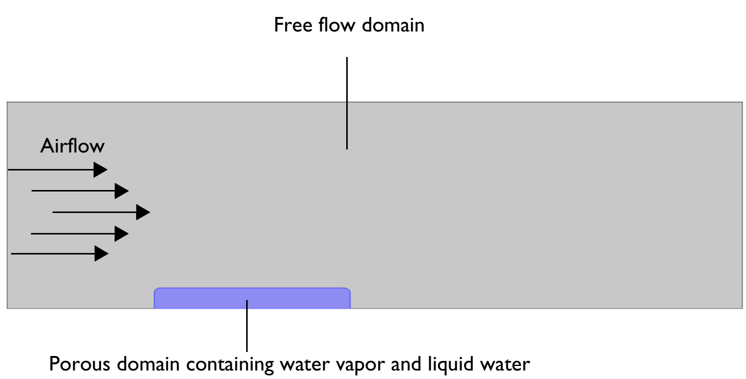


Figure 1: Geometry and principle of the model.

HEAT AND MOISTURE TRANSPORT IN AIR

In the moist air domain, it is assumed that no liquid water is present. This means that all the moisture leaves the porous medium under vapor state.

The transport and thermodynamic properties of air with water vapor can be described using mixture laws, based on the amount of water vapor and dry air. This is done automatically in the Moist Air feature and subfeature in the Heat Transfer interface. See the *Heat Transfer Module User's Guide* for the governing equations. As the input term for water vapor, the relative humidity ϕ_w from the moisture transport equation is used in the Heat Transfer and Fluid Flow interfaces.

The compressible Navier–Stokes equations are solved to compute the velocity and pressure fields of the free flow for the convective transport of heat and moisture.

Another relevant effect for the moisture transport is the binary diffusion of vapor and air. The variations of the density of moist air induced by vapor transport are relatively small in the current configuration, so the diluted species formulation is used.

TWO PHASE FLOW IN THE POTATO SAMPLE

The basic principle of modeling two phase flow in porous media is similar for many applications. First, to account for different phases, saturation variables are used that fulfill the following constraint:

$$s_g + s_l = 1 \tag{1}$$

where the index g is used for the gaseous phase (which in this model is moist air) and the index l is used for the liquid phase (which in this model is water).

Single-phase flow in porous media is described by the Brinkman equations. With an additional liquid phase, capillary effects also arise and the liquid flow is driven by a pressure gradient and the capillary pressure $p_c = p_g - p_l$. How to deal with the latter depends on the application: sometimes the capillary pressure can be neglected, sometimes it is the driving effect and different approaches exist.

In this model, the capillary effects are treated by an additional diffusion term in the transport equation. The Brinkman equations are used to calculate the flow field $\mathbf{u}_g$ and pressure distribution p_g of moist air in the porous medium. Therefore the porosity ε_p must take into account that only a fraction of the void space is occupied by the gas phase.

The liquid-phase velocity is small compared to the moist air velocity and such that Darcy's law is defined in terms of the gas-phase pressure gradient to calculate the water velocity $\mathbf{u}_l$ according to

$$\mathbf{u}_l = -\frac{\kappa_l}{\mu_l}\nabla p_g \tag{2}$$

where κ_l and μ_l are the permeability and viscosity of the liquid phase.

Finally, due to the dimensions of the porous medium, the gravity effects on transport are neglected in both phases.

MOISTURE TRANSPORT IN THE POTATO SAMPLE

Following the ideas about mechanistic formulations from (Ref. 1), and by summing the mass conservation equations for vapor and liquid water, a single equation can be written to calculate the time dependent evolution of moisture content, $w(\phi_w)$, in the porous medium:

$$\frac{\partial w(\phi_w)}{\partial t} + \rho_g \mathbf{u}_g \cdot \nabla\omega_v + \nabla \cdot \mathbf{g}_w + \mathbf{u}_l \cdot \nabla\rho_l + \nabla \cdot \mathbf{g}_{lc} = 0 \qquad (3)$$

The total moisture content accounts for the vapor and liquid water in the pores of the medium:

$$w(\phi_w) = \varepsilon_p s_l \rho_l + \varepsilon_p s_g \rho_g \omega_v$$

with ρ_l the liquid water density, ρ_g the moist air density, and ω_v the vapor mass fraction defined as:

$$\omega_v = \frac{M_v \phi_w c_{sat}(T)}{\rho_g}$$

The remaining terms in Equation 3 account for:

- Convection of vapor due to total pressure gradient, with the flow field $\mathbf{u}_g$ computed by the Brinkman equation.
- Binary diffusion of water vapor and dry air in the gaseous phase, with $\mathbf{g}_w$ defined as:

  $$\mathbf{g}_w = -\rho_g D_{eff} \nabla\omega_v$$

  A common correlation for the effective diffusivity D_{eff} in an unsaturated medium is the Millington and Quirk equation:

  $$D_{eff} = D_{va} \varepsilon_p^{4/3} s_g^{10/3}$$

  with the vapor-air diffusivity $D_{va} = 2.6 \cdot 10^{-5}\ m^2/s$.
- Convection of liquid water due to total pressure gradient, with the flow field $\mathbf{u}_l$ computed by the Darcy's Law in Equation 2. The permeability for the liquid phase κ_l

depends on the overall permeability of the porous matrix κ and a relative permeability (see Permeability) κ_{rl}.

