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Pioneering CFD Software for Education & Industry

Modelling Flow and Heat Transfer in Phase Change Material (PCM) within a Heat Storage Unit

PHOENICS transient simulation

The case considered is the transient, two-dimensional solidification of a phase-change material (PCM) in a rectangular heat storage unit of dimensions 100mm high by 12mm wide. The assumption of two-dimensionality follows from the fact that the unit is sufficiently long in the third dimension, and its boundaries well insulated.

The PCM is paraffin wax contained within an aluminum casing of 1mm wall thickness. The PCM has a liquidus temperature of 27^{o}C, and a solidus temperature of 24^{o}C.

The initial temperature throughout the entire system is 27^{o}C, and the vertical side walls are adiabatic. In the simulations heat is transferred to the top of the casing from an ambient temperature of 27^{o}C by means of a prescribed heat transfer coefficient (htc) of 5W/m^{2o}C. Similarly, heat is removed from the horizontal base of the unit to an ambient temperature of 6^{o}C by means of a prescribed htc of 10W/m^{2}C. The solution domain exploits symmetry, and so the computation is made over only one-half of the unit.

A linear phase change is employed whereby the evolution of latent heat is expressed as a linear function of temperature. The IN-FORM facility of PHOENICS is used to implement the enthalpy-porosity phase-change algorithm of Prakash and Voller by means of an effective specific-heat capacity.

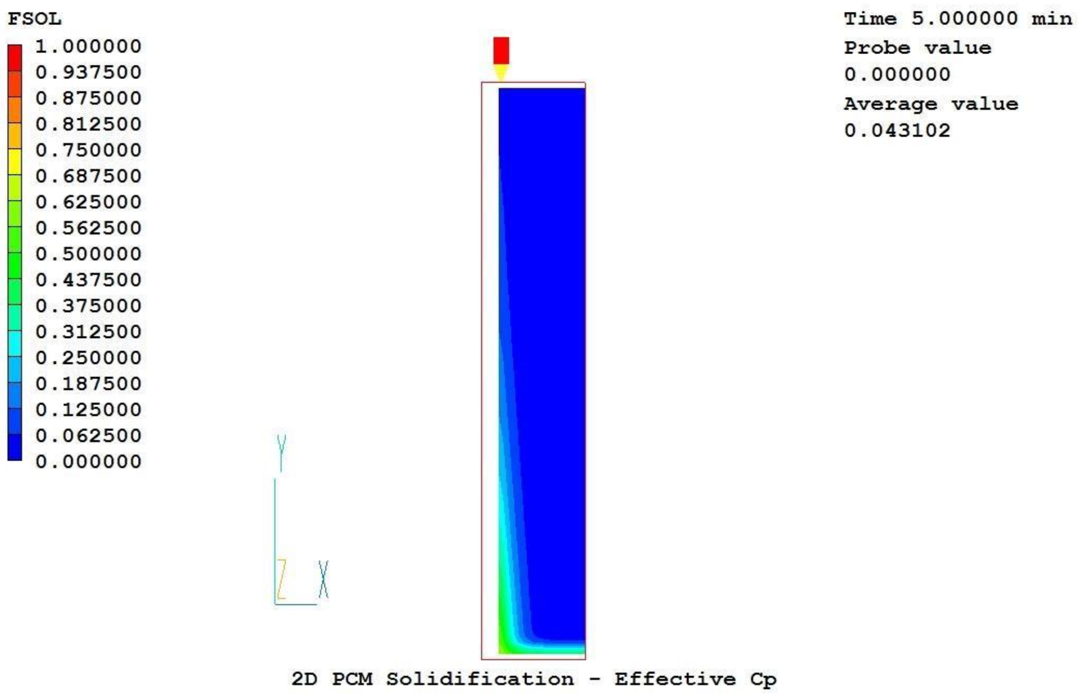
The convection in the melt is modelled, and the partially solidified region is treated as a porous medium, and the porosity in each mesh cell is defined in terms of the solid fraction f_s, which is equal to unity in fully-solidified regions. A flow resistance term is introduced into the momentum equations so as to reduce the velocities in partially-solidified regions, and to extinguish the velocities in fully-solid regions. The resistance term is based on the Kozeny-Carman equation for a porous medium, and buoyancy forces in the melt are modelled by using the Buossinesq approximation.

In these simulations, the PCM phase densities are taken as 750 kg/m^3, and the phase specific-heat capacities as 2500 J/kgK. The thermal conductivity of the PCM material is taken as 0.15W/mK, the kinematic viscosity as 9.610^{-6} m^2/s, and the latent heat of fusion as 200 kW/kg.

