Benchmark on two-phase flow in porous media : presentation of 3 tests

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cea

Aims of the benchmark

- **Solving and understanding of main numerical problems concerning gas migration in porous media for underground nuclear waste storage :**
  - Injection of gas in a fully saturated medium problem
    - ✓ **Hydrogen due to corrosion of steel containers and liners produced in clay**
  - Saturation equilibrium between contrasted materials
    - ✓ **Plugs (concrete, swelling clays, etc.), seals, clay …**

- **Separation of each problem**
- **A very simple geometry (quasi-1D flow)**
- **Several Test cases available on http://sources.univ-lyon1.fr/cas_test.html.**

=>Selection of 3 tests for this benchmark (1.a – 3 – 4)

General hypothesis

- 2 phases : liquid and gas
- 2 components (for ex. hydrogen and water)
- Incompressible water
- Isothermal Problem and vaporization neglected
- Hypothesis of perfect gas
- Capillary pressure Pc(S) = Pg-Pl
- Mass conservation of each component
- Darcy law for each phase
- Fick Law in liquid mixture (exept 4)
- Henry's law for dissolution(exept 4)
- Indeformable solid

Test 1a : Gas phase appearance in a homogeneous porous media

$t < 5.10^5\ years:$

$\mathbf{F^h.n} = 5{,}57.10^{-6}\ kg/m^2/year$

$5.10^5\ years < t < 10^6\ years:$

$\mathbf{F^h.n} = 0$

$\mathbf{F^w.n} = 0$

$\mathbf{F^h.n} = 0 \quad \mathbf{F^w.n} = 0$

$P_l^0 = 1MPa$

$S = 1$

$P_{l,out} = 1MPa$

200m

$\mathbf{F^h.n} = 0 \quad \mathbf{F^w.n} = 0$

Test proposed by F. Smaï

➢Capillary pressure curve and relative permeability expressed with a Mualem Van-Genuchten Law (Pr = 2MPa ; n=1,49 ; S_{lr} = 0,4)

$$S_{lq} = \frac{1 - S_{wre}}{\left(\left(\frac{P_c}{P_r}\right)^n + 1\right)^m} + S_{wre} \qquad k_{rel}^l = \sqrt{S_{wre}}\left(1 - \left(1 - S_{we}{}^{1/m}\right)^m\right)^2 \qquad k_{rel}^g = \sqrt{(1 - S_{we})}\left(1 - S_{we}{}^{1/m}\right)^{2m}$$

$$S_{we} = \frac{S_l - S_{lr}}{1 - S_{lr}} \qquad m = 1 - 1/n$$

Test 1a : Hypothesis of each team (1/2)

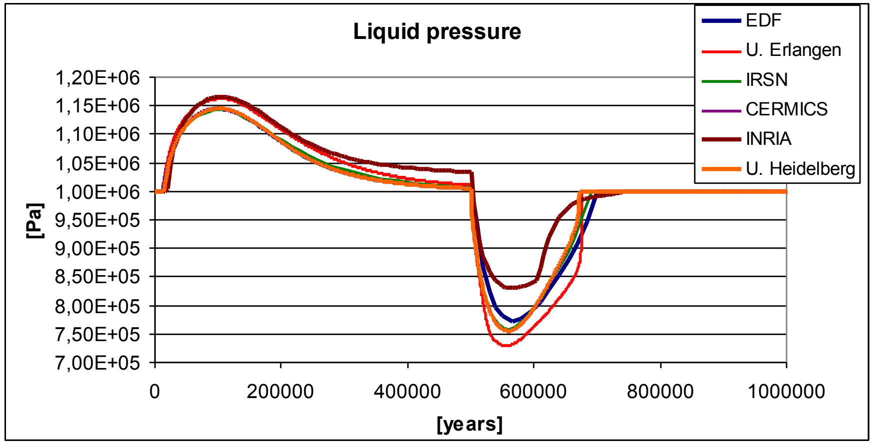
	Software	Spatial Scheme	Mesh	Regularization of MVG (S=1)	Time steps (years)
UFSC (I.Mozolezki)	Matlab	Discontinuous Galerkin	200*1*(1m*1m) quad	No	125->5000
EDF (S. Granet)	Code_Aster	FE P1 (and FV)	200*1*(1m*1m) quad	Yes	0,1->15000
INRIA (I.Ben Gharbia)	Develop. INRIA soft.	FV with upstream scheme	200*1*(1m*1m) quad	Yes	5000
IRSN (F. Smaï)	Develop. IRSN soft.	FE P1	200*1*(1m*1m) quad	No	100->15000
U. Erlangen (T. Mueller)	M++	Mixed Hybrid FE	4480 triangles	Yes	200
U. Heidelberg (R. Neumann)	Dune	FV with upstream scheme	40*20*(0,5*1m) quad	No	0,001->1010

