HSNA102 - Validation of the laws of drying on a cylindrical concrete test-tube

Summary:

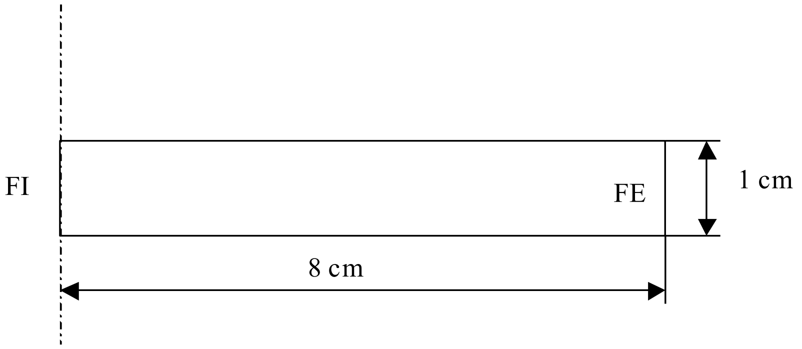
This case test is intended to validate the calculation of the drying of the concrete, developed in the operator of nonlinear thermics of *Code_Aster*. One tests here the various laws of diffusion available in *Code_Aster*, namely `SECH_GRANGER`, `SECH_MENSI`, `SECH_BAZANT` and `SECH_NAPPE`. The possible dependence at the temperature of the models is however not tested.

It is about an axisymmetric case test where the water concentration is applied directly to the external wall. The results are compared with a digital resolution of the equations using Scilab.

1 Problem of reference

1.1 Geometry

One models a cylindrical slice of test-tube of diameter $160\,mm$.



1.2 Material properties

Each modeling makes it possible to validate a coefficient of diffusion D , namely:

- modeling a: law of Mensi $D(C)=A\exp(BC)$
- modeling b: law of Granger $D(C,T)=A\exp(BC)\frac{T}{T_0}\exp\left(-\frac{Q_s}{R}\left(\frac{1}{T}-\frac{1}{T_0}\right)\right)$
- modeling C: definition of D in the form of tablecloth
- modeling D: law of Bazant $D(h)=D_1\left(\alpha+\frac{1-\alpha}{1+\left(\frac{1-h(C)}{1-0.75}\right)^n}\right)$

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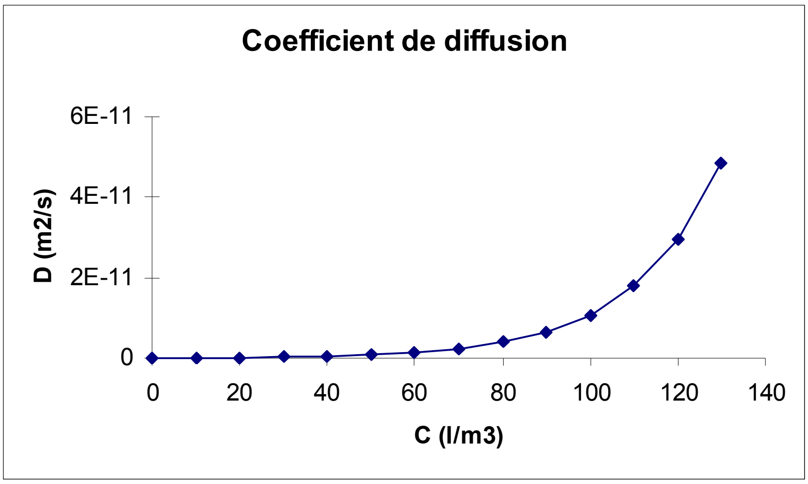
The coefficients used are those recommended by Granger in its thesis [bib1]:

`SECH_MENSI :`	$A=0.74\,10^{-13} m^2/s$ $B=0.05$
`SECH_GRANGER`	$A=0.74\,10^{-13} m^2/s$ $B=0.05$ $T_0=293°K$ $Q_s/R=4700\,K^{-1}$
`SECH_NAPPE`	One returns in the form of tablecloth the law of Mensi 
`SECH_BAZANT`	$D1=3.0\,10^{-10} m^2/s$ $\alpha=0.04$ $n=6$ $h=1-0.5\left(\frac{C-C_0}{C_0-C_{eq}}\right)^2$ with $C_0=128.8\,l/m^3$ and $C_{eq}=58.8\,l/m^3$

1.3 Boundary conditions and loadings

The calculation of drying is carried out over one 5 years duration

- the temperature remains uniform and is worth $20°C$
- one applies to FE : $C_{eq}=58.8\,l/m^3$

1.4 Initial conditions

The initial conditions are consisted the initial temperature, which one takes with $20°C$, and initial water concentration, which is worth $C_0=128.8\,l/m^3$.

