COMSOL as an Aid in the Teaching (Learning) of Heat Transfer

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Introduction: A topic that must be included in the "Heat transfer" course for undergraduate students is that referring to the heat flow through fins and bars of some solid material. In our experience, these concepts are not easy to understand for students, because they involve two types of transfer: conduction and convection; the first occurs in the bar and the second occurs both in the bar and the surrounding environment.

With this in mind, we designed and constructed an apparatus for the experimentation of heat transfer in a short bar. It was observed, however, that the time required to perform the experiment was so long, that the didactic aim was lost in time-consuming activities, such as the setting of the instrumentation, the data registration and processing, and the software calibration. The purpose of this work is to present the results obtained while using the COMSOL multiphysics software to describe the heat flow through a short bar immersed in a liquid, underlying the advantages over the actual experimentation.

Model definition. A bar with A, cross section, L, length and p, perimeter, immersed in a liquid at constant temperature , is considered. The container is surrounded by air at which is the environmental temperature. The bar is made of a material with a constant thermal conductivity, k, and the convective heat transfer coefficient between the bar and the surrounding liquid is The length of the bar is 0.15 m, the diameter is 0.0254 m, the material is copper and the surrounding fluid is water. The initial temperature of the bar and the fluid is 20 ˚ C.

The heat flow through the bar, and between the bar and the surrounding environment, which occur by conduction and convection, respectively, are described in the program by means of the following equation:

$$\delta \, \rho \, C_p \frac{\partial T}{\partial t} + \Delta \cdot (-k\Delta T) = Q - \rho C_p u \cdot \Delta T$$
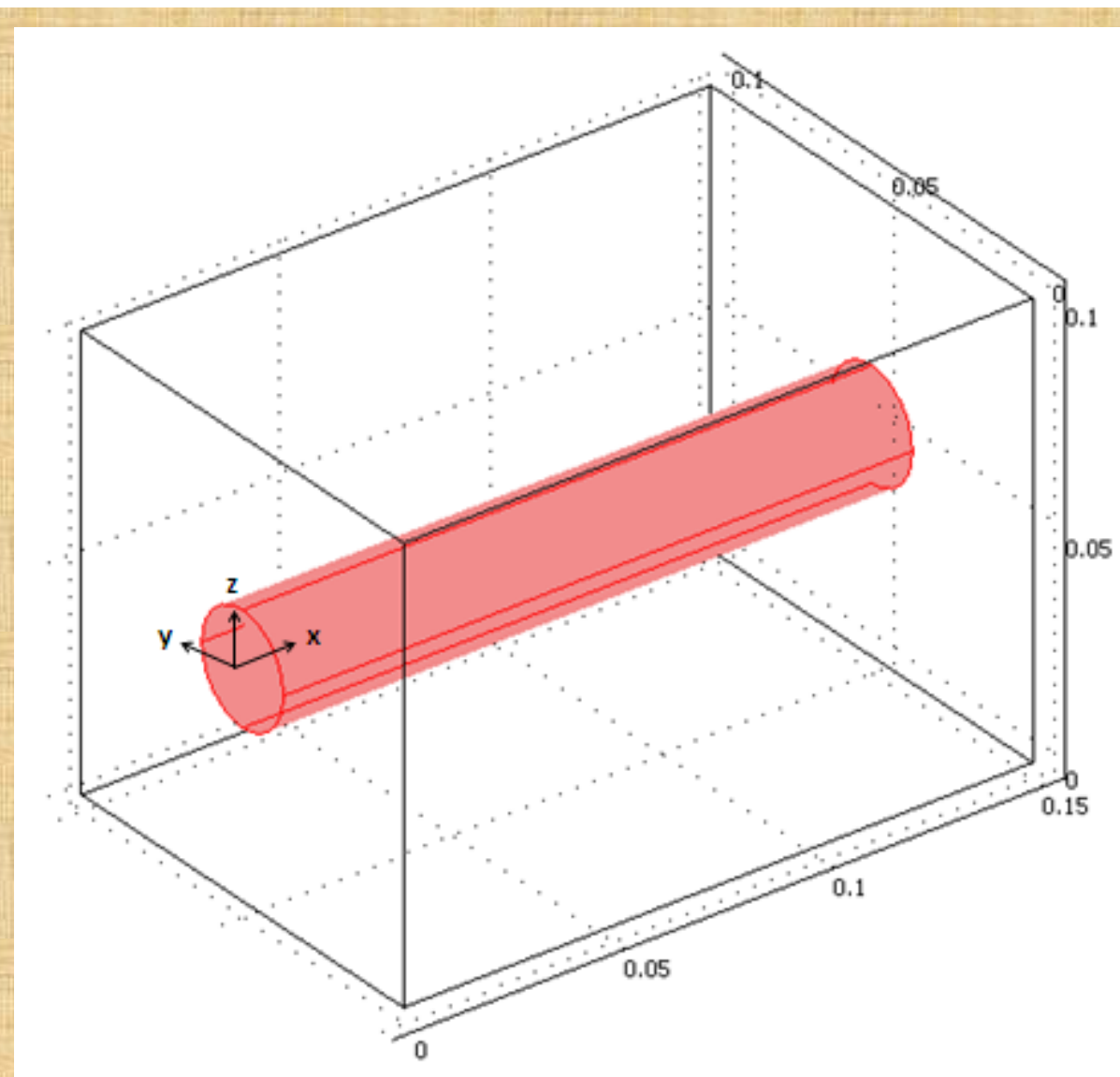