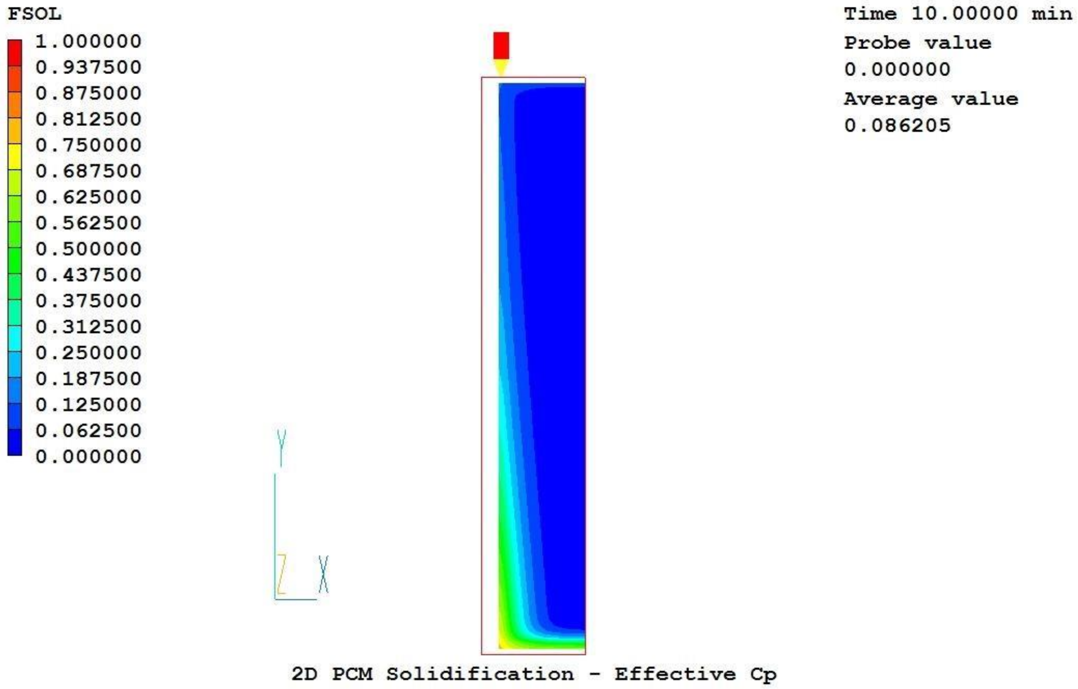
The properties of the aluminum are taken as follows: density = 2700 kg/m^3, specific heat = 896 J/kgK; and thermal conductivity= 204 W/mK.

For a period of 30 minutes, heat is removed through the base of the unit, and a transient simulation of the solidification process is performed by solving conservation equations for mass continuity, momentum and energy. The computations employ a time step of 5s.

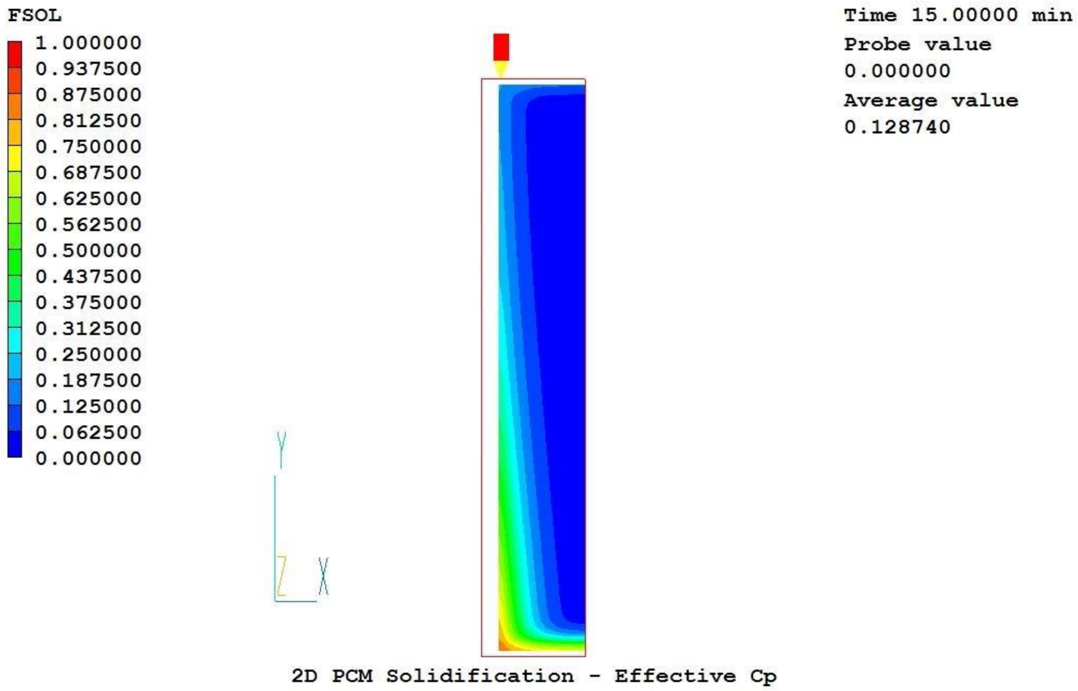
The INFORM facility is used to create an output file called MONTAB.CSV which contains for a specified monitor point the temporal history of temperature, solid fraction, effective specific heat and enthalpy, and the heat transfer rate through the base of the unit.



