COMSOL Blog

Modeling Marangoni Convection with COMSOL Multiphysics

by **Eric Favre** (https://www.comsol.com/blogs/author/eric-favre/)

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Previously on the blog, we introduced you to the **tears of wine phenomenon** (https://www.comsol.com/blogs/tears-of-wine-and-the-marangoni-effect/) and its cause — the Marangoni effect. This effect results from a gradient of surface tension at the interface between two phases. In situations where a surface gradient is temperature dependent, the Marangoni effect is referred to as *Marangoni convection*. Here, we will demonstrate how to analyze Marangoni convection in COMSOL Multiphysics and easily separate effects, such as gravity, in your simulations.

The Challenges of Studying Marangoni Convection

Marangoni convection — also called *thermocapillary convection* — is **important in a number of processes** (http://www.comsol.com/multiphysics/marangoni-effect), including welding, crystal growth, and electron beam melting. Due to the types of metals used and the extremely high temperatures involved, performing experiments to analyze Marangoni convection often proves to be rather challenging. The impact of gravity, which mixes up this convective effect with the Marangoni effect, also adds to the difficulty of studying this phenomenon.

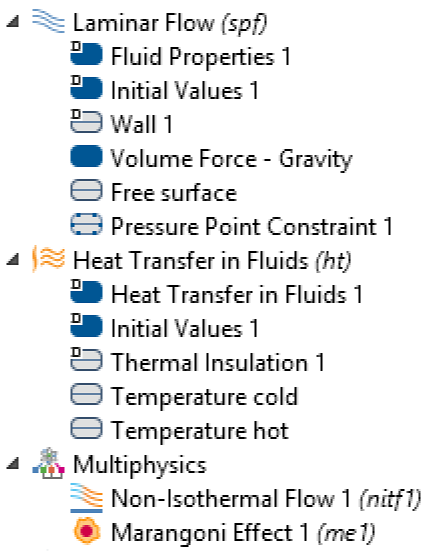
At NASA, **researchers analyzed Marangoni convection** (http://www.nasa.gov/mission_pages/station/research/news/marangoni.html) to see how mass and heat move within a fluid under microgravity conditions. Conducting the experiment in microgravity enabled the research team to create silicone oil columns much larger than those that could be studied on Earth, offering a more detailed look at the flow and instability within them. Additionally, suppressing the influence of gravity helped eliminate the possibility of gravity-induced deformation, thus enhancing the accuracy of their results.

With numerical experiments, it is very easy to separate effects that are simply impossible to remove in an experiment on Earth. Our **Marangoni Effect tutorial** (http://www.comsol.com/model/marangoni-effect-20329) uses a transparent liquid at ambient temperatures to find the velocity field induced through the Marangoni effect in a fluid with known thermo-physical properties. The transparency of the silicone oil makes it easy to implement and compare our simulation results with the microgravity experimental findings.

A Simulation Analysis

To begin, we must solve the **Navier-Stokes equations** (http://www.comsol.com/multiphysics/navier-stokes-equations) to model the velocity field and pressure distribution in the fluid. Keep in mind that variations in temperature affect the velocity and cause a buoyancy force that needs to be represented in the equations. This can be done by using the **Boussinesq approximation** (http://www.comsol.com/multiphysics/boussinesq-approximation) in the Navier-Stokes equations.

With the *Laminar Flow* interface, we can solve the momentum balance equations. To solve for heat transfer, we use the *Heat Transfer in Fluids* interface. Finally, we use the *Non-Isothermal Flow* multiphysics coupling to set the convective term in the heat equation and the *Marangoni Effect* multiphysics coupling to impose that the shear stress is proportional to the temperature gradient.