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2 Reference solution

2.1 Method of calculating used for the reference solution

The 2 reference solutions are obtained by resolution of the equation of drying by differences finished using Scilab. The command file is given in appendix to possibly be able to test new models.
The space discretization is the same one as for Aster with knowing meshs of $1\,mm$. The temporal discretization is 3600 seconds for the equation of Mensi, and 60 seconds for the equation of Bazant.

2.2 Results of reference

One is interested in the water concentration in the test-tube after 1:00, 3j, 28j, 1.25 year, 3 years and 5 years. The evolution of the profiles obtained with Scilab for the law of Mensi and the law of Bazant is visible on [the Figure 2.2-a] and [Figure 2.2-b].

Note:

The comparison between the solutions Scilab and Aster is visible in [§Annexe 2]: one shows the concentrations obtained in the test-tube after 1 a.m. and 5 years. The good correlation thus is checked excluded for the solution obtained with Aster for the law of Mensi at the end of one hour when one observes an oscillation which makes much think of a violation of the principle of the maximum observed in thermics (cf [bib2]). It would be thus interesting to be able to use the lumpés elements when one solves the equation of drying even if the phenomenon is accentuated here because of the boundary conditions, since one directly imposes the water concentration instead of imposing a flow [bib3].

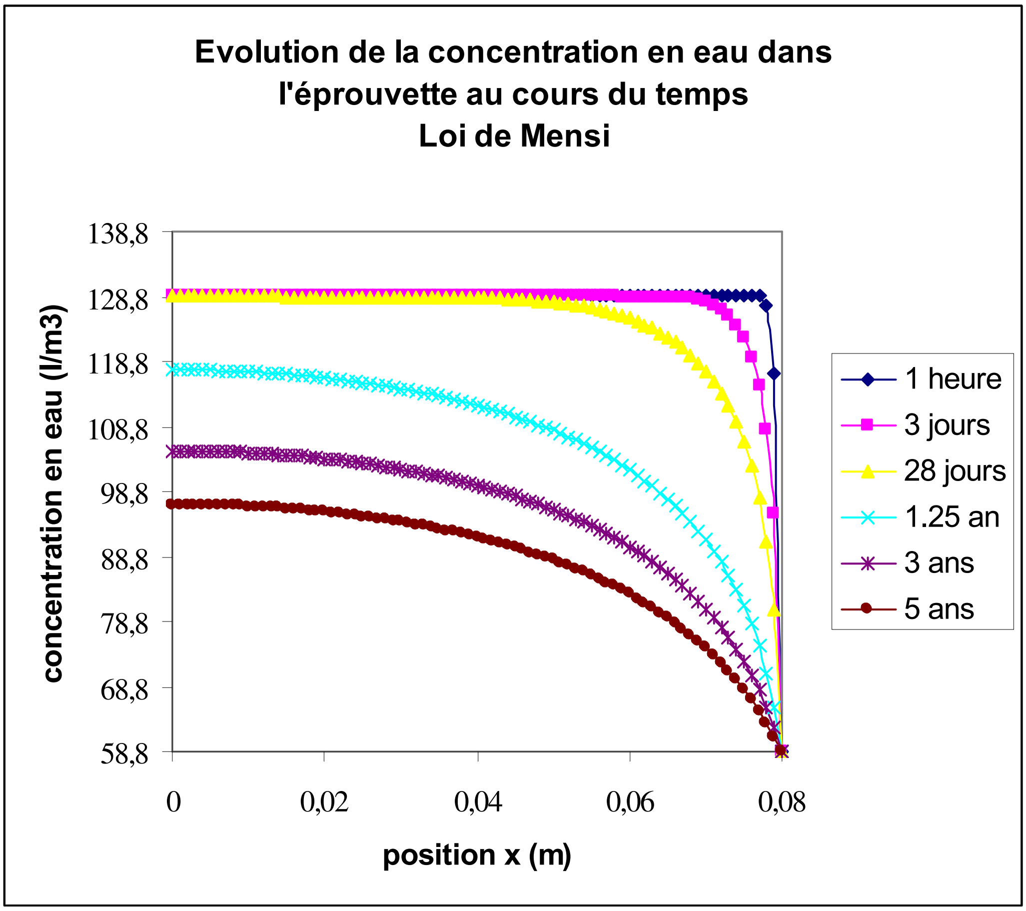

Figure 2.2-a: Scilab solution - law of Mensi

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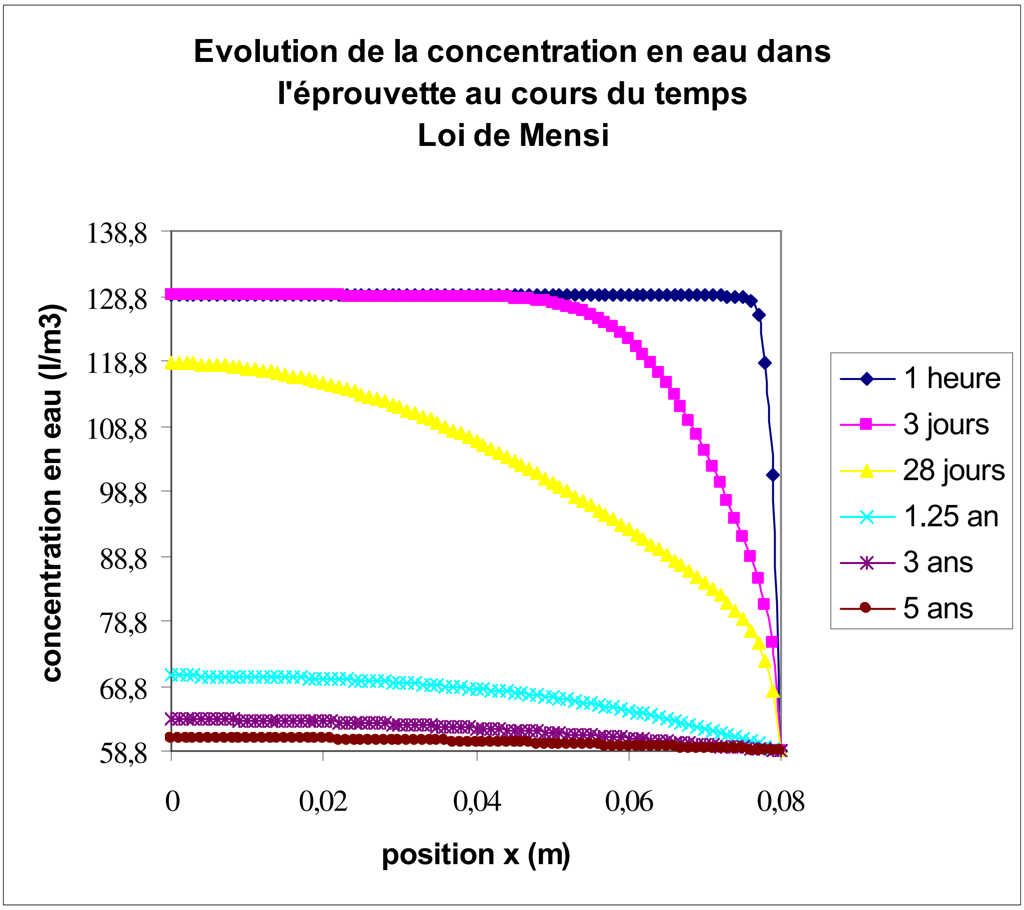

Figure 2.2-a.2-b: Scilab solution - law of Bazant