Solid Fraction Contours – 5 mins



Solid Fraction Contours – 10 mins



Solid Fraction Contours – 15 mins

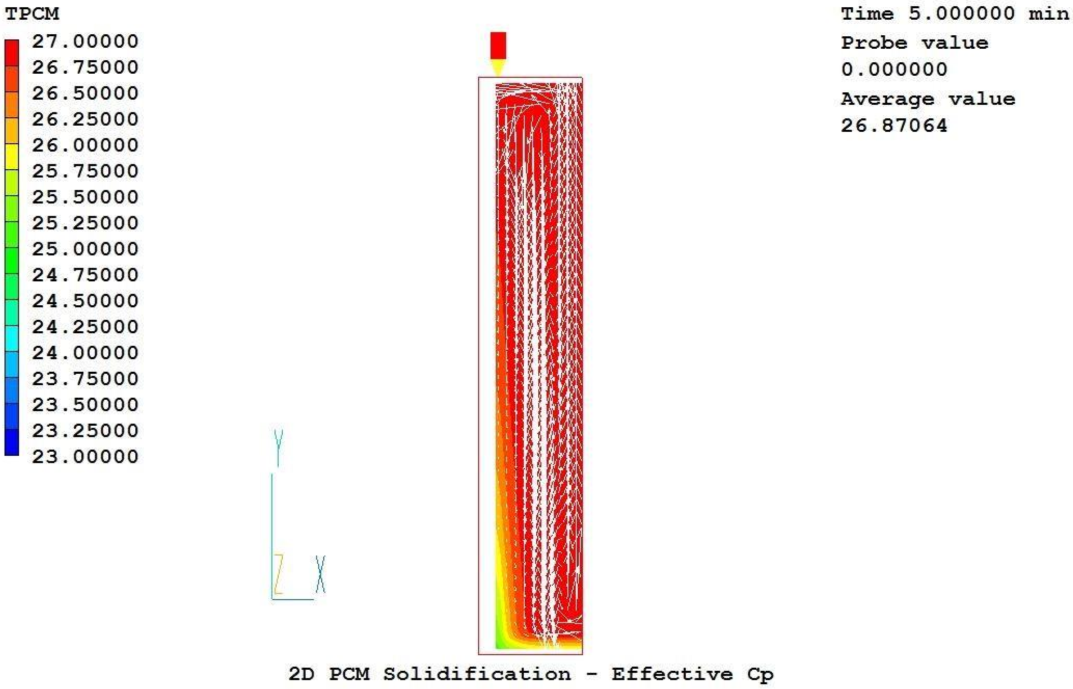
Solid Fraction Contours – 20 mins

Solid Fraction Contours – 25 mins

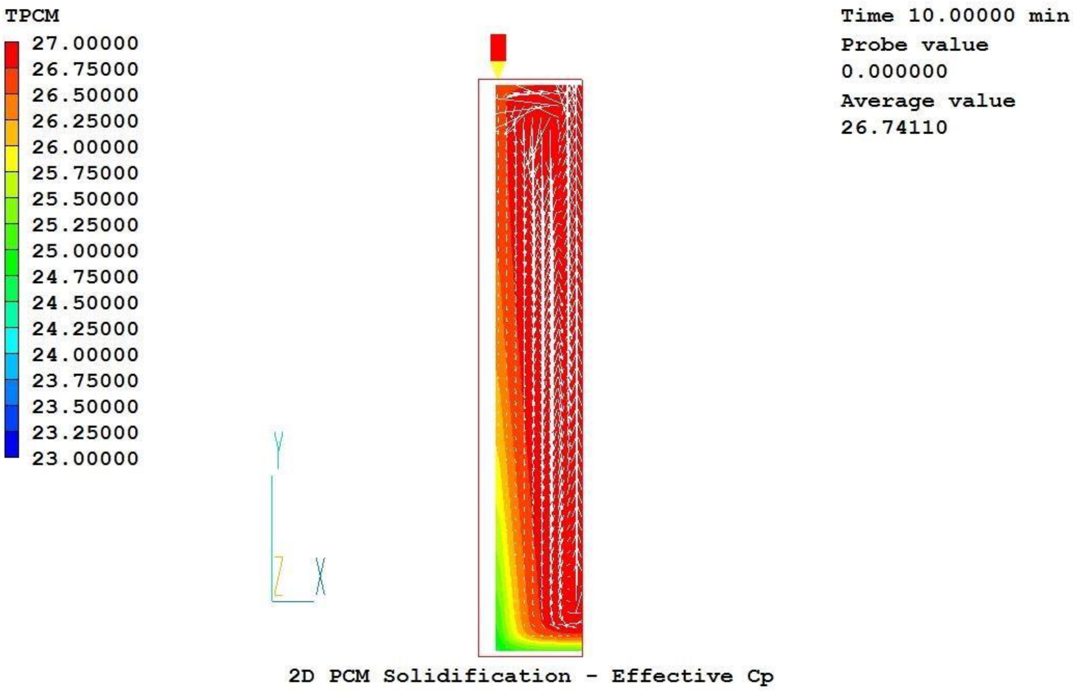
Solid Fraction Contours – 30 mins

An AVI can be found by clicking here.

Related PCM temperature contours are shown below.