Figure 1. Model geometry

Results: At the initial edge of the bar, for X = 0.00 m, comparing both values of supplied energy, the difference between the values of temperature in the central axis and the surface of the bar is minimal. The maximum temperatures that could be reached in the central line are 298.305 K, and 303.462 K respectively. The temperature profile of the bar is presented in fig. 2.

The temperature distribution in the bar observed from the cross section point of view and in the surrounding fluid at the initial edge of the bar, for X = 0.00 m, is presented in fig. 3. It can be clearly observed that the increment of the fluid temperature is proportional to the increment in the supplied energy. The temperature profile of the fluid, observed from the upper part of the container is presented in fig.4. The highest temperature values occur at the beginning of the bar and they diminish towards its final edge. The minimal values are found near the corners of the container.
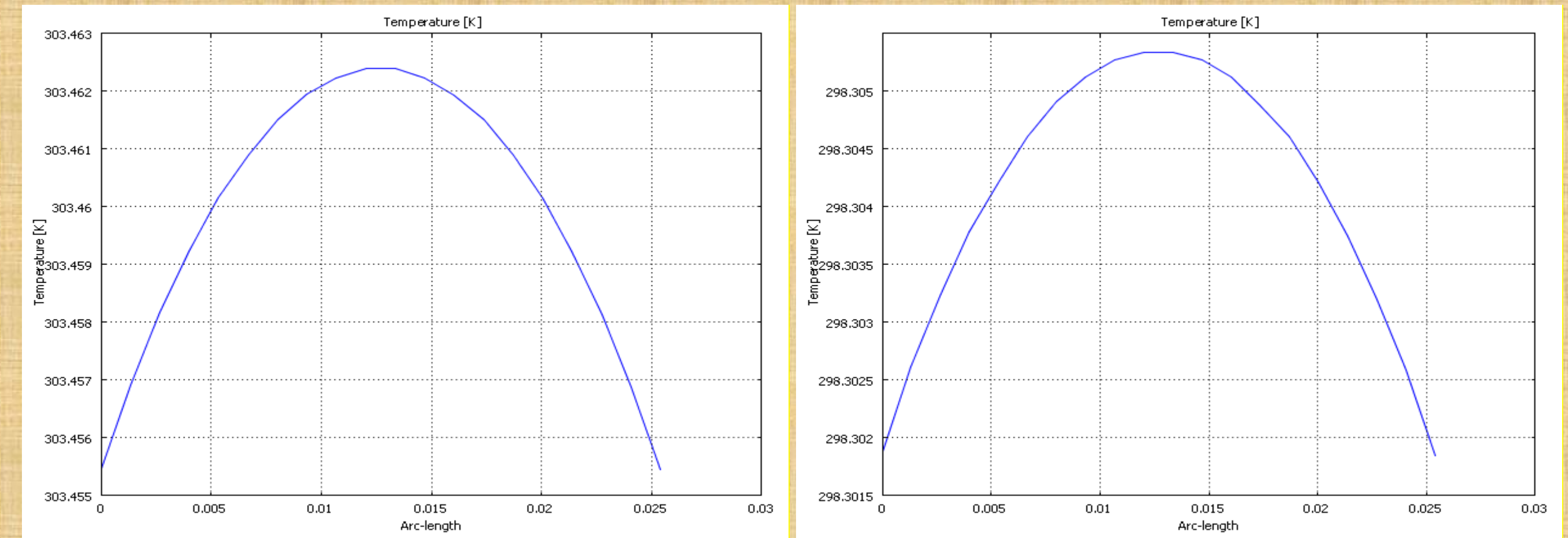