`TEST_RESU` are realized for the 6 characteristic moments with X-coordinates $x=0\text{mm}$, $x=40\,mm$ and $x=60\,mm$.

2.3 Bibliographical references

1) L. GRANGER: “Behavior differed from the concrete in the enclosures of nuclear power plants” published by the Central Laboratory from the Highways Departments (1996).

2) S. MICHEL-PONNNELLE, A. RAZAKANAIVO: “I7-01-08 project: Quality of the Studies in Mechanics of the Solids – Stage n°4: study of the finite elements”, EDF Notes: HT - 64/02/007/A, June 2002

3) G. DEBRUYNE, B. CIREE: “Modeling of thermohydration, the drying and the withdrawal of the concrete”, handbook of Reference *Code_Aster*, [R7.01.12] (2001).

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3 Modeling A

3.1 Characteristics of modeling

One uses the law of diffusion of Mensi.

3.2 Characteristics of the grid

The test-tube is with a grid using 80 `QUAD4` regularly distributed. There is only one element in the height.

Many nodes: 162
Number of meshs and type: 80 `QUAD4`

3.3 Characteristics of the temporal discretization

Initial moment (s)	**Final moment (s)**	**Many steps of time**
0	3600	10
3600	259,200	10
259,200	2,419,200	10
2,419,200	39,420,000	10
39,420,000	94,608,000	10
94,608,000	1 57,680,000	10

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3.4 Sizes tested and results

Water concentration at the point $x=0.0$:

Identification	**Reference**	***Aster***	**$\%$ difference**
afterwards 1 hour	128.80	128.80	$2.21\ 10^{-14}$
after 3 days	128.80	128.80	$-2.21\ 10^{-14}$
after 28 days	128.80	128.80	$-3.67\ 10^{-5}$
after 1.25 year	117.49	117.76	0,231
after 3 years	105.06	105.38	0,307
after 5 years	96.77	97.09	0,332

Water concentration at the point $x=0.04$:

Identification	**Reference**	***Aster***	**$\%$ difference**
afterwards 1 hour	128.80	128.80	$1.31\ 10^{-13}$
after 3 days	128.80	128.80	$-1.77\ 10^{-13}$
after 28 days	128.61	128.66	0,038
after 1.25 year	117.74	112.35	0,543
after 3 years	99.43	100.06	0,634
after 5 years	91.39	91.99	0,661

Water concentration at the point $x=0.06$:

Identification	**Reference**	***Aster***	**$\%$ difference**
afterwards 1 hour	128.80	128.80	$2.53\ 10^{-11}$
after 3 days	128.80	128.80	0,002
after 28 days	124.98	125.67	0,552
after 1.25 year	101.32	102.42	1,089
after 3 years	89.60	90.64	1,158
after 5 years	82.33	83.27	1,140

3.5 Comments

It is checked here that the made mistake is weak since lower than 1.5% , which is completely correct being given the relatively coarse temporal discretization used, in particular at the end of the calculation.

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4 Modeling B

4.1 Characteristics of modeling

One uses the law of diffusion of Granger

4.2 Characteristics of the grid

The test-tube is with a grid using 80 `QUAD4` regularly distributed. There is only one element in the height.

Many nodes: 162
Number of meshs and type: 80 `QUAD4`

4.3 Characteristics of the temporal discretization

Initial moment (s)	**Final moment (s)**	**Many steps of time**
0	3600	10
3600	259,200	10
259,200	2,419,200	10
2,419,200	39,420,000	10
39,420,000	94,608,000	10
94,608,000	1 57,680,000	10

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4.4 Sizes tested and results

Water concentration at the point $x=0.0$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$2.21\ 10^{-14}$
after 3 days	128.80	128.80	$-2.21\ 10^{-14}$
after 28 days	128.80	128.80	$-3.67\ 10^{-5}$
after 1.25 year	117.49	117.76	0,231
after 3 years	105.06	105.38	0,307
after 5 years	96.77	97.09	0,332

Water concentration at the point $x=0.04$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$1.31\ 10^{-13}$
after 3 days	128.80	128.80	$-1.77\ 10^{-13}$
after 28 days	128.61	128.66	0,038
after 1.25 year	117.74	112.35	0,543
after 3 years	99.43	100.06	0,634
after 5 years	91.39	91.99	0,661

Water concentration at the point $x=0.06$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$2.53\ 10^{-11}$
after 3 days	128.80	128.80	0,002
after 28 days	124.98	125.67	0,552
after 1.25 year	101.32	102.42	1,089
after 3 years	89.60	90.64	1,158
after 5 years	82.33	83.27	1,140

4.5 Comments

One finds the same solution exactly as the law of Mensi.

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5 Modeling C

5.1 Characteristics of modeling

The law of diffusion is used `SECH_NAPPE`, for which one returns simply the law of diffusion of Mensi.

5.2 Characteristics of the grid

The test-tube is with a grid using 80 `QUAD4` regularly distributed. There is only one element in the height.

Many nodes: 162
Number of meshs and type: 80 `QUAD4`

5.3 Characteristics of the temporal discretization

Initial moment (s)	Final moment (s)	Many steps of time
0	3600	10
3600	259,200	10
259,200	2,419,200	10
2,419,200	39,420,000	10
39,420,000	94,608,000	10
94,608,000	1 57,680,000	10

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6 Results of modeling C

6.1 Values tested

Water concentration at the point $x=0.0$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$1.32\ 10^{-13}$
after 3 days	128.80	128.80	$8.83\ 10^{-14}$
after 28 days	128.80	128.80	$-4.35\ 10^{-5}$
after 1.25 year	117.49	117.51	0,012
after 3 years	105.06	105.04	-0,021
after 5 years	96.77	96.73	-0,037

Water concentration at the point $x=0.04$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$1.32\ 10^{-13}$
after 3 days	128.80	128.80	$-4.41\ 10^{-13}$
after 28 days	128.61	128.65	0,029
after 1.25 year	117.74	112.11	0,328
after 3 years	99.43	99.74	0,318
after 5 years	91.39	91.68	0,319

Water concentration at the point $x=0.06$:

Identification	**Reference**	***Aster***	$\%$ **difference**
afterwards 1 hour	128.80	128.80	$2.45\ 10^{-11}$
after 3 days	128.80	128.80	0,002
after 28 days	124.98	125.57	0,471
after 1.25 year	101.32	102.18	0,856
after 3 years	89.60	90.35	0,843
after 5 years	82.33	82.99	0,798

6.2 Comments

It is seen here that the error is lower than 1% .

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7 Modeling D

7.1 Characteristics of modeling

One uses the law of diffusion of Bazant.

7.2 Characteristics of the grid

The test-tube is with a grid using 80 `QUAD4` regularly distributed. There is only one element in the height.

