TPNL301 - Thermohydration of a Summarized concrete cylinder

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The purpose of this test is validating the behavior thermo-hydrating 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.

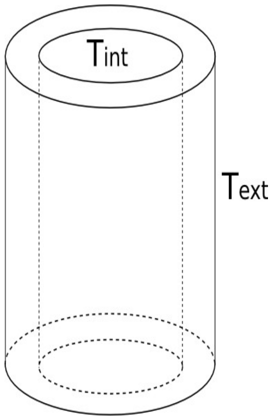
4 modelizations are carried out:

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

1 Problem of reference

1.1 Geometry

Rolls infinite length and of internal and $Rint=20\mathrm{m}$ external radius $Rext=21\mathrm{m}$.



1.2 Properties of the material

the material has the following thermal characteristics:

- thermal conductivity: $\lambda=6\,kJ/h/m/°K$
- voluminal variation of enthalpy: $\rho C_p=2400\,kJ/m3°K.$,

and the characteristic relating to the behavior hydrating following:

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

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

- with constant of Arrhenius: $QSR_K=4000/°K$.

Note: The constant of Arrhenius is always expressed in Kelvin degree. The temperatures are expressed in $°C$.

1.3 Boundary conditions and loadings

$$T(r=R_{int},t)=T_{int}=40°C$$
$$T(r=R_{ext},t)=T_{ext}=15°C$$

1.4 Initial conditions

$T(r,t=0)=T_0(r)$ corresponds to the steady solution of the cylinder without internal source of heat subjected to stresses of temperature in intern skin and external, 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 $t=300\text{h}$ $\Delta t=2h$.
Of $t=300\text{h}$ with $t=730\text{h}$ $\Delta t=10h$.

2 Reference solution

2.1 Method of calculating

the steady 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 means of the method of resolution numerical of Crank-Nicholson (implicit).

The solution in hydration is obtained by an explicit diagram (time step = 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 Quantities and results of reference

the reference solution in temperature and hydration is known on a grid (r,t) , with:
r vary from 20 with 21m a step $\Delta r=0{,}05$ and t varies from 0 with 730h a step of $\Delta t=0{,}01h$.

One will more particularly observe the results in $r=20{,}5m$ with $t=0$, 50h and 730h 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: time step must thus be sufficiently small.

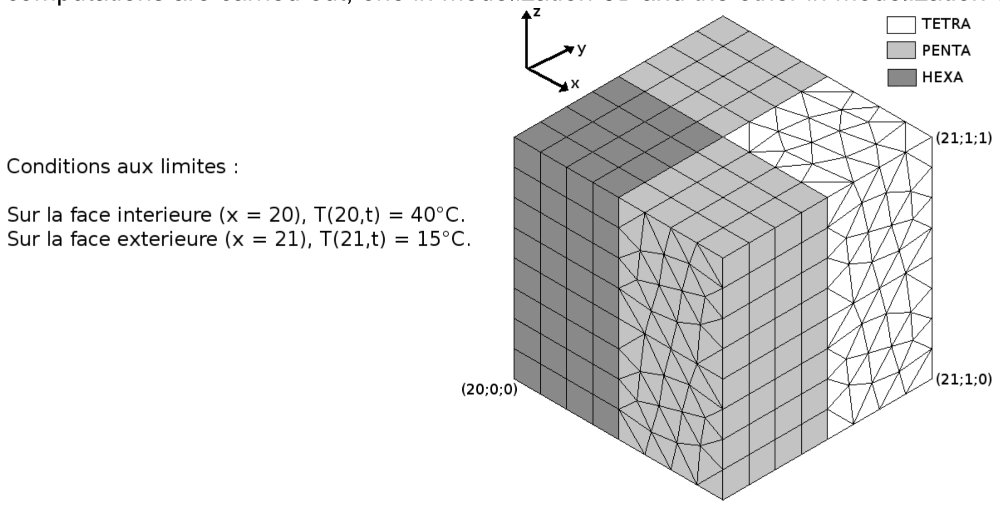
2.4 Bibliographical references

[1] J. HAELEWYN, Assessment of the thermal elements with thermohydration Report AMA 10.021 (2010)

3 Modelization A

3.1 Characteristic of the modelization

Two computations are carried out, one in modelization 3D and the other in modelization 3D_DIAG.