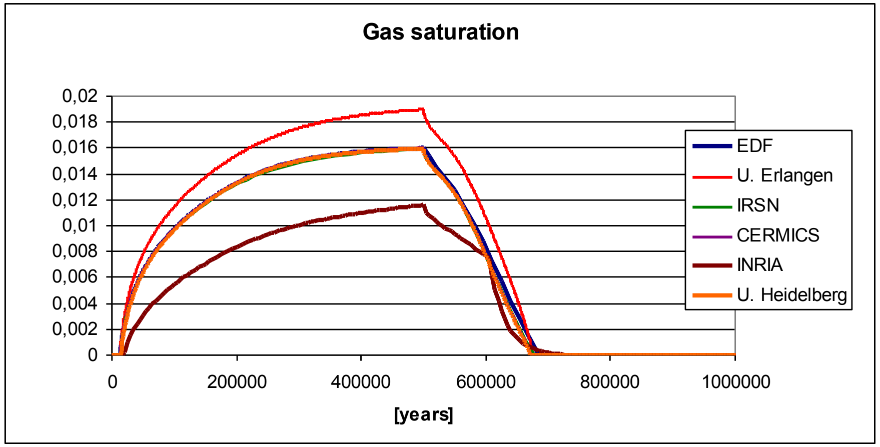
Test 1a : Hypothesis of each team (2/2)

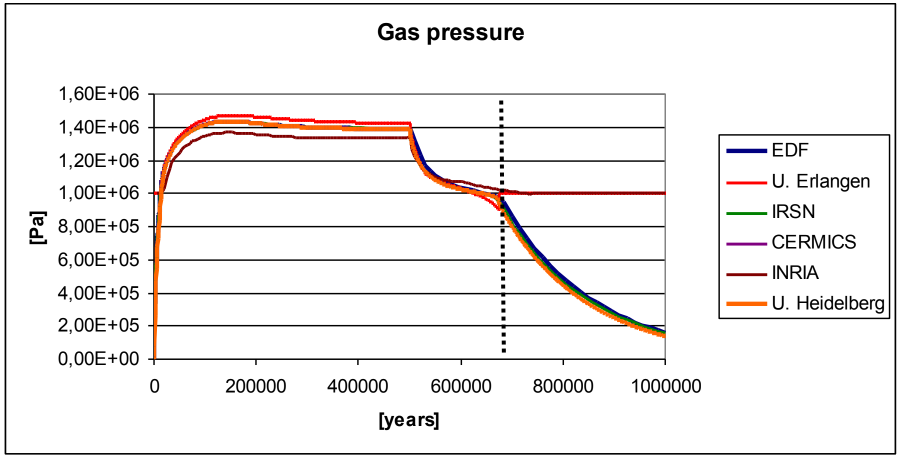
- **Time disretization : Euler implicit for all team**
- **Treatment of gas appearance**
  - ✓ included in choice of unknows, for exemple : $\left(P_l, \frac{\rho_l^h}{H.M^h}\right)$
    - A. Bourgeat, M. Jurak, F. Smaï, Two phase partially miscible flow and transport modeling in porous media: application to gas migration in a nuclear waste repository. Comp. Geoscience. 2009
    - *O. Angelini, C. Chavant, E. Chénier, R. Eymard, S. Granet*, Finite Volume Approximation of a Diffusion-dissolution model and application to nuclear waste storage, Mathematics & Computers in simulation. matcom.2010
    - Neumann, R., Ippisch, O. Bastian, P. Modeling Two-Phase Two-Component Flow with Disapearing Gas Phase. Preprint 2011
  - ✓ INRIA use $\left(S_l, P_l, \chi_l^h\right)$ and complementarities conditions