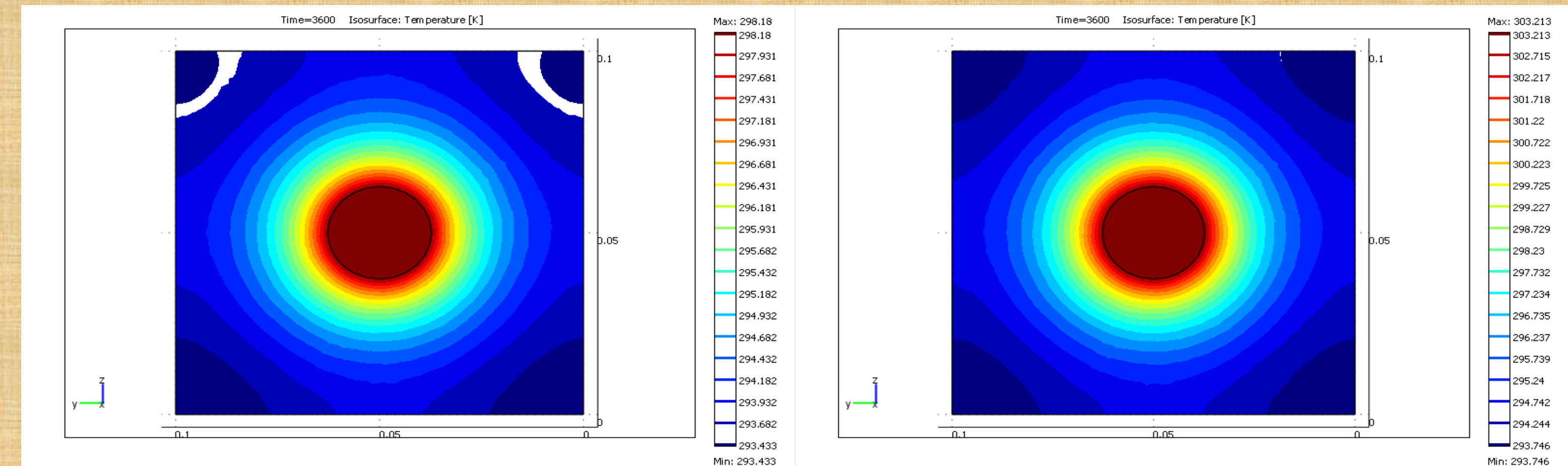**Figure 2**. Temperature profile in the bar, for 5 000 and 10 000W/m^2

Figure 3. Temperature patterns in the bar and the surrounding fluid, at the initial edge of the bar, for 5 000 and 10 000W/m^2
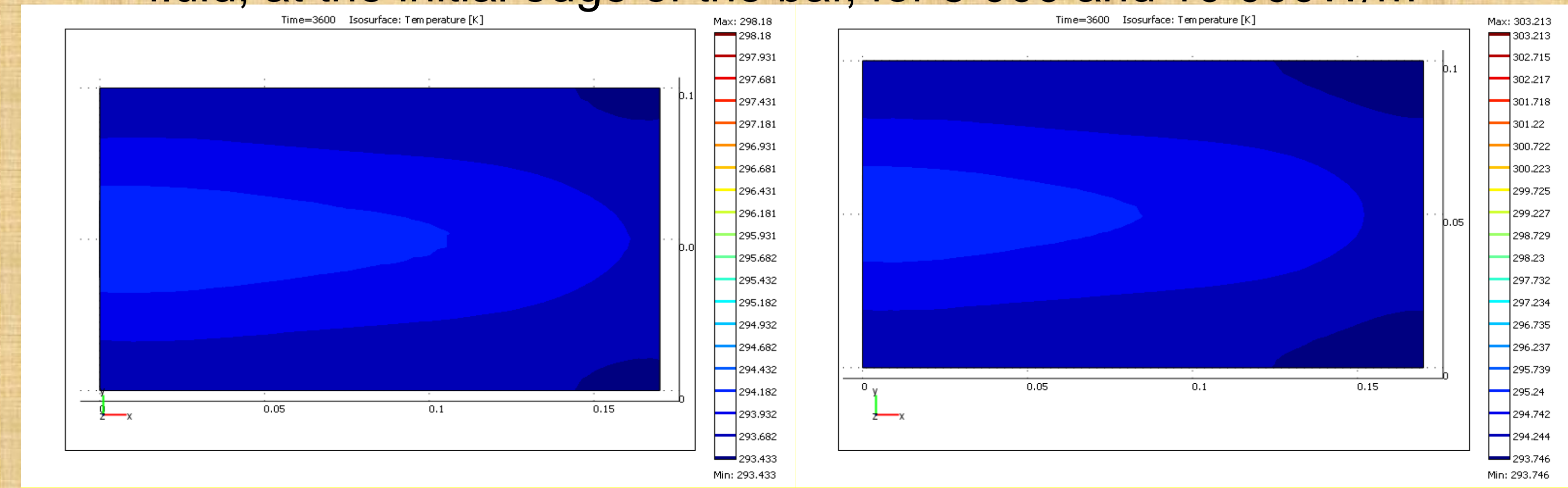

