Parameter sheet for InterFrost Test Case TH2 "Frozen Inclusion"

Geometrical features, boundary conditions and parameter sets are provided below as well as performance measures.

Geometrical features

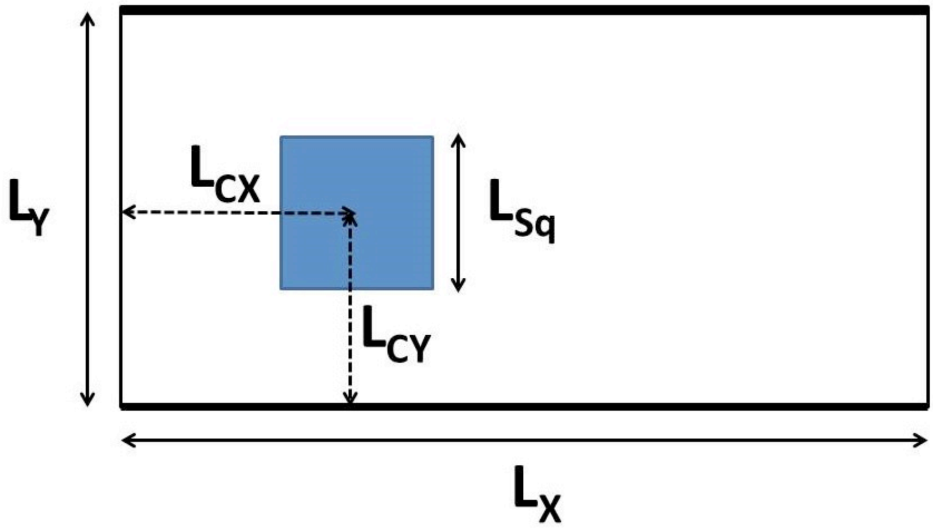

FIGURE 1 – Geometrical setup for TH2 Test Case

Symbol	Description	Value	Unit
L_x	Longitudinal extension of the simulated domain	3	m
L_y	Lateral extension of the simulated domain	1	m
$(L_{cx}; L_{cy})$	Postion of the inclusion center	$(1; 0.5)$	m
L_{sq}	Size of the square shaped inclusion	0.333	m

TABLE 1 – Geometrical parameter values for TH2 Test Case

Boundary and initial conditions

Symbol	Description	Value	Unit
$T^{-}_{initial}$	Initial temperature of the frozen inclusion	-5	$^{\circ}C$
$T^{+}_{initial}$	Initial temperature of the thawed domain	$+5$	$^{\circ}C$
T_{in}	Temperature on the incoming flow	$+5$	$^{\circ}C$
$\Delta H/L_x$	Hydraulic head gradient 1	0	$(-)$
$\Delta H/L_x$	Hydraulic head gradient 2	0.03	$(-)$
$\Delta H/L_x$	Hydraulic head gradient 3	0.09	$(-)$
$\Delta H/L_x$	Hydraulic head gradient 4	0.15	$(-)$

TABLE 2 – Initial and boundary conditions for temperature and suggested hydraulic head gradients for TH2 Test Case