- Capillary transport of liquid water, with $\mathbf{g}_{lc}$ defined as:

$$\mathbf{g}_{lc} = -D_w \frac{\partial w(\phi_w)}{\partial \phi_w} \nabla \phi_w$$

with the diffusion coefficient D_w defined as (Ref. 1):

$$D_w = 1e^{-8} \times \exp(-2.8 + 2w(\phi_w)/((1-\varepsilon_p)\rho_s))$$

with ρ_s the solid phase density.

When summing the conservation equations to obtain Equation 3, the condensation source term in the mass conservation equation for liquid water cancels out with the evaporation source term in the mass conservation equation for vapor. However, the evaporation source can be expressed as follows:

$$G_{evap} = \frac{\partial[\varepsilon_p \rho_g \omega_v s_g]}{\partial t} + \rho_g \mathbf{u}_g \cdot \nabla \omega_v + \nabla \cdot \mathbf{g}_w$$

HEAT TRANSFER

Inside the porous domain the overall velocity field for liquid and gaseous phase contributes to the heat convection term. It is possible to account for the liquid water and moist air phases, by using the liquid saturation calculated by the moisture transport equation.

The mixture law is applicable in the gaseous phase, and averaged thermal properties $(\rho C_p)_{eff}$ and k_{eff} are defined by taking into account the properties of the porous matrix (ρ_s, $C_{p,s}$, k_s), moist air (ρ_g, $C_{p,g}$, k_g), and liquid water (ρ_l, $C_{p,l}$, k_l):

$$\begin{aligned}(\rho C_p)_{eff} &= \varepsilon_p(s_g \rho_g C_{p,g} + s_l \rho_l C_{p,l}) + \theta_s \rho_s C_{p,s} \\ k_{eff} &= \varepsilon_p(s_g k_g + s_l k_l) + \theta_s k_s\end{aligned} \tag{4}$$

Then the overall velocity can be expressed as the average of moist air and liquid water velocity, which is

$$(\rho C_p)_{eff} \mathbf{u}_{eff} = \rho_g C_{p,g} \mathbf{u}_g + \rho_l C_{p,l} \mathbf{u}_l \tag{5}$$

The diffusive flux of enthalpy, due to vapor diffusion in air, and the capillary flux, due to the presence of the liquid water in the pores, are included in the following heat source term:

$$Q = -[(C_{p,\mathrm{v}} - C_{p,\mathrm{a}})\mathbf{g}_\mathrm{w} + C_{p,\mathrm{l}}\mathbf{g}_\mathrm{lc}] \quad (6)$$

The heat of evaporation is inserted as a source term in the heat transfer equation according to

$$Q_\mathrm{evap} = L_\mathrm{v} G_\mathrm{evap} \quad (7)$$

where L_v (J/mol) is the latent heat of evaporation.

PERMEABILITY

The permeability of the porous matrix κ defines the absolute permeability. When two phases are present, the permeability of each phase depends also on the saturation. This is defined by the relative permeabilities κ_rl and κ_rg for liquid and gaseous phase respectively, so that $\kappa_\mathrm{l} = \kappa\kappa_\mathrm{rl}$ and $\kappa_\mathrm{g} = \kappa\kappa_\mathrm{rg}$. The determination of relative permeability curves is often done empirically or experimentally and the form strongly depends on the porous material properties and the liquids themselves. The functions that are used in this model (Ref. 2) are defined such that they are always positive:

$$\kappa_\mathrm{rg} = \begin{cases} 1 - 1.1 s_\mathrm{l}, & s_\mathrm{l} < 1/1.1 \\ \mathrm{eps}, & s_\mathrm{l} \ge 1/1.1 \end{cases}$$

$$\kappa_\mathrm{rl} = \begin{cases} \left(\dfrac{s_\mathrm{l} - s_\mathrm{li}}{1 - s_\mathrm{li}}\right)^3, & s_\mathrm{l} > s_\mathrm{li} \\ \mathrm{eps}, & s_\mathrm{l} \le s_\mathrm{li} \end{cases}$$

The variable s_li is the irreducible liquid phase saturation, describing the saturation of the liquid phase that will remain inside the porous medium.

Results and Discussion

Inside the potato sample, the relative humidity decreases from about 100% everywhere at the beginning of the simulation to about 10% at the end, which is the ambient air condition (Figure 2 and Figure 3).