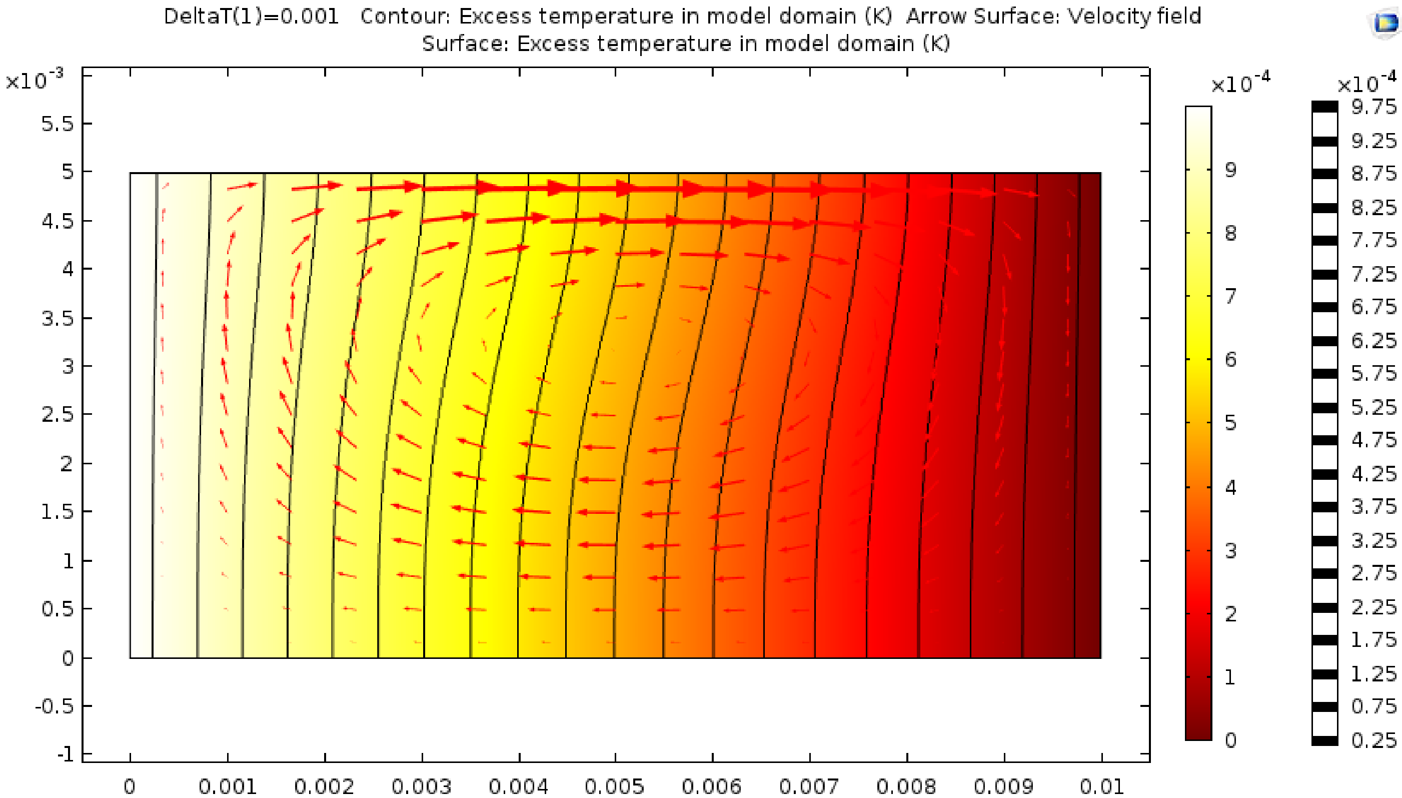
The setup of the tutorial model. The Multiphysics node contains both the nonisothermal coupling and the Marangoni effect.

This simulation presents three multiphysics couplings that must be solved using the nonlinear solver:

1. Because of the temperature dependency of the fluid density, ρ, accounted for following the Boussinesq approximation, the gravity force, $-\rho\mathbf{g}$, is given by an expression that includes temperature.
2. Convective heat transfer depends on the velocity of the momentum balance.
3. The Marangoni effect relates the shear stress applied at the free surface to the surface temperature gradient.