Many nodes: 162
Number of meshs and type: 80 `QUAD4`

7.3 Characteristics of the temporal discretization

Initial moment (s)	Final moment (s)	Many steps of time
0	3600	10
3600	259,200	20
259,200	2,419,200	20
2,419,200	39,420,000	20
39,420,000	94,608,000	10
94,608,000	1 57,680,000	10

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8 Results of modeling D

8.1 Values tested

Water concentration at the point $x=0.0$:

Identification	**Reference**	***Aster***	**% difference**
afterwards 1 hour	128.80	128.80	0.
after 3 days	128.80	128.80	$-3.70\ 10^{-7}$
after 28 days	118.42	118.63	0,175
after 1.25 year	70.36	70.51	2,227
after 3 years	63.63	63.76	0,210
after 5 years	60.67	60.73	0,102

Water concentration at the point $x=0.04$:

Identification	**Reference**	***Aster***	**% difference**
afterwards 1 hour	128.80	128.80	$-2.21\ 10^{-14}$
after 3 days	128.66	128.70	0,031
after 28 days	105.89	106.80	0,853
after 1.25 year	68.25	68.53	0,415
after 3 years	62.24	62.40	0,259
after 5 years	60.06	60.13	0,119

Water concentration at the point $x=0.06$:

Identification	**Reference**	***Aster***	**% difference**
afterwards 1 hour	128.80	128.80	$-1.18\ 10^{-11}$
after 3 days	120.99	122.47	1,225
after 28 days	92.11	93.21	1,192
after 1.25 year	65.16	64.80	0,563
after 3 years	60.62	60.76	0,234
after 5 years	59.43	59.49	0,097

8.2 Comments

It is checked here that the made mistake is weak since lower than 1.5% .

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9 Summary of the results

For the whole of modelings, one obtains a difference between the solution SCILAB and the solution *Code_Aster* lower than 1.5% what makes it possible to validate the establishment of the various laws of drying in the code. Let us note simply that one observes a violation of the principle of the maximum at the beginning of simulation with Aster for the law of Mensi. This can be explained (by analogy with thermics) by the "hydrous shock" important due like imposing the boundary conditions (imposed water concentration). This problem should be able to be solved by the use of the elements lumpés in the same way that in thermics.

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Annexe 1 Command file Scilab

Main.sci:

```
getf ('/home/xxxx/librairie.sci');
//PARAMETERS OF THE DIGITAL SIMULATION
//
//discretization of the width
x0 = 0.08;
X = [- 0.080:0.001: +0,080]; [n1 N2] = size (X);
//water content initial
Cinit = 128.8;
Ci = Cinit*ones (1, N2);
//boundary conditions with 50%HR
CL = [58.8 58.8];.
Ci (1) = CL (1); Ci ($) = CL (2);
Ci_bazant = Ci;
//not of time
dt = 60; //[S]
//coefficients of the law of Bazant
D1 = 3.0E-10; //[m2/s]
= 0.04 have;
N = 6;
TMAX = 5; //years
//____________________________________________________________________
//
//DIGITAL SIMULATION
//
J = 0;
u=file ('open', 'resultat_g', 'unknown');
for year = 0: TMAX,
 year
  for day = 0:364,
  for hour = 0:23,
   minute = 0;
    for times = 0:59,
     D_bazant = diffusion_bazant (D1, has, N, Cinit, 58.8, Ci_bazant, 293,293*ones (Ci), 4700);
    Ci_bazant = linear_drying (D_bazant, Ci_bazant, CL, dt, X, "whodunnit");
    yew ((year ==  0 & == day   0 & hour == 1 & time == 0) | …
        (year ==  0 & == day   3 & hour == 0 & times == 0) | …
        (year ==  0 & == day  28 & hour == 0 & times == 0) | …
        (year ==  1 & == day  91 & hour == 0 & times == 0) | …
        (year ==  3 & == day   0 & hour == 0 & time == 0) | …
        (year ==  5 & == day   0 & hour == 0 & time == 0) ) then,
       year, day, hour
       t=81: 1:161;
       for tk=t,
         fprintf (U, '%6.3f %6.3f', X (tk), Ci_bazant (tk)) ;
       end,
     end, //yew
   end, //for times
  end, //for hour
 end, //for day
end, //for year

file ('closed', U);
```