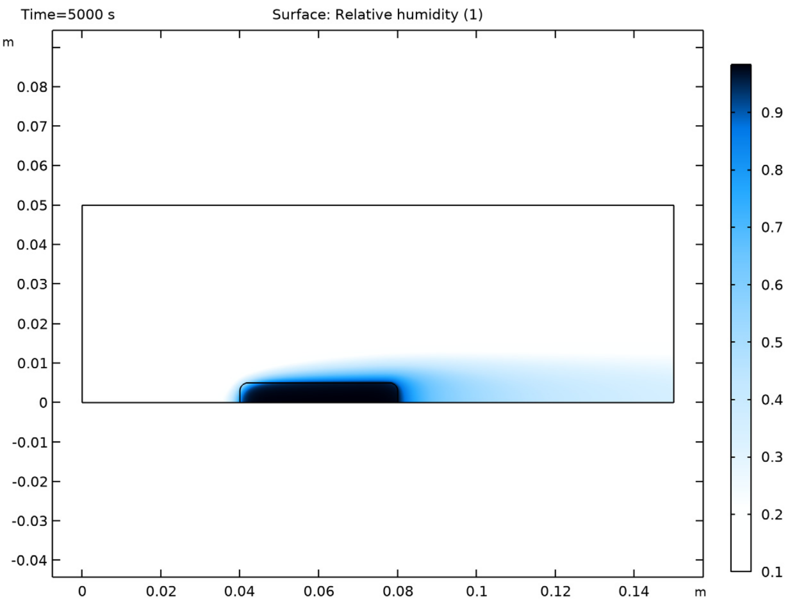


Figure 2: Relative humidity after 5000 s.

At the beginning of the simulation (time 5000 s), the vapor concentration is close to its saturation value in the moist air enclosed in the pores. It goes down to the ambient concentration toward the end of the simulation.

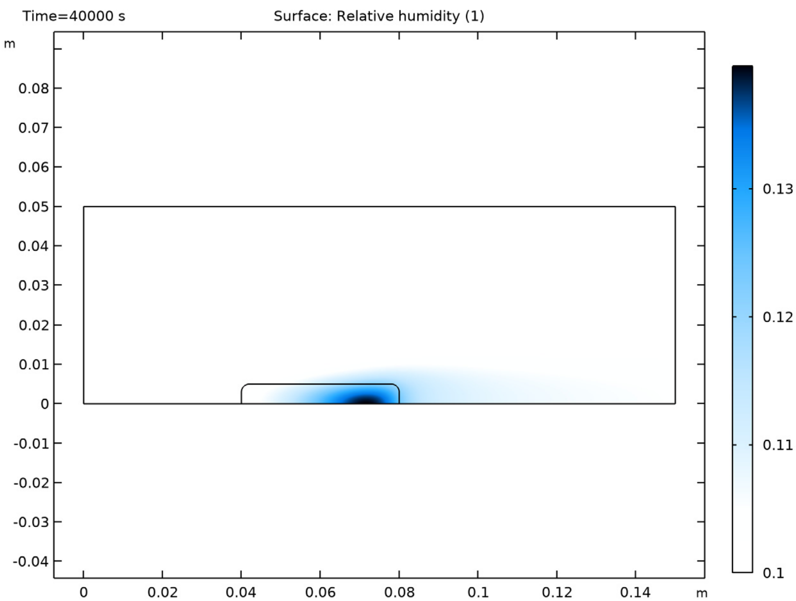


Figure 3: Relative humidity after 40,000 s.

Because moisture is composed of vapor and liquid water in the porous medium, a good quantifier of the drying process is the liquid saturation. Figure 4 shows the drying front in the porous medium at time 5000 s, starting from the top-left corner, which is facing the dry air flow.

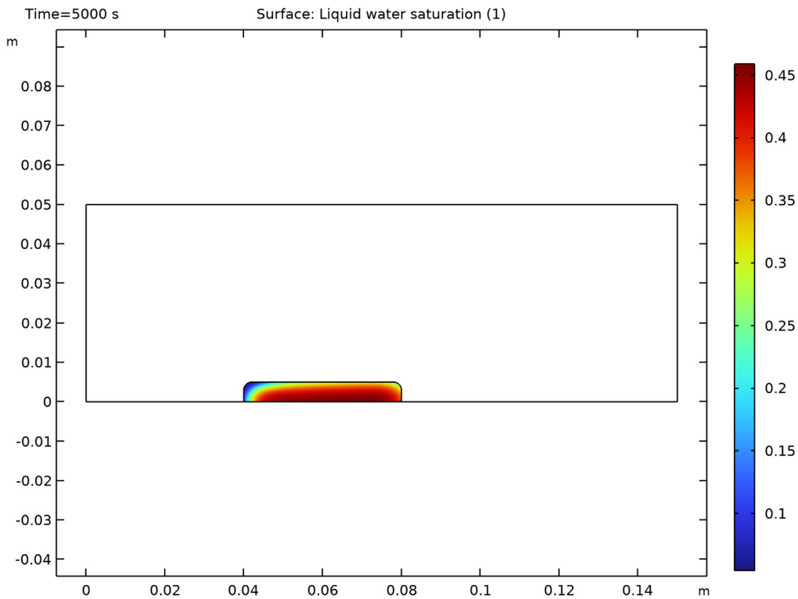


Figure 4: Liquid saturation after 5000 s.

The temperature plot (Figure 5) shows the corresponding cooling in the potato sample at time 5000 s, due to evaporation of the liquid water close to the drying front.