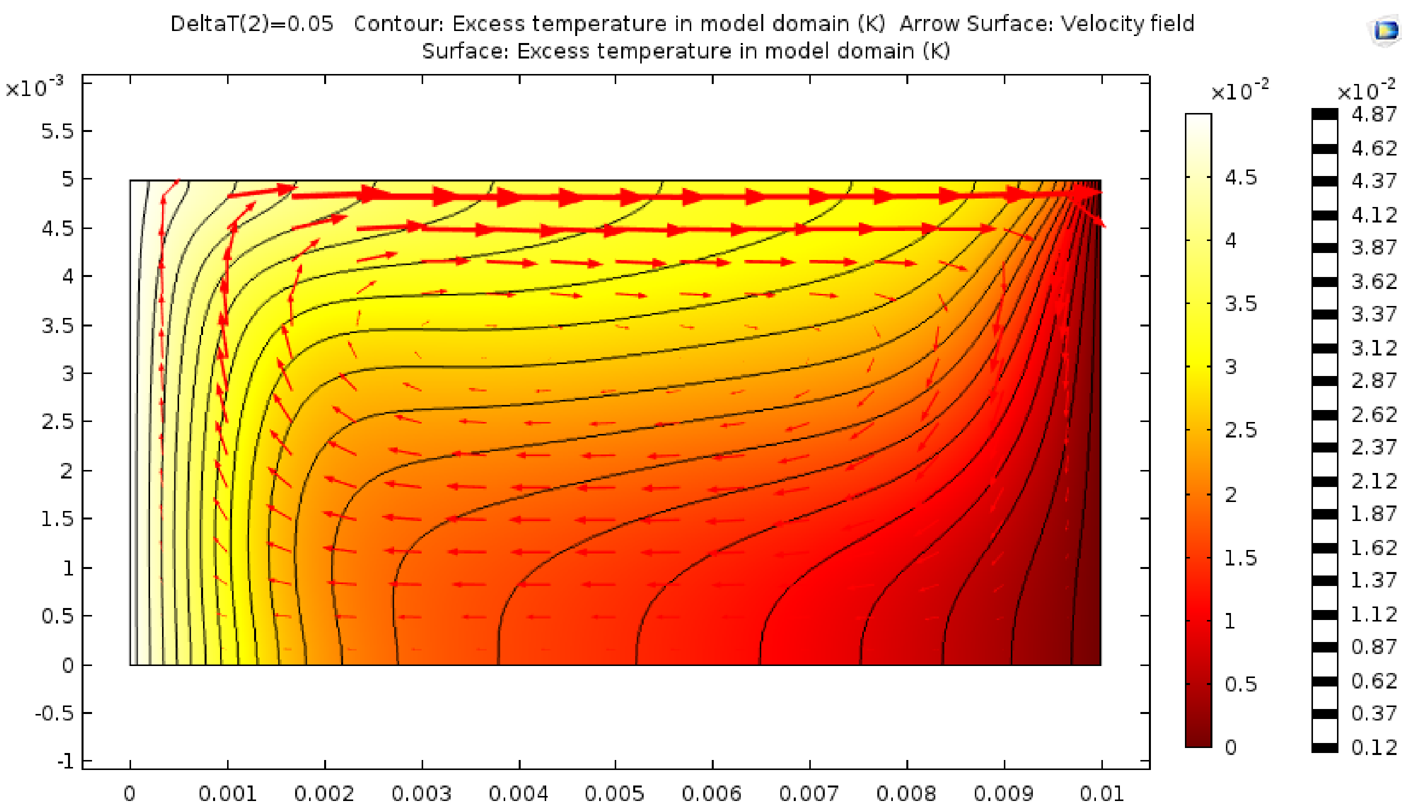
Simulation Results

In our simulations, we analyze a gradual increase in temperature difference between vertical walls. For an almost unnoticeable temperature increase of 1 mK, the temperature field and velocity field have only a slight relation, and the decrease appears linear from left to right.