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Librairie.sci:

```
 _______________________________________________________________
//
//NONLINEAR COEFFICIENT OF DIFFUSION FOR THE DRYING OF THE CONCRETE
//LAW OF MENSI D (C) = a.exp (b.C)
//THERMIC ACTION D (C, T) = D (C, T0). (T/T0) .EXP [- Q/R* (1/T-1/T0)]
//
//has      coefficient of the law of Mensi
//B       coefficient of the law of Mensi
//C       vector of the water contents [-]
//T0      temperature of reference [K]
//T       vector of the temperatures [K]
//Q_R  Q/R (being worth 4700 K)
function D = diffusion_mensi (has, B, C, T0, T, Q_R),
  D = a*ones (C).*exp (b*C);
  D = D.* (T./(T0*ones (T))) ;
  D = D.*exp (Q_R* ((ones (T). /T0) - (ones (T). /T))) ;
endfunction,
//
//_______________________________________________________________
//
//NONLINEAR COEFFICIENT OF DIFFUSION FOR THE DRYING OF THE CONCRETE
//LAW OF BAZANT
//THERMIC ACTION D (C, T) = D (C, T0). (T/T0) .EXP [- Q/R* (1/T-1/T0)]
//
//D1      coefficient of the law of Bazant
//has      coefficient of the law of Bazant (alpha)
//N       coefficient of the law of Bazant
//C0      water content with 100%HR
//Cext    water content of the surrounding medium
//C       vector of the water contents [-]
//T0      temperature of reference [K]
//T       vector of the temperatures [K]
//Q_R  Q/R (being worth 4700 K-1)
function D = diffusion_bazant (D1, has, N, C0, Cext, C, T0, T, Q_R),
  H = ones (C) - 0.5* ((C-C0*ones (C))/(Cext-C0))** 2;
  D = (((1-a) *ones (C). /(ones (C)+ (4 ** N) * (ones (C) - H) ** N))+a*ones (C))
*D1;
  D = D.* (T./(T0*ones (T))) ;
  D = D.*exp (Q_R* ((ones (T). /T0) - (ones (T). /T))) ;
endfunction,
//_______________________________________________________________
//
//DIFFUSION
//Resolution by the method the finite differences
//
//D       vector of the coefficients of diffusion
//Ci      vector of the water contents at the moment J [-]
//CL      boundary condition in xmin and xmax of the type Dirichlet (C=C0)
//dt      pas de time [S]
//X       vector of the X-coordinates [m]
//mode_   polar/Cartesian
function cf = linear_drying (D, Ci, CL, dt, X, mode_),
  [n1, N2] = size (Ci);
  dx_ = zeros (1, N2-2)   ; dx_ (1: $) = (X (3: $) - X (1: $-2))*0.5;
//  Cf_ = (D*dt* (ones (dx_). /(dx_ ** 2)). * (Ci (3: $) - 2*Ci (2: $-1) +Ci (1:
$-2)))+Ci (2: $-1);
  dx3     = ((                    …
```

```
               (X (2: $-1) - X (1: $-2)). *…
               (X (3: $  ) - X (1: $-2))    …
              ). *                          …
               (X (3: $) - X (2: $-1))      …
            ) ;
  d2C_dx2 = 2* (Ci (3: $  ). * (X (2: $-1) - X (1: $-2))…
               here (2: $-1). * (X (3: $  ) - X (1: $-2))…
               +Ci (1: $-2). * (X (3: $  ) - X (2: $-1)));
  d2C_dx2 = d2C_dx2. /dx3;
  yew (mode_ == "whodunnit") then,
    dC_dx = (Ci (3: $  ). * (X (2: $-1) - X (1: $-2)) ** 2…
             here (1: $-2). * (X (3: $  ) - X (2: $-1)) ** 2);
//              here (2: $-1). * ((X (2: $-1) - X (1: $-2)) ** 2 - (X (3: $  ) - X
(2: $-1))** 2)…
    dD_dx = (  D (3: $  ). * (X (2: $-1) - X (1: $-2)) ** 2…
             - D (1: $-2). * (X (3: $  ) - X (2: $-1)) ** 2);
//              - D (2: $-1). * ((X (2: $-1) - X (1: $-2)) ** 2 - (X (3: $  ) - X
(2: $-1))** 2)…
    dC_dx = dC_dx. /dx3;
    dD_dx = dD_dx. /dx3;
    I = find (x==0); [k1 k2] = size (I);
    yew (| (k1==0)) then, X (I) = X (i+1)/10, end,
//printf ("1st order %s; 2nd order %s", G-string (min (dC_dx)), G-string (min
(d2C_dx2)));
    d2C_dx2 = d2C_dx2 + dC_dx. /x (2: $-1);
  end,
  Cf_ = Ci (2: $-1) +dt* (D (2: $-1). *d2C_dx2);
  yew (mode_ == "whodunnit") then,
    Cf_ = Cf_ +dt* (dD_dx.*dC_dx);
  end,
  Cf  = zeros (1, N2); Cf (2: $-1) = Cf_; Cf (1) = CL (1); Cf ($) = CL (2);
endfunction,
//
//_______________________________________________________________
//
```