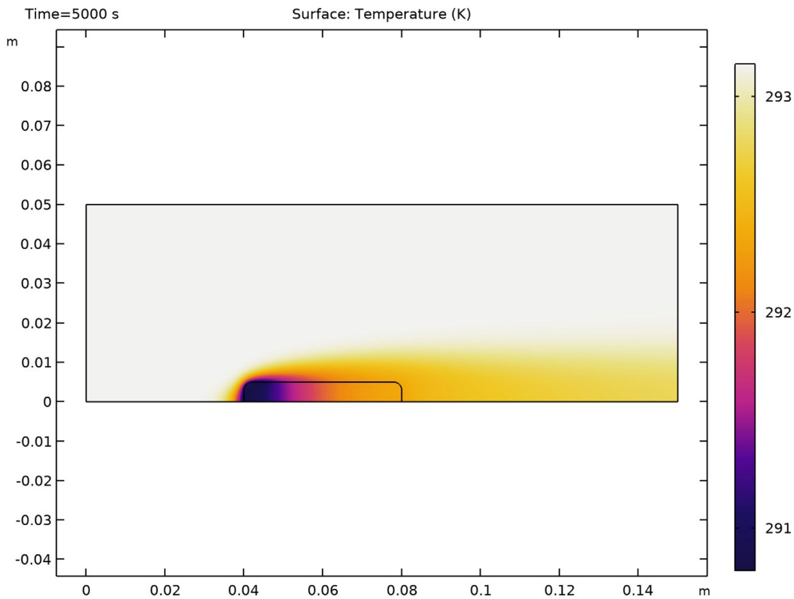


Figure 5: Temperature field after 5000 s.

Finally, the evolution of the moisture content in the potato sample over time is shown below.

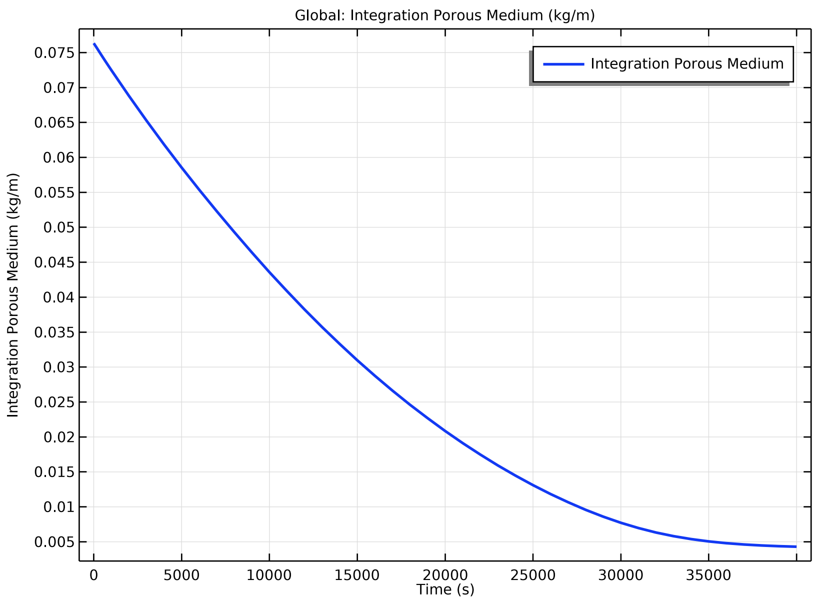


Figure 6: Moisture content in the potato sample over time.

Notes About the COMSOL Implementation

Using a proper mesh size is important to resolve the steep gradients at the interface boundaries. Therefore the default mesh is refined.

To get good convergence of the time dependent behavior, first solve the stationary flow equations only. This solution will then be used for the time dependent study step. This approximation neglects the evaporation mass source in the fluid flow computation.

References

1. A.K. Datta, "Porous media approaches to studying simultaneous heat and mass transfer in food processes. I: Problem formulations," *J. Food Eng.*, vol. 80, 2007.

2. A.K. Datta, "Porous media approaches to studying simultaneous heat and mass transfer in food processes. II: Property data and representative results," *J. Food Eng.*, vol. 80, 2007.

3. A. Halder, A. Dhall, and A.K. Datta, “Modeling Transport in Porous Media with Phase Change: Applications to Food Processing,” *J. Heat Transfer*, vol. 133, no. 3, 2011.

Application Library path: `Heat_Transfer_Module/Phase_Change/potato_drying`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.

2 In the **Select Physics** tree, select **Heat Transfer>Heat and Moisture Transport>Heat and Moisture Flow>Laminar Flow**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Time Dependent**.

6 Click **Done**.

For this model, some parameters are needed. Start by loading all of them from a text file.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model’s Application Libraries folder and double-click the file `potato_drying_parameters.txt`.

Define the relative permeabilities for water vapor and liquid water as functions of liquid water saturation. The advantage of using functions is that they can be plotted immediately.

DEFINITIONS

Relative Permeability, Moist Air

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Definitions** node.