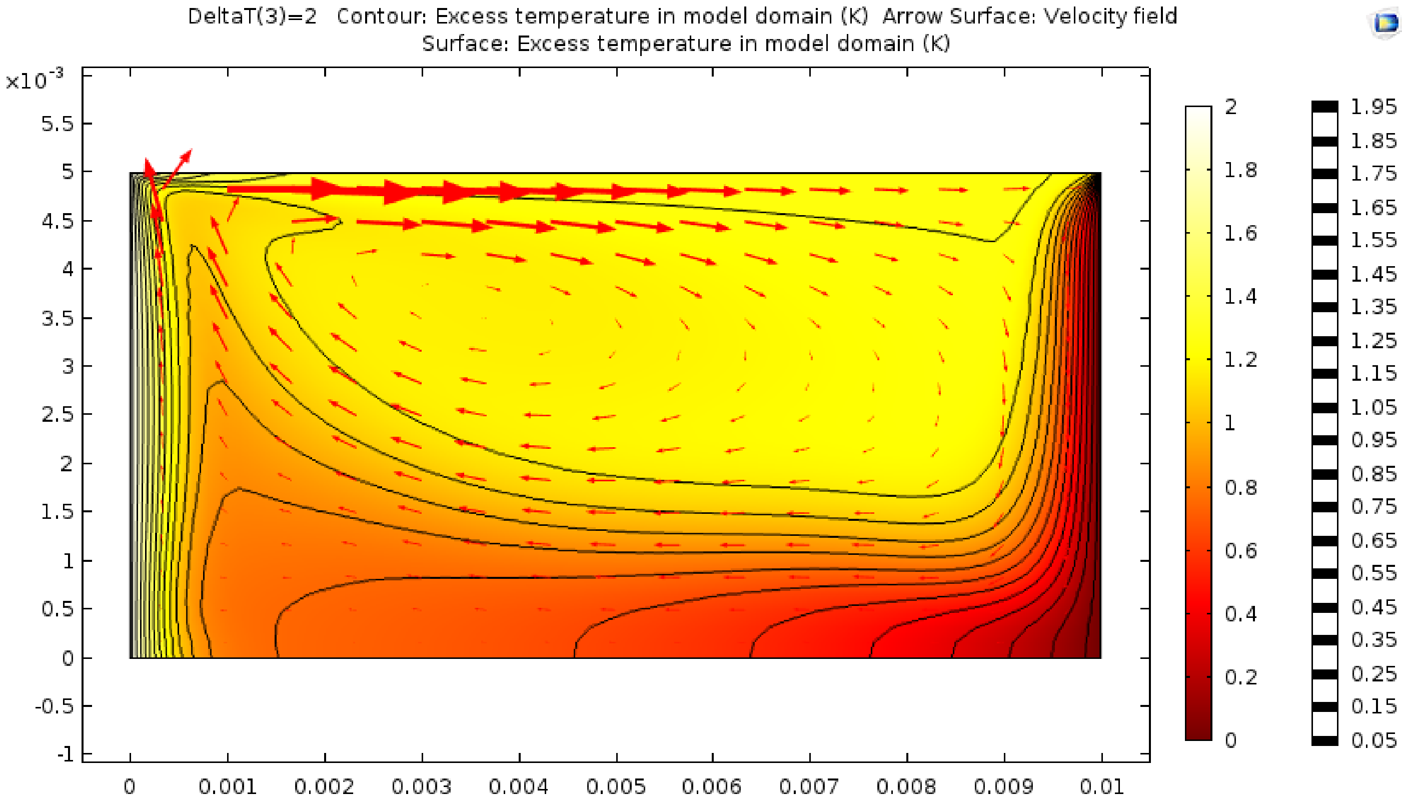
The results of a Marangoni effect simulation after only a small change in temperature. The background color represents the temperature field and the red arrows indicate the velocity field. The black lines are isotherms.

With an increase of 50 mK, Marangoni convection increases the fluid flow and temperature distribution. The temperature decrease is no longer linear across the plot.



The results of the simulation after a temperature increase of 50 mK.

Finally, we test a temperature difference of 2 K. The temperature and velocity fields are distinctly coupled and the fluid accelerates at the surface where the temperature gradient is highest.