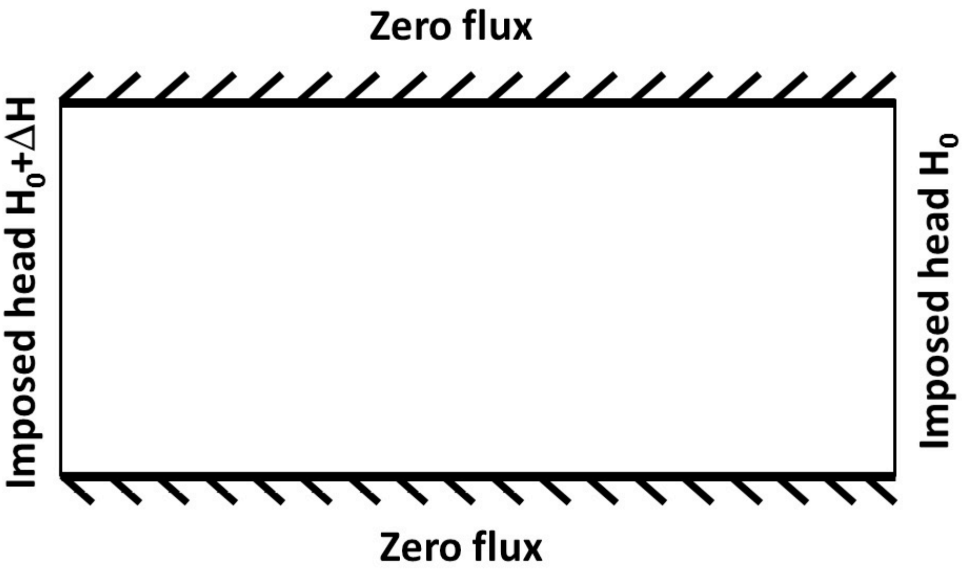

FIGURE 2 – Water flow boundary conditions

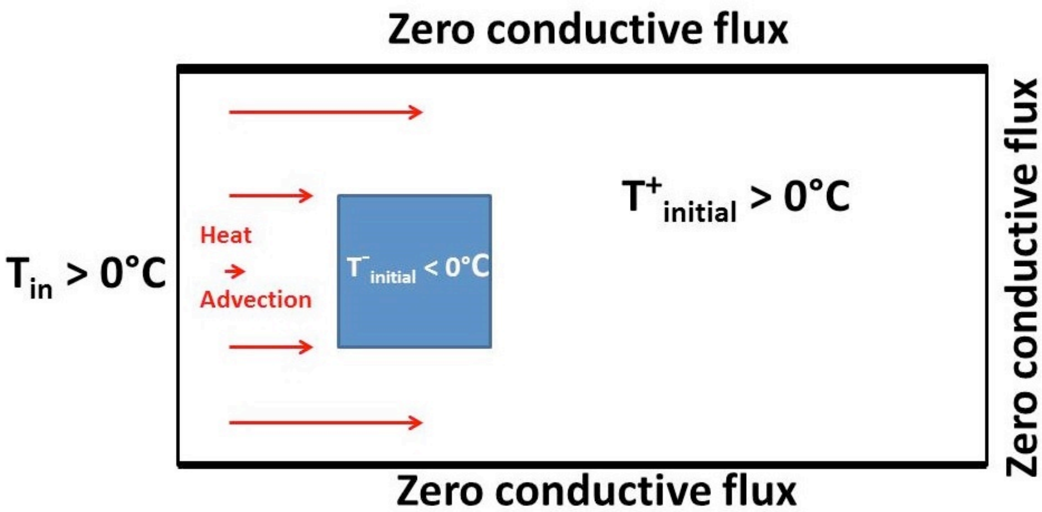

FIGURE 3 – Heat transfer boundary conditions and thermal initial condition

Equations

Flow equation (Eq. 1) :

$$(S_w \epsilon \rho_w g \beta)\frac{\partial p}{\partial t} = \vec{\nabla} \cdot \left(\mathbf{K_w}(\vec{\nabla} p + \vec{\nabla} z)\right) + \left(\epsilon \frac{\rho_i - \rho_w}{\rho_w} \frac{\partial S_w}{\partial t}\right) \tag{1}$$

Heat transfer (Eq. 2) :

$$\left(\epsilon(S_w \rho_w C_w + S_i \rho_i C_i) + (1-\epsilon)\rho_s C_s + \epsilon \rho_i L \frac{\partial S_w}{\partial T}\right)\frac{\partial T}{\partial t} = \vec{\nabla} \cdot (\lambda_{\mathbf{eq}} \vec{\nabla} T) + \vec{\nabla} \cdot \left(\rho_w C_w T\, \mathbf{K_w}(\vec{\nabla} p + \vec{\nabla} z)\right) \tag{2}$$

Subscripts denote w for water, i for ice, s for solid matrix. Unknowns are p for pressure expressed in meters ($p = P/\rho_w g$, with P pressure in Pascal) and T for temperature ($^\circ K$).