2 Right-click **Definitions** and choose **Functions>Piecewise**.

3 In the **Settings** window for **Piecewise**, type `Relative Permeability, Moist Air` in the **Label** text field.

4 In the **Function name** text field, type `kappa_rma`.

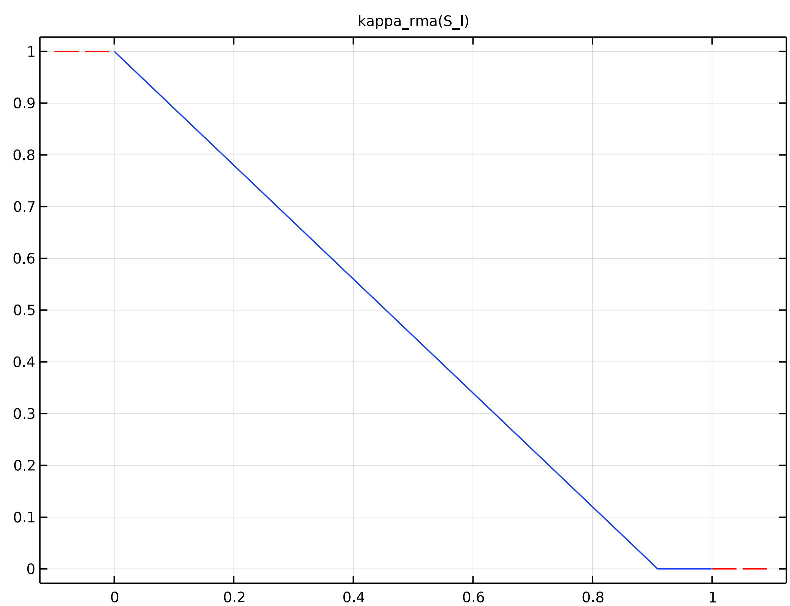
5 Locate the **Definition** section. In the **Argument** text field, type `S_l`.

6 Find the **Intervals** subsection. In the table, enter the following settings:

Start	End	Function
0	1/1.1	1-1.1*S_l
1/1.1	1	eps

To force the saturation to be always positive `eps` is used as minimum value.

7 Click **Plot**.



Relative Permeability, Liquid Phase

1 In the **Home** toolbar, click f(X) **Functions** and choose **Global>Piecewise**.

2 In the **Settings** window for **Piecewise**, type `Relative Permeability, Liquid Phase` in the **Label** text field.

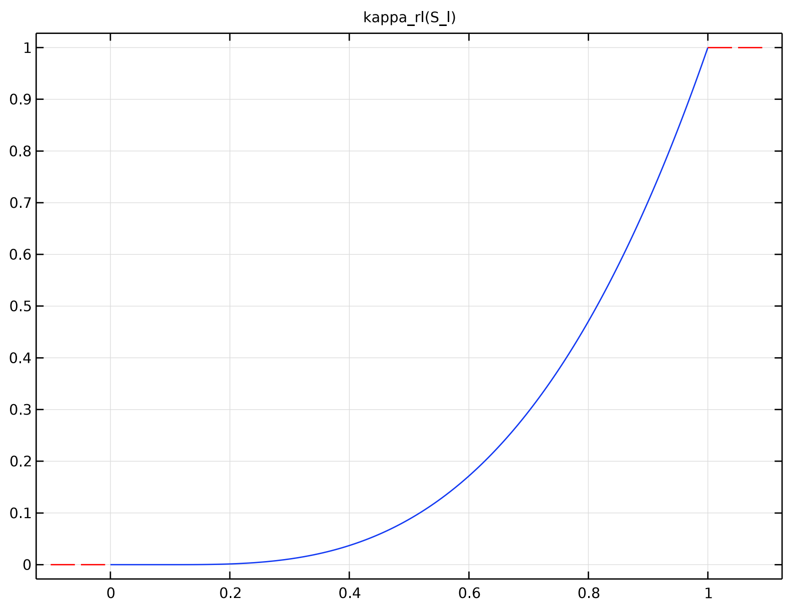
3 In the **Function name** text field, type `kappa_rl`.

4 Locate the **Definition** section. In the **Argument** text field, type `S_l`.

5 Find the **Intervals** subsection. In the table, enter the following settings:

Start	End	Function
0	S_il	eps
S_il	1	((S_l-S_il)/(1-S_il))^3

6 Click **Plot**.



Define the sorption isotherm by interpolation of tabulated data.

Sorption Isotherm

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Interpolation**.