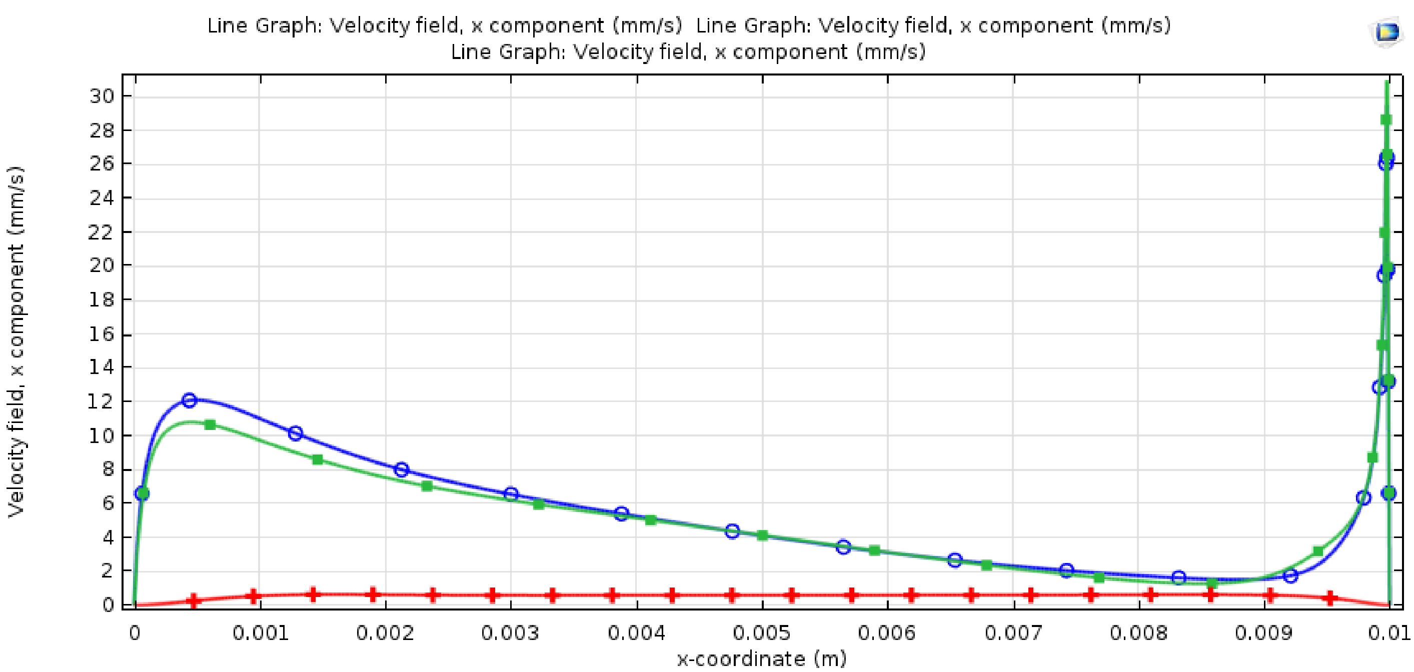


The results of the simulation when the temperature difference is raised to 2 K.

As indicated by the simulation results, the Marangoni effect becomes predominant as the difference in temperature increases.

Separating Gravity from the Marangoni Effect

For the same temperature difference of 2 K, we can easily remove the gravity contribution and keep the Marangoni effect. With the same objective of understanding how buoyancy forces compare with the Marangoni effect, we can simply disable the Marangoni contribution at the surface, leaving the surface free of stress. The results show that the Marangoni effect is predominant versus buoyancy forces. The shape of the curve shows a peak close to the cold right wall, which is characteristic of the fluid behavior of high Prandtl numbers.



The results of the horizontal velocity at the surface versus the horizontal coordinate (m) for a temperature difference of 2 K. Blue represents both the Marangoni effect and the buoyancy effect; green represents only the Marangoni effect; and red represents only the buoyancy effect.

Summary

In this blog post, we have demonstrated how to set up a model representing an experiment combining gravity and Marangoni effects. Separating these two effects is challenging in an experimental setting. In numerical simulations, this process is straightforward, facilitating an understanding of each effect.

You can reproduce the results shown here by downloading the **Marangoni Effect tutorial** (http://www.comsol.com/model/marangoni-effect-20329) from our Application Gallery. This example uses the Non-Isothermal Flow and Marangoni Effect multiphysics couplings available in the **Heat Transfer Module** (http://www.comsol.com/heat-transfer-module).

While we have focused our attention here on single-phase flows, it is worth mentioning that the Marangoni effect is also handled in the two-phase flow interfaces, which are available in the **CFD Module** (http://www.comsol.com/cfd-module) and the **Microfluidics Module** (http://www.comsol.com/microfluidics-module).