Parameter values

Symbol	Description	Value or expression	Unit
ϵ	Porosity	0.37	$(-)$
β	Compressibility	10^{-8}	Pa^{-1}
g	Acceleration of Gravity	9.81	$m.s^{-2}$
λ_w	Water thermal conductivity	0.6	$W.m^{-1}.K^{-1}$
λ_i	Ice thermal conductivity	2.14	$W.m^{-1}.K^{-1}$
λ_s	Solid matrix thermal conductivity	3.5	$W.m^{-1}.K^{-1}$
λ_{eq}	Equivalent thermal conductivity	$\epsilon\big(S_w\lambda_w + (1-S_w)\lambda_i\big) + (1-\epsilon)\lambda_s$	$W.m^{-1}.K^{-1}$
C_w	Water Heat capacity	4182	$J.kg^{-1}.K^{-1}$
C_i	Ice Heat capacity	2060	$J.kg^{-1}.K^{-1}$
C_s	Solid matrix heat capacity	835	$J.kg^{-1}.K^{-1}$
ρ_w	Water volumetric mass	1000	$kg.m^{-3}$
ρ_i	Ice volumetric mass	920	$kg.m^{-3}$
ρ_s	Solid matrix volumetric mass	2650	$kg.m^{-3}$
$(\rho C)_{eq}$	Equivalent volumetric Heat capacity	$\epsilon\big(S_w\rho_w C_w + (1-S_w)\rho_i C_i\big) + (1-\epsilon)\rho_s C_s$	$J.m^{-3}.K^{-1}$
μ	Water dynamic viscosity	$1.793\,10^{-3}$	$kg.m^{-1}.s^{-1}$
L	Latent heat	$3.34\,10^{5}$	$J.kg{-1}$
$S_w(T)$	Water saturation for $T \geq 273.15$	1	$(-)$
$S_w(T)$	Water saturation for $T < 273.15$	$(1-S_{wres})e^{-((T-273.15)/W)^2} - S_{wres}$	$(-)$
S_{wres}	Residual saturation in $S_w(T)$	0.05	$(-)$
W	Parameter in $S_w(T)$	0.5	K
K_w	Permeability	$k_r k_{int}\rho_w g/\mu$	$m.s^{-1}$
k_{int}	Intrinsic permeability	$1.3\,10^{-10}$	m^2
$k_r(S_w)$	Relative permeability	$10^{-\Omega\epsilon(1-S_w)}$ if $k_r(S_w) > 10^{-6}$	$(-)$
$k_r(S_w)$	Relative permeability	10^{-6} if $k_r(S_w) \leq 10^{-6}$	$(-)$
Ω	Impedance factor	50	$(-)$

TABLE 3 – Physical parameter values and expressions considered for TH2 Test Case

Performance measures

Performance measures for code results inter-comparison are :

- **PF1** : Plot the evolution of the minimum of the simulated temperature field as a function of time. Practically speaking it is located at the centre of the inclusion as long as its temperature is below zero.
- **PF2** : Plot the evolution of the total heat flux exiting the system (right / downstream boundary) as a function of time.
- **PF3** : Plot the evolution of the total liquid water volume in the domain as a function of time.

A parameter sensitivity study is proposed to vary flow velocities with a series of imposed head gradient values (see Tab. 2). So these performance measures should be provided for these 4 flow regimes on the same graph and excel file.

Another sensitivity study is suggested as an option. It concerns the W parameter in the $S_w(T)$ law providing larger or smaller "mushy zones". The unique value of 0.5 is proposed in Tab. 3, corresponding to a B_t value of roughly $-1°C$ for the linear law (see [McKenzie et al. 2007], mushy zone extends from $0°C$ to $-1°C$). However two other values are suggested : 1.87 corresponding roughly to a B_t of $-4°C$ and 0.05 corresponding to a B_t value of $-0.1°C$. These runs should be considered for the base case head gradient of 0.03. The performance measures associated with these 3 values should be plot together on a separate graph.