Figure 4. Temperature distribution in the container fluid

COMSOL Multiphysics software is designed to produce different types of graphs. For instance, the wireframe is an option that allows to selectively eliminating "layers" of fluid, showing only areas where the analysis of temperature is of interest, an example of this feature is presented in fig. 5..
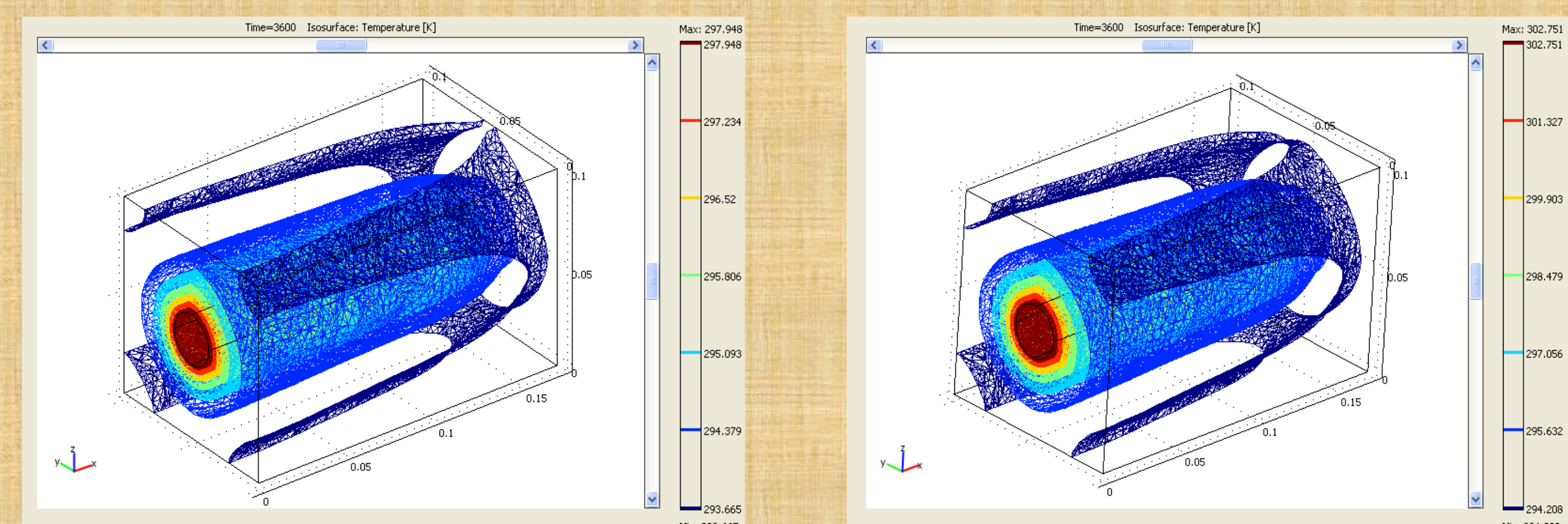

Figure 5. Wireframe type graphs of temperature distribution

Conclusions: The COMSOL Multiphysics software has been shown as a suitable tool for undergraduate engineering courses in Heat Transfer. It has been applied to solve and illustrate the analysis of heat transfer in a short metal bar with constant supply of heat, focusing on conditions of conduction and convection. The use of this software in the solution of this type of problems offers very attractive advantages over the actual experimentation, which requires an important economical investment and is time consuming with limited results.

The sensitivity analysis is an easy task that can be performed using the COMSOL software, where the geometry, the power supply, the materials and fluid are freely exchanged and graphs produced are presented in an ample spectrum of presentations and views and focus. All this allows the student a better understanding of the phenomena studied and therefore better academic results.