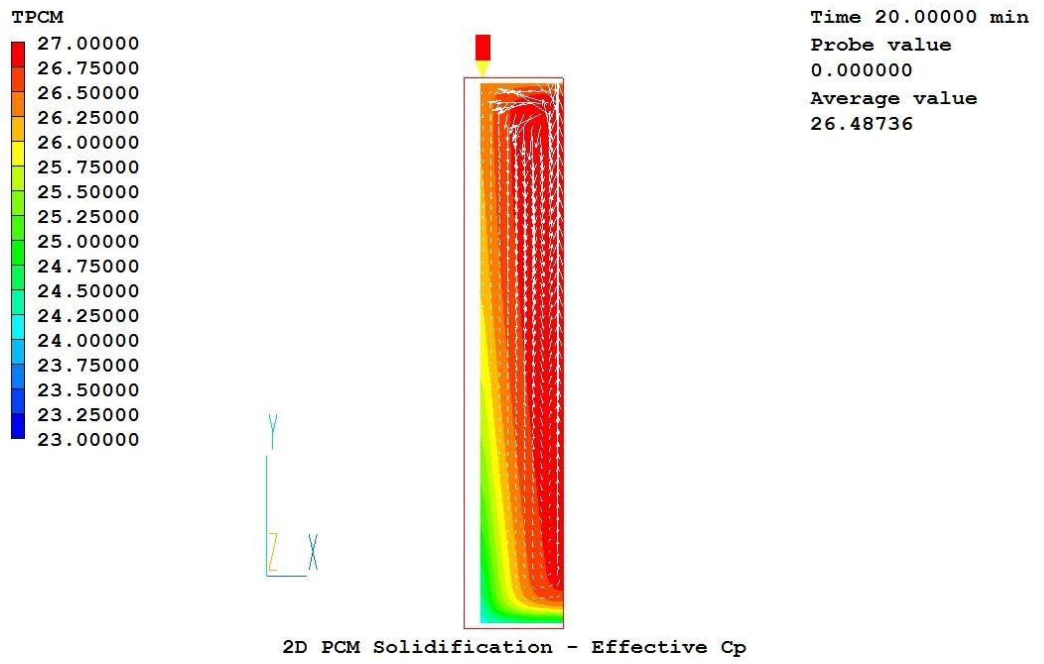


PCM Temperature Contours – 5 mins

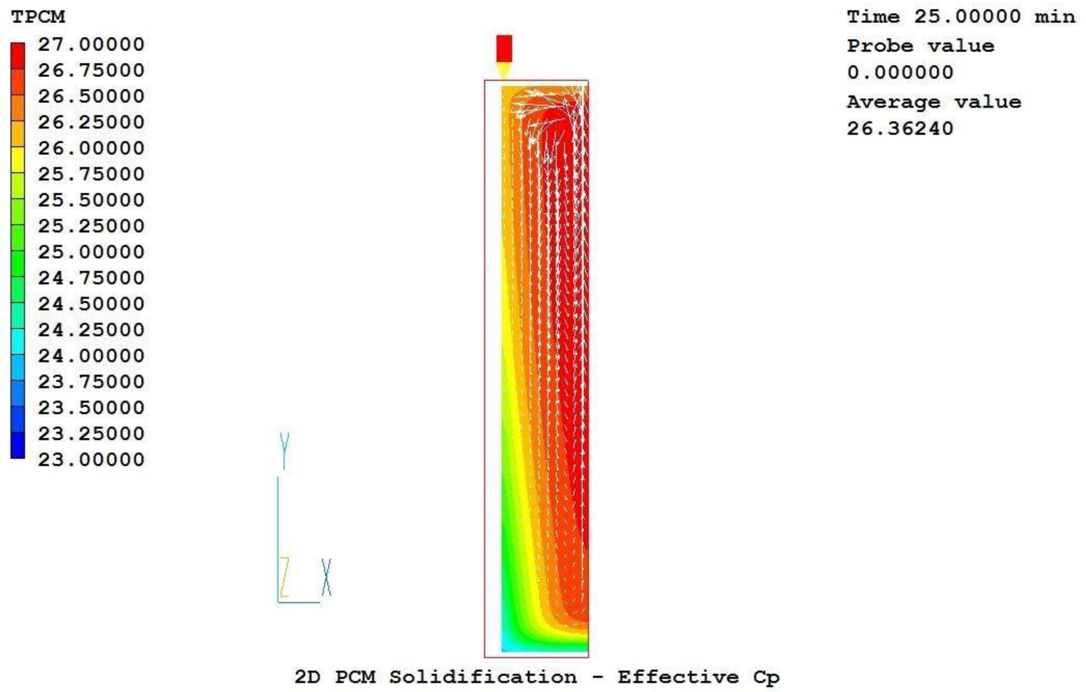


Solid Fraction Contours – 10 mins

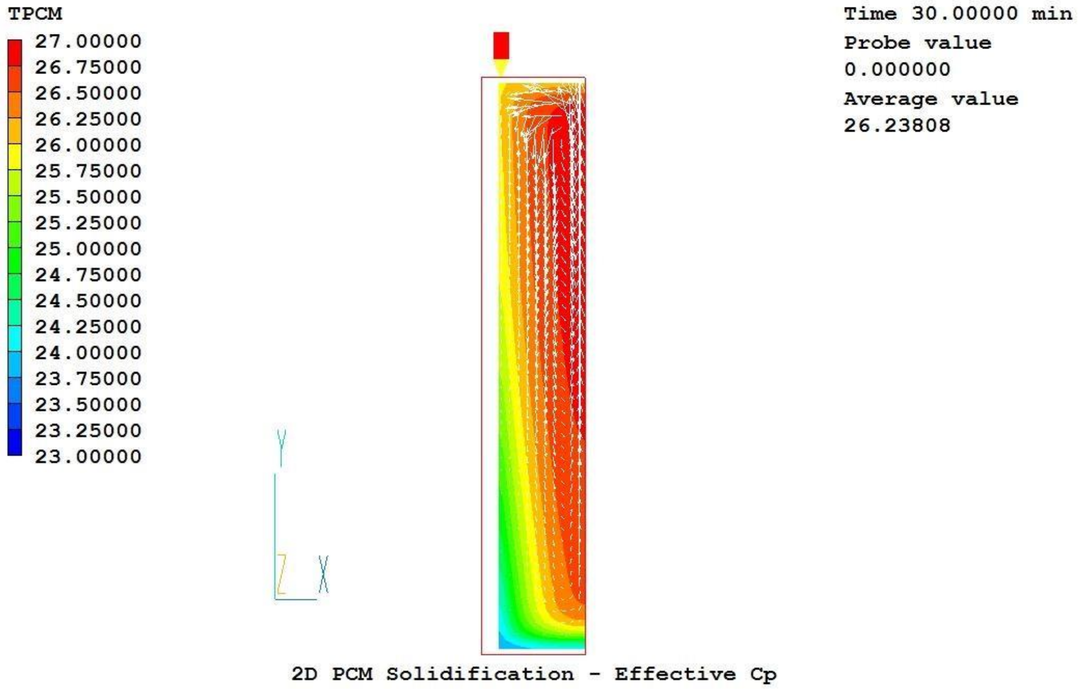
Solid Fraction Contours – 15 mins



