

TPNL301 - Thermohydration of a concrete cylinder

Summary:

The purpose of this test is to validate the thermo-hydrating behavior `THER_HYDR`, consists in imposing two temperatures inside and outside a presumedly infinite hollow roll.

It is a question of finding the field of temperature and hydration in the course of time.

The reference solution semi-analytical, is obtained by an implicit scheme for the temperature and explicit for the hydration.

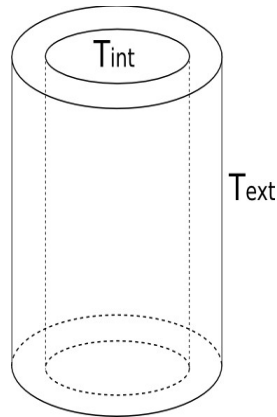
4 modelings are carried out:

- 3D and 3D_DIAG on a mixed grid TETRA4, HEXA8, PENTA6
- 3D on a mixed grid TETRA10, HEXA20, PENTA15
- AXIS and AXIS_DIAG on a mixed grid TRIA3 and QUAD4
- AXIS and AXIS_DIAG on a mixed grid TRIA6 and QUAD9

1 Problem of reference

1.1 Geometry

Cylinder infinite length and internal ray $R_{int} = 20\text{m}$ and outside $R_{ext} = 21\text{m}$.



1.2 Properties of material

The material has the following thermal characteristics:

- thermal conductivity: $\lambda = 6 \text{ kJ/h/m/}^\circ\text{K}$
- voluminal variation of enthalpy: $\rho C_p = 2400 \text{ kJ/m}^3 \text{ }^\circ\text{K}$,

and characteristics relating to the behavior hydrating following:

- heat per degree of hydration: $Q_0 = 1.4904 \text{ e}^5 \text{ kJ/m}^3$
- affinity function of the hydration (polynomial evaluation of the function known by points) and of the temperature (tablecloth):

$$A(h, T) = (1586000h^5 - 5224000h^4 + 6432000h^3 - 353500h^2 + 730000h + 6510) \exp\left(\frac{-QSR_K}{(273,15 + T)}\right)$$

- with constant of Arrhenius: $QSR_K = 4000 / ^\circ\text{K}$.

Note: The constant of Arrhenius is always expressed in Kelvin degree. The temperatures are expressed in $^\circ\text{C}$.

1.3 Boundary conditions and loadings

$$T(r = R_{int}, t) = T_{int} = 40^\circ\text{C}$$

$$T(r = R_{ext}, t) = T_{ext} = 15^\circ\text{C}$$

1.4 Initial conditions

$T(r, t = 0) = T_0(r)$ corresponds to the stationary solution of the cylinder without internal source of heat subjected to constraints of temperature in internal and external skin, T_{int} and T_{ext} .

1.5 Discretization in time

The explicit integration of the hydration requires a fine temporal discretization until the end of the phenomenon of hydration:

Of $t=0$ with $t=300h$, $\Delta t=2h$.

Of $t=300h$ with $t=730h$ $\Delta t=10h$.

2 Reference solution

2.1 Method of calculating

The stationary solution is obtained analytically:

$$T_0(r) = T_{int} - \frac{(T_{int} - T_{ext})}{\ln\left(\frac{R_{ext}}{R_{int}}\right)} \ln\left(\frac{r}{R_{int}}\right)$$

Then, the transitory problem in temperature is solved by using the method of resolution digital of Crank-Nicholson (implicit).

The solution in hydration is obtained by a diagram clarifies (not time = 1h).

$$h(r, t + \Delta t) = h(r, t) + \frac{dh}{dt} = h(r, t) + A(h(r, t)) \exp\left(\frac{-A_r}{T(r, t) + 273,15}\right)$$

2.2 Sizes and results of reference

The reference solution in temperature and hydration is known on a grid (r, t) , with:

r vary 20 with 21m with a step $\Delta r=0,05$ and t vary 0 with 730h with a step of $\Delta t=0,01h$.

