The Effect of the Mushy-Zone Constant on Simulated Phase Change Heat Transfer

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ABSTRACT

Solid-liquid phase change heat transfer is of the type of problem known as “moving boundary” problems. With very few solutions known analytically, the fast majority of those problems are solved numerically; either through the use of deformable mesh/grid, or the more common use of enthalpy or modified specific heat methods. Those methods account for the additional latent heat of fusion required for physical energy conservation during phase change.

It has also been shown through numerous experimental work that natural convection in the liquid phase during melting plays a dominating role. This therefore requires the addition of buoyancy forces to model natural convection during overall phase change processes of various phase change materials. Since most methods used to simulate phase change heat transfer cannot handle a constant temperature phase change process, they must simulate phase change over a given temperature interval, which results in the addition of a mushy region where the phase change materials is in a state between fully solid and fully liquid. The treatment of possible fluid flow from natural convection in this mushy zone has been the subject of numerous discussions at heat transfer conferences in the last few years. Typically, an equation of this form is used to account for the change in viscosity, from liquid to nearly infinite in the solid, and to force trivial solutions of the Navier-Stokes equations in the solid:

$$A(T) = \frac{C\left(1-B(T)\right)^2}{B(T)^3+\varepsilon}$$

with ε being a small constant to avoid division by zero, $B(T)$ is a function changing from 0 to 1 over the mushy region and C is the mushy-zone constant that is debated here. Various commercial software guidelines and various researchers using different values ranging from 10^3 to nearly 10^{10}, a variation of 7 orders of magnitude.

This paper presents a study of the impact of this mushy-zone constant C value on overall melting simulation results. A simple rectangular geometry is employed for which experimental results are published; the impact of the value of C on the physicality of the results can therefore be assessed. Simulation are also performed using two different software: ANSYS Fluent which has a predefined phase change physics where the constant C is an input and COMSOL Multiphysics where the entire set of physical equations needed to account for natural convection and phase change material movement must be added by the user, again with constant C playing a definite role.