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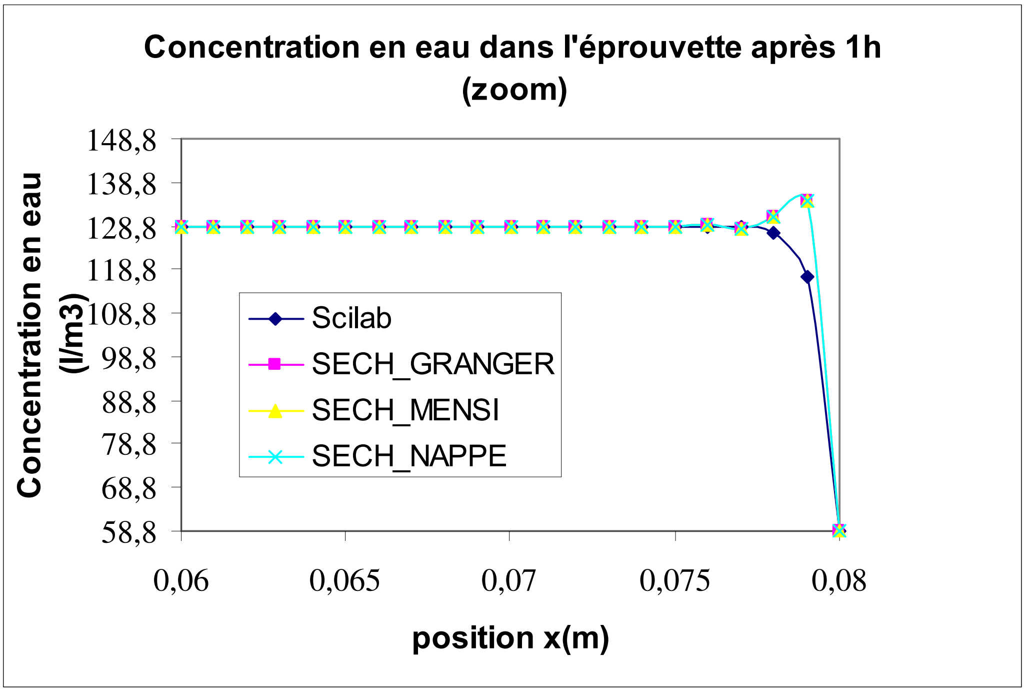
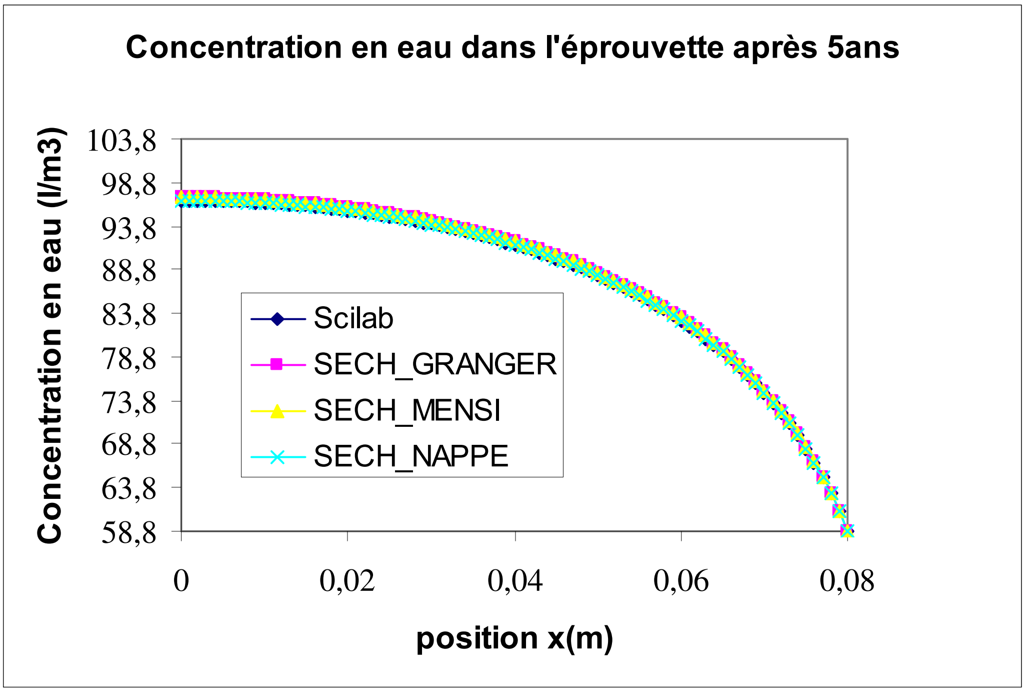
Annexe 2 Comparison Aster/Scilab