One will observe the results more particularly in $r=20,5m$ with $t=0$, 50h and 730h and the maximum value of the temperature.

T_0	T_{50}	T_{730}	T_{max}	h_{50}	h_{730}
27,3475	48,7091	27,7116	48,7557	0,4778	0,9558

2.3 Uncertainties on the solution

The method of resolution is semi-analytical. Moreover, the hydration is integrated explicitly: the step of time must thus be sufficiently small.

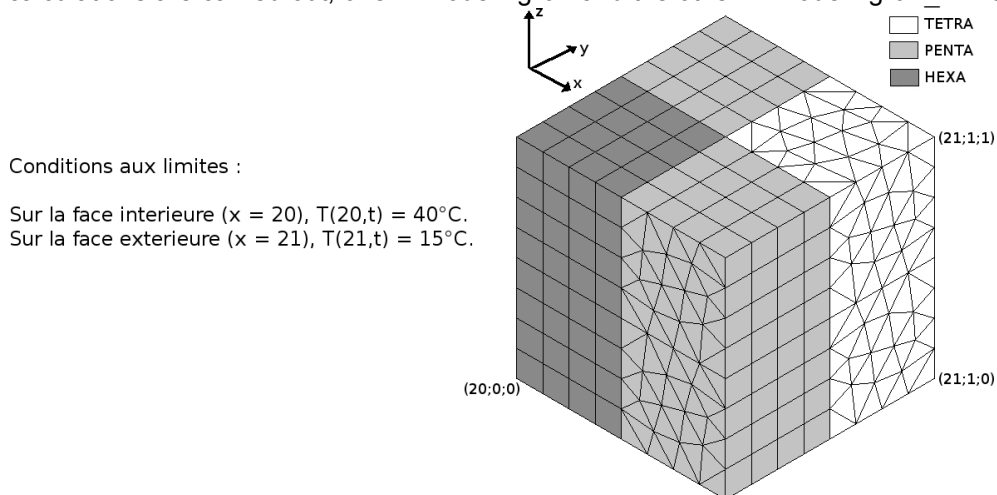
2.4 Bibliographical references

- [1] J. HAELEWYN, Assessment of the thermal elements with thermohydratation Report AMA 10,021 (2010)

3 Modeling A

3.1 Characteristics of modeling

Two calculations are carried out, one in modeling 3D and the other in modeling 3D_DIAG.



3.2 Characteristics of the grid

Many nodes: 798

Many meshes and types: 128 HEXA8, 544 PENTA6, 926 TETRA4.

3.3 Sizes tested and results

The node tested is X205 coordinates (20.5 ; 0.5 ; 0.5)

Test	Modeling	Reference	Aster	Difference (%)
$T_0(^{\circ}\text{C})$	3D	27,3475	27,5000	0,56
$T_0(^{\circ}\text{C})$	3D_DIAG	27,3475	27,5000	0,56
$T_{50}(^{\circ}\text{C})$	3D	48,7091	49,2586	1,1
$T_{50}(^{\circ}\text{C})$	3D_DIAG	48,7091	49,0701	0,74
$T_{730}(^{\circ}\text{C})$	3D	27,7116	27,8709	0,57
$T_{730}(^{\circ}\text{C})$	3D_DIAG	27,7116	27,8713	0,57
$T_{max}(^{\circ}\text{C})$	3D	48,7557	49,4487	1,4
$T_{max}(^{\circ}\text{C})$	3D_DIAG	48,7557	49,3345	1,2
h_{50}	3D	0,4778	0,4722	-1,2
h_{50}	3D_DIAG	0,4778	0,4704	-1,5
h_{730}	3D	0,9558	0,9545	-0,13
h_{730}	3D_DIAG	0,9558	0,9542	-0,17