Solid Fraction Contours – 20 mins

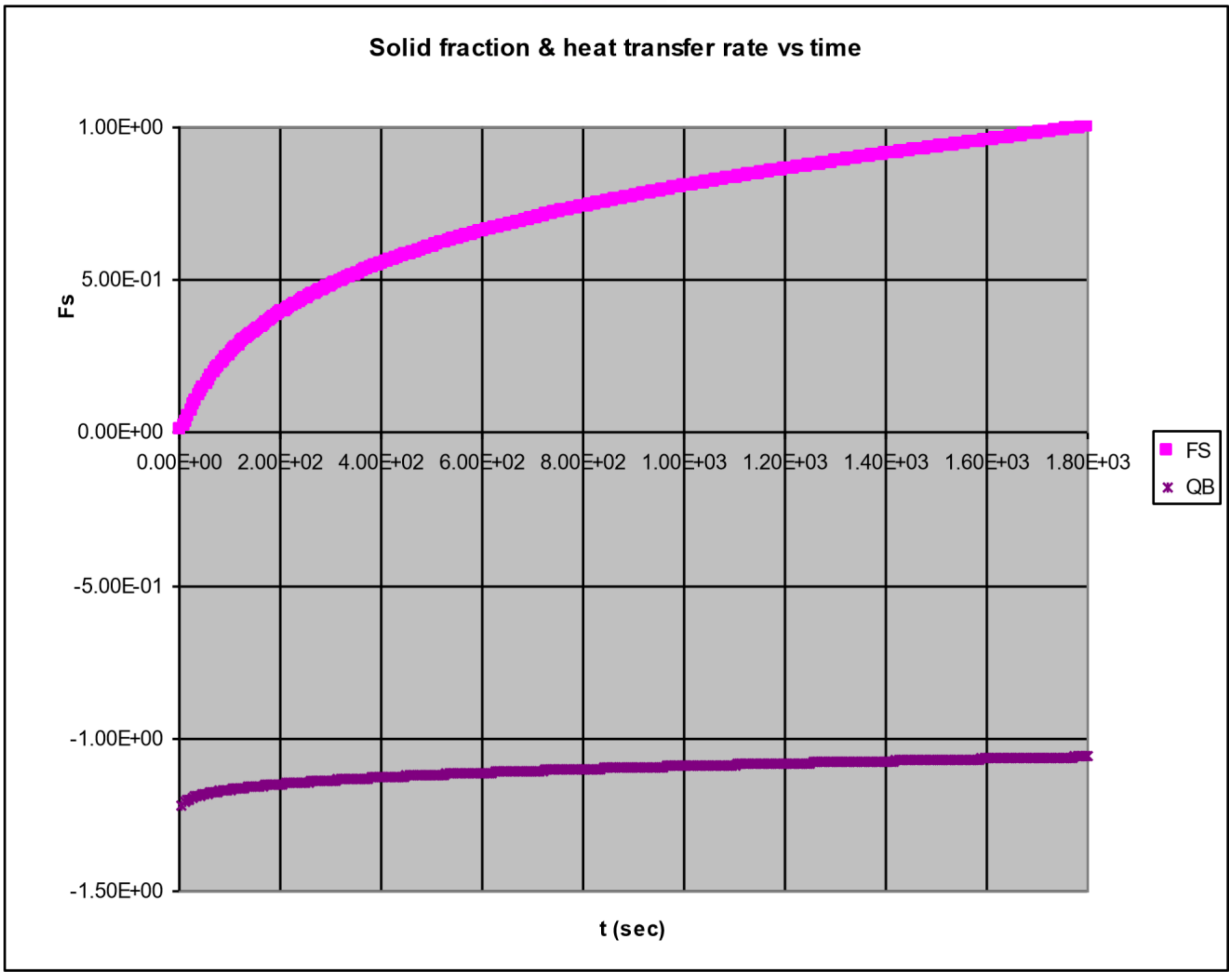


Solid Fraction Contours – 25 mins



Solid Fraction Contours – 30 mins

An AVI can be found by clicking here.



The final graph shown above displays the temporal histories of the solid fraction present in the bottom right-hand corner of the PCM, and the heat transfer rate through the base of unit in Watts.

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