A2.1 `SECH_MENSI` / `SECH_GRANGER` / `SECH_NAPPE`





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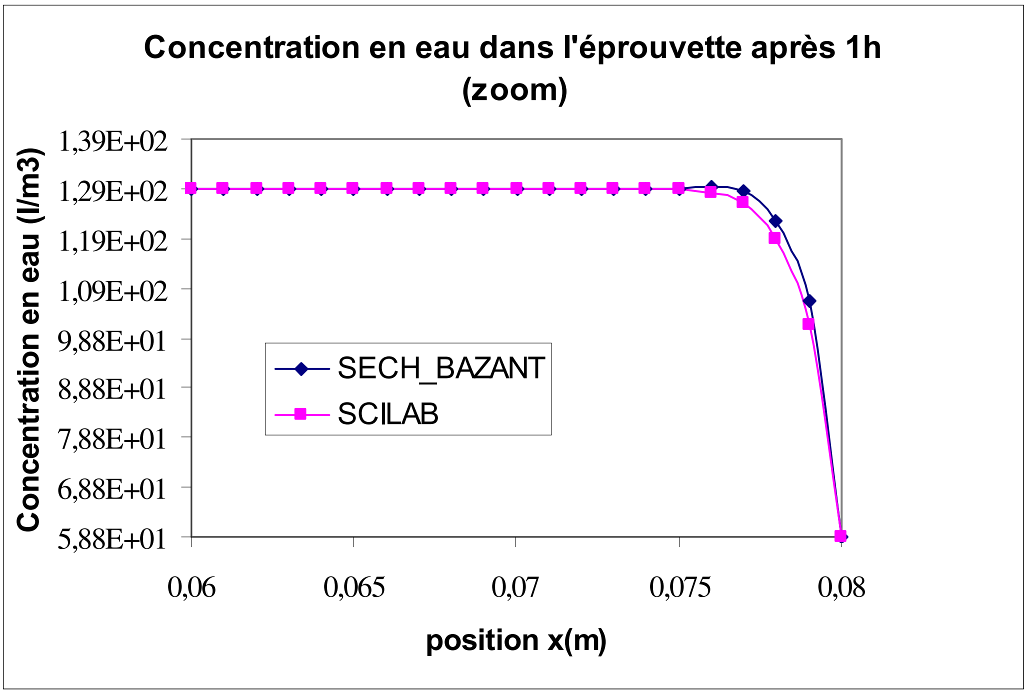
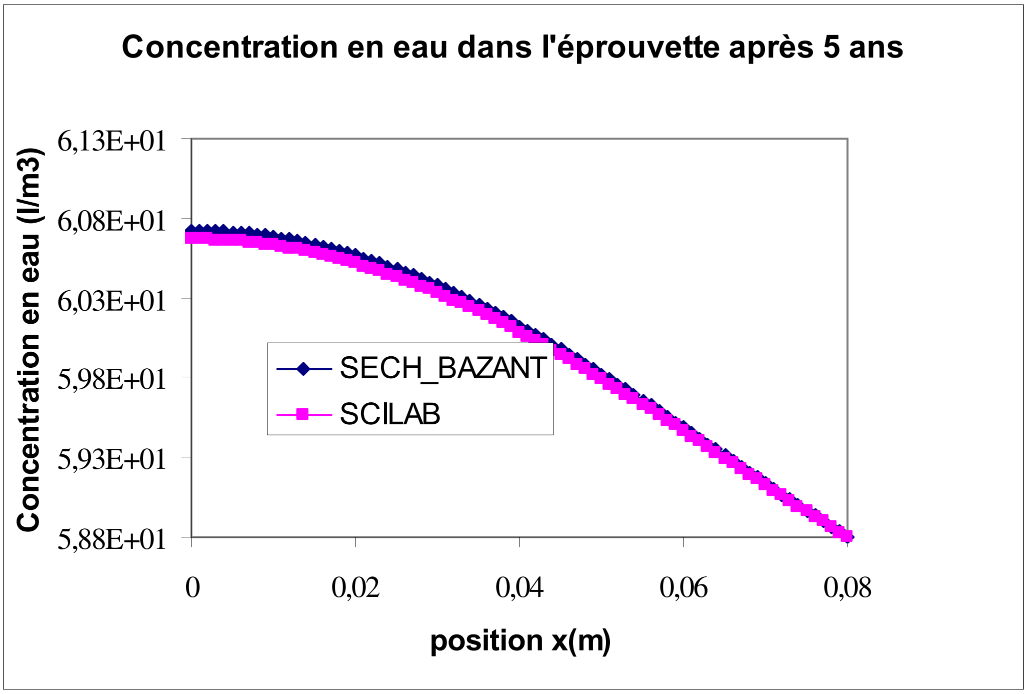
A2.2 `SECH_BAZANT`





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