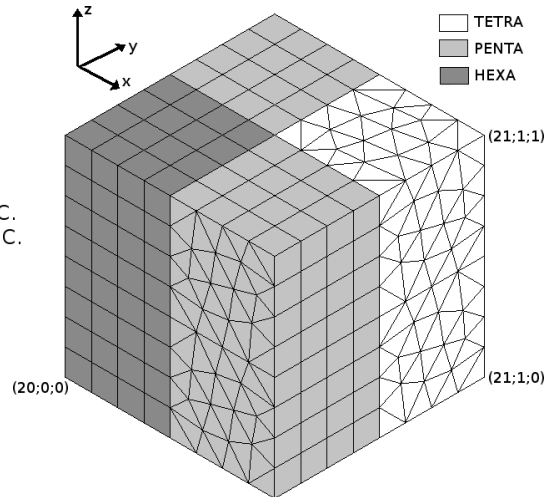
4 Modeling B

4.1 Characteristics of modeling

Modeling 3D with quadratic elements.

Conditions aux limites :

Sur la face interieure (x = 20), $T(20,t) = 40^{\circ}\text{C}$.
Sur la face exterieure (x = 21), $T(21,t) = 15^{\circ}\text{C}$.



4.2 Characteristics of the grid

Many nodes: 3933

Many meshes and types: 128 HEXA20, 544 PENTA15, 926 TETRA10.

4.3 Sizes tested and results

The node tested is X205 coordinates (20.5; 0.5; 0.5)

	Modeling	Reference	Aster	Difference (%)
$T_0(^{\circ}\text{C})$	3D	27,3475	27,5495	0,74
$T_{50}(^{\circ}\text{C})$	3D	48,7091	52,0074	6,8
$T_{730}(^{\circ}\text{C})$	3D	27,7116	27,9624	0,91
$T_{max}(^{\circ}\text{C})$	3D	48,7557	52,8420	8,1
h_{50}	3D	0,4778	0,4868	1,9
h_{730}	3D	0,9558	0,9609	0,54

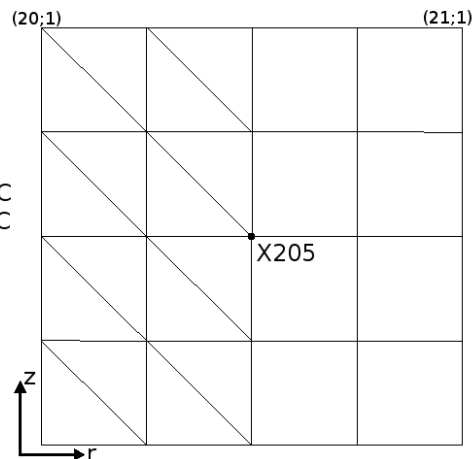
5 Modeling C

5.1 Characteristics of modeling

Two calculations are carried out, one in modeling `AXIS` and the other in modeling `AXIS_DIAG`.

Conditions aux limites :

Sur la face interieure ($r = 20$), $T = 40^{\circ}\text{C}$
Sur la face exterieure ($r = 21$), $T = 15^{\circ}\text{C}$



5.2 Characteristics of the grid

Many nodes: 25
Many meshes and types: 16 TRIA3, 8 QUAD4.