2 In the **Settings** window for **Interpolation**, type `Sorption Isotherm` in the **Label** text field.

3 Locate the **Definition** section. In the **Function name** text field, type `wc_int`.

4 Click **Load from File**.

5 Browse to the model's Application Libraries folder and double-click the file `potato_drying_wc.txt`.

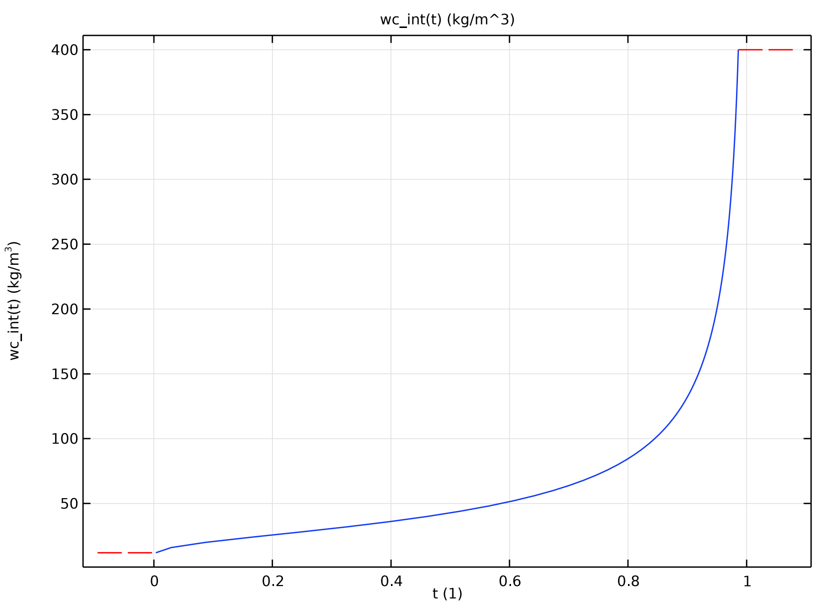
6 Locate the **Units** section. In the **Argument** table, enter the following settings:

Argument	Unit
t	1

7 In the **Function** table, enter the following settings:

Function	Unit
wc_int	kg/m^3

8 Click **Plot**.



Now, define the geometry.

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.15`.

4 In the **Height** text field, type `0.05`.

Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.04`.

4 In the **Height** text field, type `0.005`.

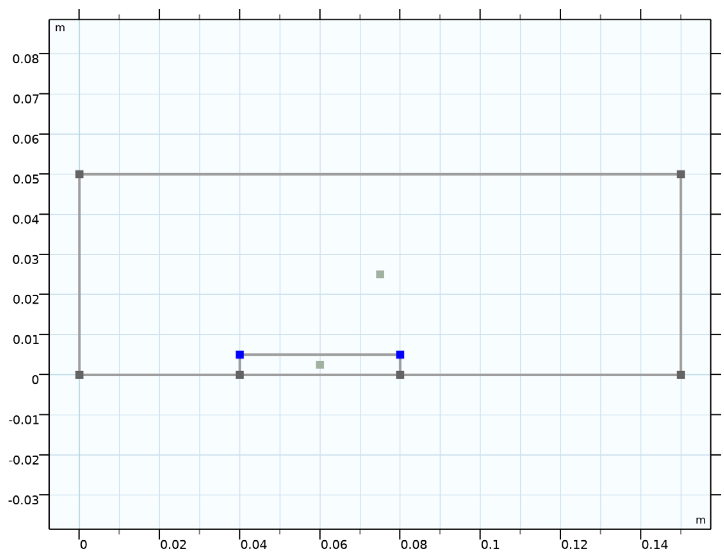
5 Locate the **Position** section. In the **x** text field, type `0.04`.

Fillet 1 (fil1)

1 In the **Geometry** toolbar, click **Fillet**.

2 On the object **r2**, select Points 3 and 4 only.

It might be easier to select the points by using the **Selection List** window. To open this window, in the **Home** toolbar click **Windows** and choose **Selection List**. (If you are running the cross-platform desktop, you find **Windows** in the main menu.)



3 In the **Settings** window for **Fillet**, locate the **Radius** section.

4 In the **Radius** text field, type `2e-3`.

5 In the **Geometry** toolbar, click **Build All**.

6 Click the **Zoom Extents** button in the **Graphics** toolbar.

DEFINITIONS

Define the ambient conditions used later in the domain and boundary conditions.

Ambient Properties 1 (ampr1)

1 In the **Physics** toolbar, click **Shared Properties** and choose **Ambient Properties**.

2 In the **Settings** window for **Ambient Properties**, locate the **Ambient Conditions** section.

3 In the T_{amb} text field, type `T0`.

4 In the ϕ_{amb} text field, type `phi_0`.

HEAT TRANSFER IN MOIST AIR (HT)

Define the domain and boundary conditions for each interface. Start with the **Heat Transfer in Moist Air** interface, by setting the initial and boundary conditions, and by adding a **Moist Porous Medium** domain condition.

Initial Values 1

Use the ambient temperature defined previously as input.

1 In the **Model Builder** window, under **Component 1 (comp1)>Heat Transfer in Moist Air (ht)** click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 From the T list, choose **Ambient temperature (ampr1)**.

Moist Porous Medium 1

1 In the **Physics** toolbar, click **Domains** and choose **Moist Porous Medium**.

2 Select Domain 2 only.

Porous Matrix 1

1 In the **Model Builder** window, click **Porous Matrix 1**.

2 In the **Settings** window for **Porous Matrix**, locate the **Matrix Properties** section.

3 From the **Define** list, choose **Solid phase properties**.

Inflow 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Inflow**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Inflow**, locate the **Upstream Properties** section.