3.2 Characteristics of the mesh

Many nodes: 798
Number of meshes and types: 128 HEXA8, 544 PENTA6, 926 TETRA4.

3.3 Quantities tested and results

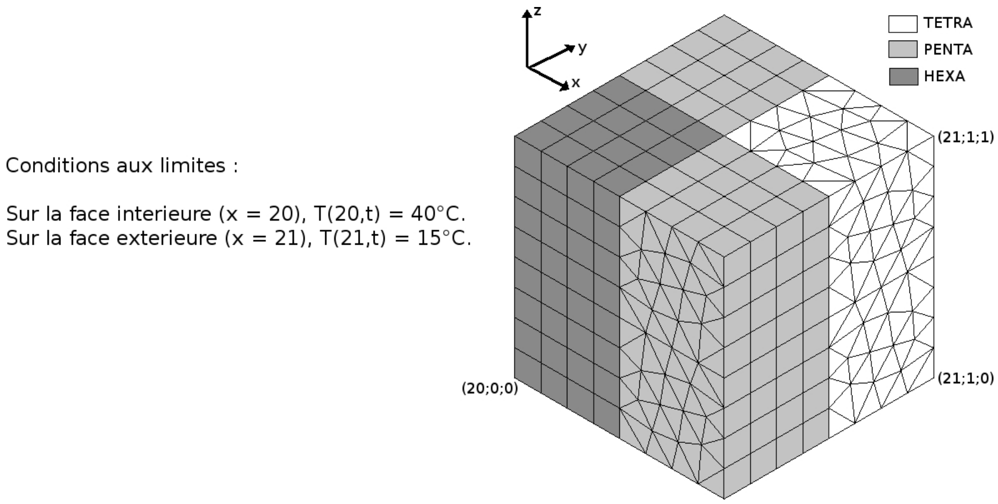
the node tested is $X205$ coordinates $(20.5;0.5;0.5)$

Test	Modelization	Reference	Aster	Difference (%)
$T_0(°C)$	3D	27.3475	27.5000	0.56
$T_0(°C)$	3D_DIAG	27.3475	27.5000	0.56
$T_{50}(°C)$	3D	48.7091	49.2586	1.1
$T_{50}(°C)$	3D_DIAG	48.7091	49.0701	0.74
$T_{730}(°C)$	3D	27.7116	27.8709	0.57
$T_{730}(°C)$	3D_DIAG	27.7116	27.8713	0.57
$T_{max}(°C)$	3D	48.7557	49.4487	1.4
$T_{max}(°C)$	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 Modelization B

4.1 Characteristic of the modelization

Modelization 3D with quadratic elements.



4.2 Characteristics of the mesh

Many nodes: 3933
Number of meshes and types: 128 HEXA20, 544 PENTA15, 926 TETRA10.

4.3 Quantities tested and results

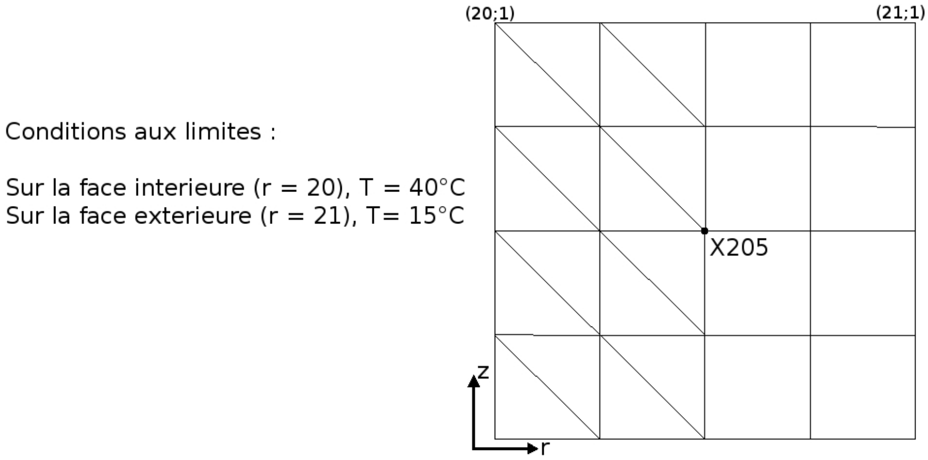
the node tested is $X205$ coordinates $(20.5; 0.5; 0.5)$

