



Beverage Refrigeration Simulation in Dependence on Container Shape, Material and Orientation

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Introduction: Liquid beverages are often available in different containers, like soda-lime glass, Aluminum or PET. Simulation techniques can be used to determine their individual cooling behavior, regarding heat transfer properties and shape of different container materials (glass, Aluminum and PET) as well as the horizontal or vertical orientation of the container. To examine the influence of several input parameters – like the initial beverage temperature – on the cooling process, an easy-to-use simulation interface was built, using the COMSOL Application Builder.

The component's geometry and mesh can be reviewed using the graphics views on the right side. Afterwards the material properties are selected from one of the given presets using the dropdown box (2) or custom values can be entered in the three subsequent text fields. If the glass bottle is selected, the properties of the bottle's cap have to be set, too, using the *Material Cap* tab.

Section *Initial & Boundary conditions* (3) provides possibilities to insert the initial interior temperature as well as the exterior temperature and the heat transfer coefficient of the container's exterior boundaries. Finally, in section *Miscellaneous* (4), the total simulation time and the length of time-steps can be inserted. The ribbon button *Compute* (5) starts the simulation.

Once the simulation is finished, a plot of the beverage's average temperature over time is shown in the *Current Result* tab on the right side. Using the *Plot to history* button (6) in the ribbon menu, this plot can be copied to the history plot (cf. figure 3), providing an easy way to compare several simulation results.

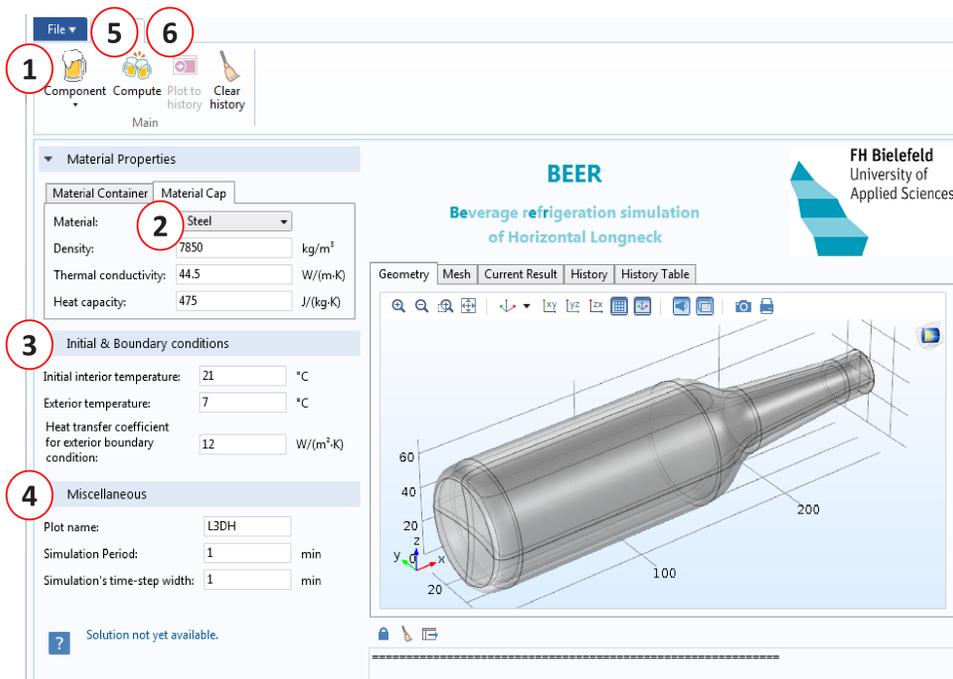


Figure 1. Application overview.

Computational Methods: The studied cooling process can be described using the two physics interfaces *heat transfer in fluids* and *laminar flow*. Thus, the process is governed by the energy equation (1) for heat transfer, conservation of mass (2) and the Navier-Stokes equation (3) for fluid dynamics.

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q \quad (1)$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \quad (2)$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho (\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot \left[-p \mathbf{I} + \mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3} \mu (\nabla \cdot \mathbf{u}) \mathbf{I} \right] + \mathbf{F} \quad (3)$$

Application Description: The ribbon menu provides the basic commands for the application. All buttons are placed, from left to right, in the same order that they are supposed to be used.

To prepare a new simulation the container shape and orientation can be chosen from the ribbon sub-menu *Component* (see figure 1, mark 1 and figure 2).

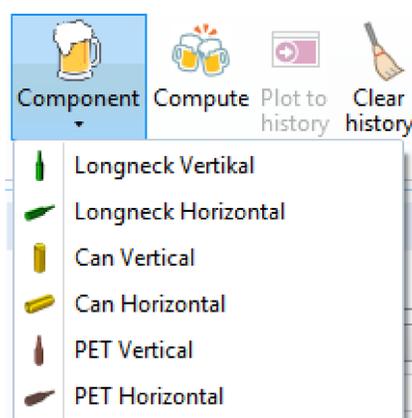


Figure 2. Component selection.

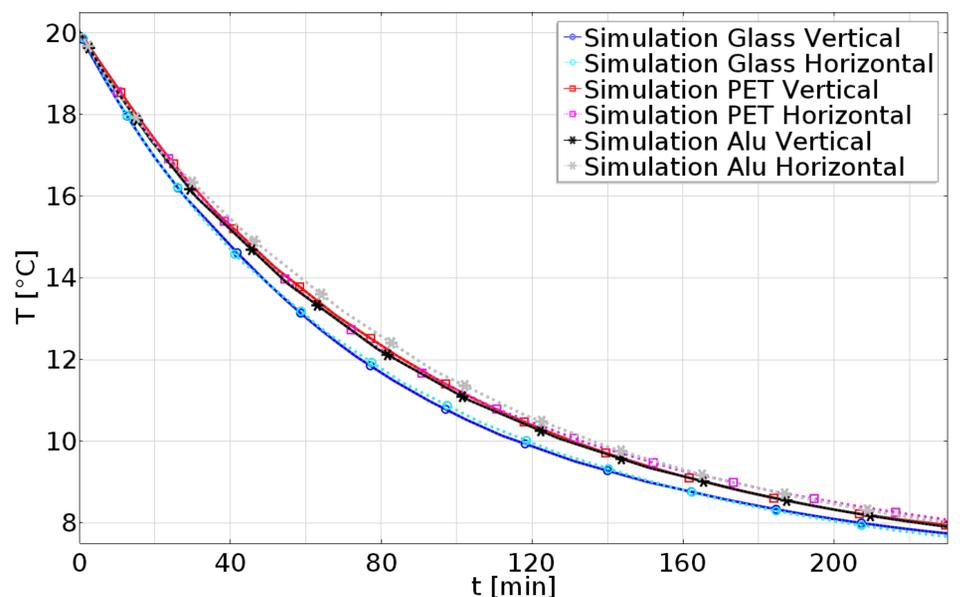


Figure 3. Simulation results comparison

Findings: COMSOL Applications provide a way to build easy-to-use interfaces, that hide the technical details of FEM. But such simplification also hides portions of the design space, if essential parameters need to be hard-coded into the application. E.g. the presented application does not allow the user to change the bottle's wall thickness, to prevent failure of the mesh-sequence. Thus, COMSOL Applications must be developed with their exact use case in mind.

Regarding the actual question of differences in the cooling behavior of glass, Aluminum and PET containers: Do not bother buying PET-bottled beer, glass bottles cool slightly faster.