4 From the T_{ustr} list, choose **Ambient temperature (ampr1)**.

Outflow 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Outflow**.

2 Select Boundary 9 only.

LAMINAR FLOW (SPF)

Continue with the **Laminar Flow** interface.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Laminar Flow (spf)**.

2 In the **Settings** window for **Laminar Flow**, locate the **Physical Model** section.

3 From the **Compressibility** list, choose **Compressible flow (Ma<0.3)**.

The next step enables additional features for the flow interface to account for porous domains also.

4 Select the **Enable porous media domains** check box.

Porous Medium 1

1 In the **Physics** toolbar, click **Domains** and choose **Porous Medium**.

2 Select Domain 2 only.

Porous Matrix 1

Set the material properties for the definition of Brinkman equation for vapor phase.

1 In the **Model Builder** window, click **Porous Matrix 1**.

2 In the **Settings** window for **Porous Matrix**, locate the **Matrix Properties** section.

3 From the ε_p list, choose **User defined**. In the associated text field, type `por*(1-mt.sl)`.

The pore space is partially filled with liquid water, so that the available space for water vapor depends on the porosity and the saturation.

4 From the κ list, choose **User defined**. In the associated text field, type `kappa_rma(mt.sl)*kappa`.

Inlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Inlet**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Inlet**, locate the **Boundary Condition** section.

4 From the list, choose **Fully developed flow**.

5 Locate the **Fully Developed Flow** section. In the U_{av} text field, type `u0`.

Outlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Outlet**.

2 Select Boundary 9 only.

MOISTURE TRANSPORT IN AIR (MT)

Finally, set the domain, initial, and boundary conditions for the **Moisture Transport in Air** interface.

Initial Values 1

1 In the **Model Builder** window, under **Component 1 (comp1)> Moisture Transport in Air (mt)** click **Initial Values 1**.

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 From the $\phi_{w,0}$ list, choose **Ambient relative humidity (ampr1)**.

Hygroscopic Porous Medium 1

1 In the **Physics** toolbar, click **Domains** and choose **Hygroscopic Porous Medium**.

2 Select Domain 2 only.

3 In the **Settings** window for **Hygroscopic Porous Medium**, locate the **Moisture Transport Properties** section.

4 From the **Capillary model** list, choose **Diffusion**.

Liquid Water 1

1 In the **Model Builder** window, expand the **Hygroscopic Porous Medium 1** node, then click **Liquid Water 1**.

2 In the **Settings** window for **Liquid Water**, locate the **Liquid Water Properties** section.

3 In the κ_{rl} text field, type `kappa_rl(mt.sl)`.

Initial Values 2

1 In the **Physics** toolbar, click **Domains** and choose **Initial Values**.

2 Select Domain 2 only.

3 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

4 In the $\phi_{w,0}$ text field, type `phi_1`.

Inflow 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Inflow**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Inflow**, locate the **Upstream Properties** section.

4 From the T_{ustr} list, choose **Ambient temperature (ampr1)**.

5 From the $\phi_{w,ustr}$ list, choose **Ambient relative humidity (ampr1)**.

Outflow 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Outflow**.

2 Select Boundary 9 only.

MATERIALS

Next, define the hygrothermal properties for the porous medium, based on measured data for potato.

Potato

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **More Materials>Porous Material**.

2 In the **Settings** window for **Porous Material**, type `Potato` in the **Label** text field.

3 Select Domain 2 only.

Add the **Solid** subnode and define its material properties.

4 Locate the **Phase-Specific Properties** section. Click **Add Required Phase Nodes**.

Solid 1 (pmat1.solid1)

1 In the **Model Builder** window, click **Solid 1 (pmat1.solid1)**.

2 In the **Settings** window for **Solid**, locate the **Solid Properties** section.

3 In the θ_s text field, type `1-por`.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Density	rho	rho_s	kg/m³	Basic
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	k_s	W/(m·K)	Basic
Heat capacity at constant pressure	Cp	cp_s	J/(kg·K)	Basic
Porosity	epsilon	0.8	1	Porous model

Potato (pmat1)

Set the remaining material properties in the **Homogenized Properties** section.

1 In the **Model Builder** window, click **Potato (pmat1)**.

2 In the **Settings** window for **Porous Material**, locate the **Homogenized Properties** section.

3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Diffusion coefficient	D_iso ; Dii = D_iso, Dij = 0	`1e-8[m^2/s]*exp(-2.8+2*w_c/rho_s/(1-por))`	m²/s	Basic
Water content	w_c	`wc_int(phi)`	kg/m³	Basic
Permeability	kappa_iso ; kappaii = kappa_iso, kappaij = 0	`kappa`	m²	Basic
Porosity	epsilon	0.8	1	Porous model

As the water content is defined as a function of the relative humidity, add the relative humidity as a model input required by the material.

4 In the **Model Builder** window, click **Basic (def)**.

5 In the **Settings** window for **Basic**, locate the **Model Inputs** section.

6 Click **Select Quantity**.

7 In the **Physical Quantity** dialog box, type `relative` in the text field.

8 In the tree, select **General>Relative humidity (1)**.

9 Click **OK**.

DEFINITIONS (COMP1)

Define an integration operator in the porous domain, in order to check the moisture content evolution.