	Modelization	Reference	Aster	Difference (%)
$T_0(°C)$	3D	27.3475	27.5495	0.74
$T_{50}(°C)$	3D	48.7091	52.0074	6.8
$T_{730}(°C)$	3D	27.7116	27.9624	0.91
$T_{max}(°C)$	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 Modelization C

5.1 Characteristic of the modelization

Two computations are carried out, one in modelization AXIS and the other in modelization AXIS_DIAG.



5.2 Characteristics of the mesh

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

5.3 Quantities tested and results

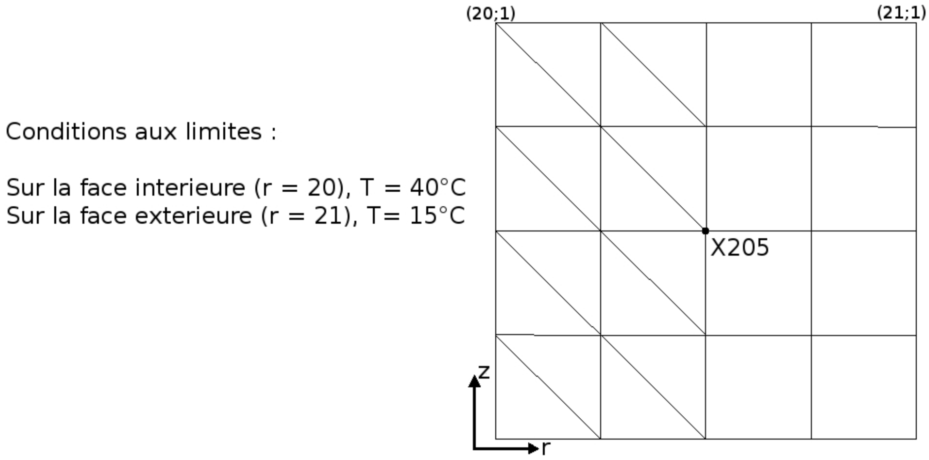
the node tested is $X205$ coordinates $(20.5; 0.5)$.

	Modelization	Reference	Aster	Difference (%)
$T_0(°C)$	AXIS	27.3475	27.3475	0
$T_0(°C)$	AXIS_DIAG	27.3475	27.3475	0
$T_{50}(°C)$	AXIS	48.7091	48.3622	-0.71
$T_{50}(°C)$	AXIS_DIAG	48.7091	47.8223	-1.8
$T_{730}(°C)$	AXIS	27.7116	27.6526	-0.21
$T_{730}(°C)$	AXIS_DIAG	27.7116	27.6524	-0.21
$T_{max}(°C)$	AXIS	48.7557	48.3622	-1
$T_{max}(°C)$	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 Modelization D

6.1 Characteristic of the modelization

Two computations are carried out, one in modelization `AXIS` and the other in modelization `AXIS_DIAG`.



6.2 Characteristics of the mesh

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

6.3 Quantities tested and results

the node tested is $X205$ coordinates $(20.5\,;\,0.5)$

	Modelization	Reference	Aster	Difference (%)
$T_0(°C)$	AXIS	27.3475	27.9568	2.2
$T_0(°C)$	AXIS_DIAG	27.3475	27.6960	1.3
$T_{50}(°C)$	AXIS	48.7091	51.8141	6.4
$T_{50}(°C)$	AXIS_DIAG	48.7091	51.2837	5.3
$T_{730}(°C)$	AXIS	27.7116	28.2898	2.1
$T_{730}(°C)$	AXIS_DIAG	27.7116	28.0643	1.3
$T_{max}(°C)$	AXIS	48.7557	52.1296	6.7
$T_{max}(°C)$	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 the modelizations 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 while decreasing time step.

The results for the quadratic elements are rather bad. The peak of temperature is overestimated. The tolerances for the modelizations B and D rather important but are thus supplemented by tests of NON-regression.

The modelization with diagonalization of thermal mass matrix "DIAG" seems to improve the results.