5.3 Sizes tested and results

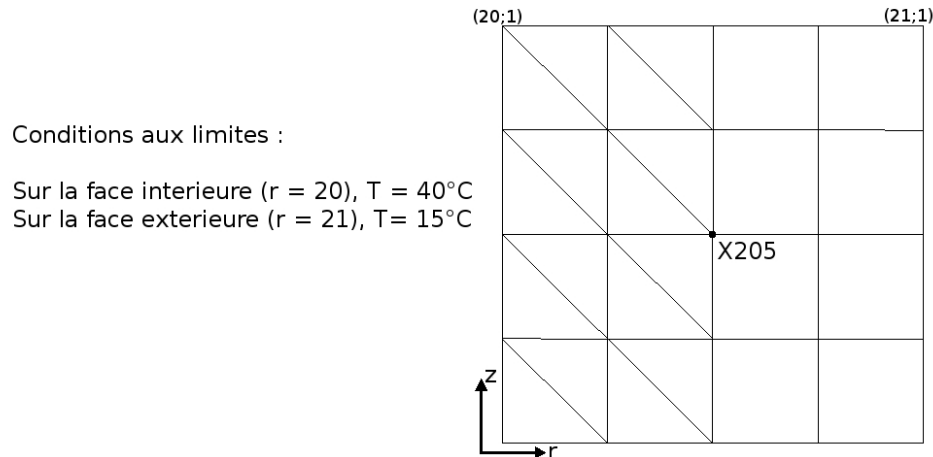
The node tested is `X205` coordinates $(20.5; 0.5)$.

	Modeling	Reference	Aster	Difference (%)
$T_0(^{\circ}\text{C})$	AXIS	27,3475	27,3475	0
$T_0(^{\circ}\text{C})$	AXIS_DIAG	27,3475	27,3475	0
$T_{50}(^{\circ}\text{C})$	AXIS	48,7091	48,3622	-0,71
$T_{50}(^{\circ}\text{C})$	AXIS_DIAG	48,7091	47,8223	-1,8
$T_{730}(^{\circ}\text{C})$	AXIS	27,7116	27,6526	-0,21
$T_{730}(^{\circ}\text{C})$	AXIS_DIAG	27,7116	27,6524	-0,21
$T_{max}(^{\circ}\text{C})$	AXIS	48,7557	48,3622	-1
$T_{max}(^{\circ}\text{C})$	AXIS_DIAG	48,7557	47,9020	-2
h_{50}	AXIS	0,4778	0,4917	2,9
h_{50}	AXIS_DIAG	0,4778	0,4852	1,6
h_{730}	AXIS	0,9558	0,9579	0,23
h_{730}	AXIS_DIAG	0,9558	0,9570	0,13

6 Modeling D

6.1 Characteristics of modeling

Two calculations are carried out, one in modeling `AXIS` and the other in modeling `AXIS_DIAG`.



6.2 Characteristics of the grid

Many nodes: 81
Many meshes and types: 16 TRIA6, 8 QUAD9.

6.3 Sizes tested and results

The node tested is `X205` coordinates (20.5 ; 0.5)

	Modeling	Reference	Aster	Difference (%)
$T_0(^{\circ}\text{C})$	AXIS	27,3475	27,9568	2,2
$T_0(^{\circ}\text{C})$	AXIS_DIAG	27,3475	27,6960	1,3
$T_{50}(^{\circ}\text{C})$	AXIS	48,7091	51,8141	6,4
$T_{50}(^{\circ}\text{C})$	AXIS_DIAG	48,7091	51,2837	5,3
$T_{730}(^{\circ}\text{C})$	AXIS	27,7116	28,2898	2,1
$T_{730}(^{\circ}\text{C})$	AXIS_DIAG	27,7116	28,0643	1,3
$T_{max}(^{\circ}\text{C})$	AXIS	48,7557	52,1296	6,7
$T_{max}(^{\circ}\text{C})$	AXIS_DIAG	48,7557	52,5950	5,6
h_{50}	AXIS	0,4778	0,5151	7,8
h_{50}	AXIS_DIAG	0,4778	0,4969	4
h_{730}	AXIS	0,9558	0,9611	0,55
h_{730}	AXIS_DIAG	0,9558	0,9651	0,97

7 Summary of the results

The results of modelings with linear elements are rather correct. The maximum error is obtained for the hydration (2,9%). The hydration is integrated explicitly. This error can thus be decreased by decreasing the step of time.

The results for the quadratic elements are rather bad. The peak of temperature is overestimated. The tolerances for modelings B and D rather important but are thus supplemented by tests of not-regression.

Modeling with diagonalisation of the thermal matrix of mass 'DIAG' seems to improve the results.