Integration Porous Medium

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Integration**.

2 Select Domain 2 only.

3 In the **Settings** window for **Integration**, type `Integration Porous Medium` in the **Label** text field.

4 In the **Operator name** text field, type `intopPorous`.

To resolve all effects and get a better convergence for this highly nonlinear problem, refine the mesh to resolve the interface properly.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extra fine**.

4 Click **Build All**.

STUDY 1

Add a stationary step that solves for the fluid flow only. This approximation does not account for the evaporation mass source in the porous medium for the fluid flow initialization. The solution is used for the computation of the time dependent solution of all the processes.

Step 2: Stationary

1 In the **Study** toolbar, click **Study Steps** and choose **Stationary>Stationary**.

2 Drag and drop above **Step 2: Time Dependent**.

3 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

4 In the table, clear the **Solve for** check boxes for **Moisture Transport in Air (mt)** and **Heat Transfer in Moist Air (ht)**.

Step 2: Time Dependent

1 In the **Model Builder** window, click **Step 2: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 In the **Output times** text field, type `range(0,10,90) range(100,100,900) range(1000,1000,40000)`.

Reduce the solver tolerance to enhance accuracy on mass balance.

4 From the **Tolerance** list, choose **User controlled**.

5 In the **Relative tolerance** text field, type `0.001`.

6 In the **Study** toolbar, click **Compute**.

RESULTS

The default plots show the velocity, the pressure, the relative humidity (Figure 3), and the temperature.

Relative Humidity (mt)

Change the plot time to 5000 s for the relative humidity and the temperature to obtain Figure 2 and Figure 5.

1 In the **Model Builder** window, click **Relative Humidity (mt)**.
2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.
3 From the **Time (s)** list, choose **5000**.
4 In the **Relative Humidity (mt)** toolbar, click **Plot**.

Temperature (ht)

1 In the **Model Builder** window, click **Temperature (ht)**.
2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.
3 From the **Time (s)** list, choose **5000**.
4 In the **Temperature (ht)** toolbar, click **Plot**.

ADD PREDEFINED PLOT

Insert one of the predefined plots of the liquid saturation in the porous medium at time 5000 s as in Figure 4, in order to check the evolution of the drying front.

1 In the **Home** toolbar, click **Windows** and choose **Add Predefined Plot**.
2 Go to the **Add Predefined Plot** window.
3 In the tree, select **Study 1/Solution 1 (sol1)>Moisture Transport in Air>Saturation (mt)**.
4 Click **Add Plot** in the window toolbar.

RESULTS

Saturation (mt)

1 In the **Settings** window for **2D Plot Group**, locate the **Data** section.
2 From the **Time (s)** list, choose **5000**.
3 In the **Saturation (mt)** toolbar, click **Plot**.

Moisture Content in Porous Medium over Time

Follow the instructions below to plot the evolution of the moisture content over time in the porous medium as in Figure 6, in order to check the efficiency of the drying process.

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2 In the **Settings** window for **1D Plot Group**, type `Moisture Content in Porous Medium over Time` in the **Label** text field.
3 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Total moisture content in the potato`.

5 Locate the **Plot Settings** section.

6 Select the **y-axis label** check box. In the associated text field, type `Total moisture content in the potato (kg/m)`.

Global 1

1 Right-click **Moisture Content in Porous Medium over Time** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`intopPorous(mt.wcVar)`	`kg/m`	`Integration Porous Medium`

4 Click to expand the **Coloring and Style** section. From the **Width** list, choose **2**.

5 Click to expand the **Legends** section. Clear the **Show legends** check box.

6 In the **Moisture Content in Porous Medium over Time** toolbar, click **Plot**.

Mass Balance

Finally, follow the instructions below to check the overall mass balance over time.

1 In the **Results** toolbar, click 8.5 **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, type `Mass Balance` in the **Label** text field.

3 Click **Replace Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)>Moisture Transport in Air>Mass balance> mt.massBalance - Mass balance - kg/s**.

4 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)>Moisture Transport in Air>Mass balance> mt.dwcInt - Total accumulated moisture rate - kg/s**.

5 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)>Moisture Transport in Air>Mass balance> mt.ntfluxInt - Total net moisture rate - kg/s**.

6 Click **Add Expression** in the upper-right corner of the **Expressions** section. From the menu, choose **Component 1 (comp1)>Moisture Transport in Air>Mass balance>mt.GInt - Total mass source - kg/s**.

7 Click **Evaluate**.

TABLE 1

1 Go to the **Table 1** window.

2 Click **Table Graph** in the window toolbar.

RESULTS

Mass Balance

1 In the **Model Builder** window, under **Results** click **1D Plot Group 8**.

2 In the **Settings** window for **1D Plot Group**, type `Mass Balance` in the **Label** text field.

Table Graph 1

1 In the **Model Builder** window, click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, click to expand the **Legends** section.

3 Select the **Show legends** check box.

4 Locate the **Coloring and Style** section. From the **Width** list, choose **2**.