Test 1a : Results

- **Time evolution**

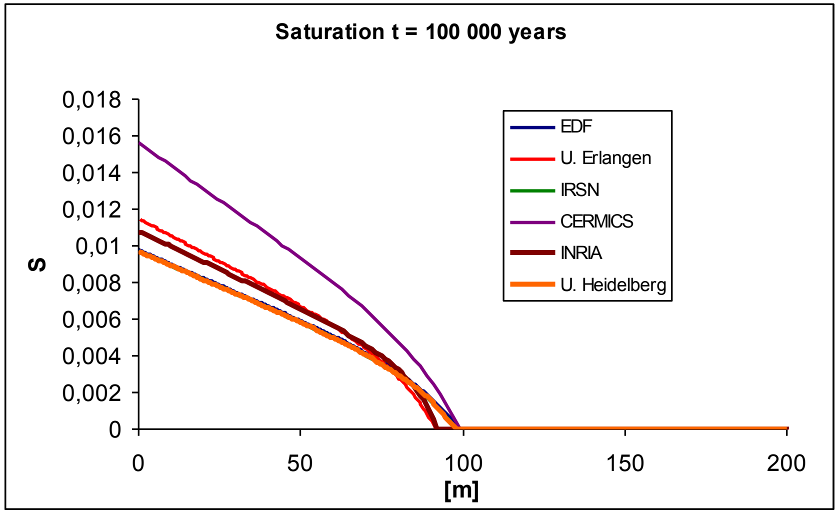


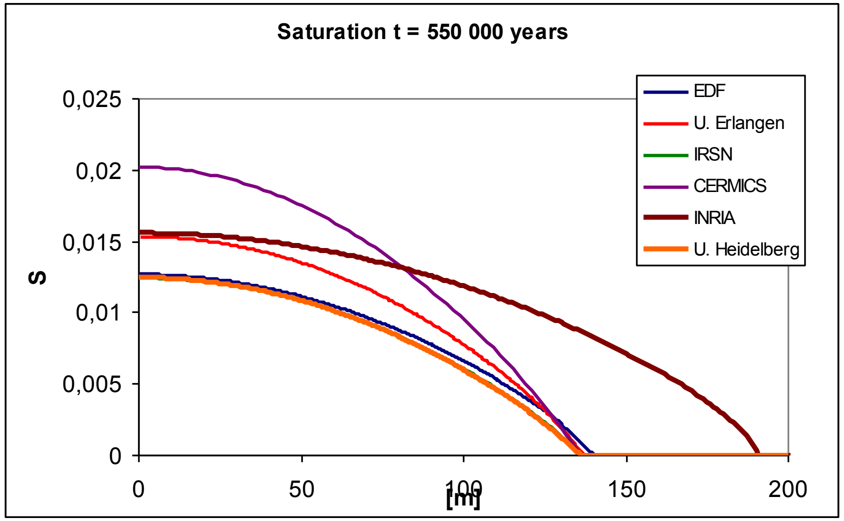


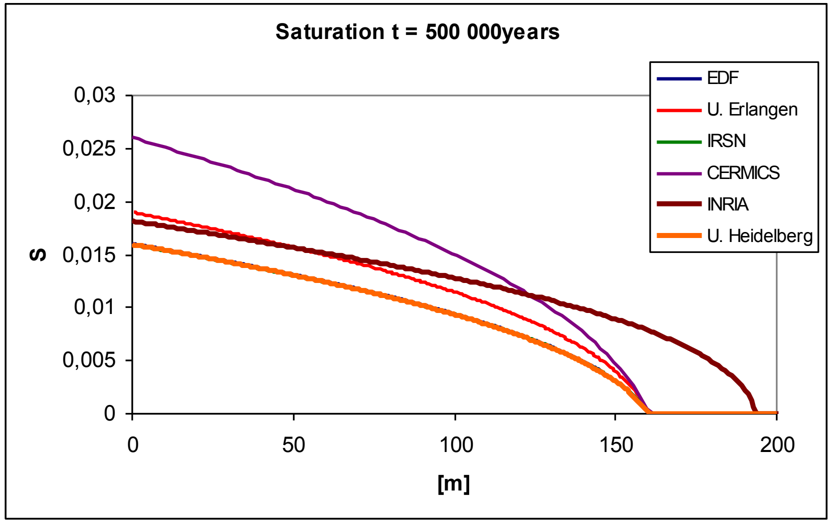


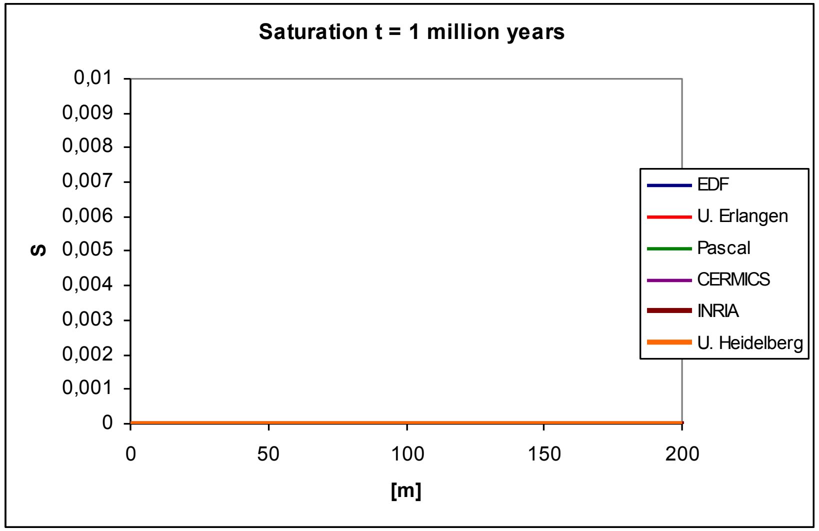
1- Dissolution
2- Desaturation and increase of gas pressure
3- Equilibrium in a desaturated state
4- End of Injection : quick desaturation, water comes from the left : decrease of liquid pressure
5- End of desaturation the water is coming back
6- back to initial state

Test 1 : results (2/2)

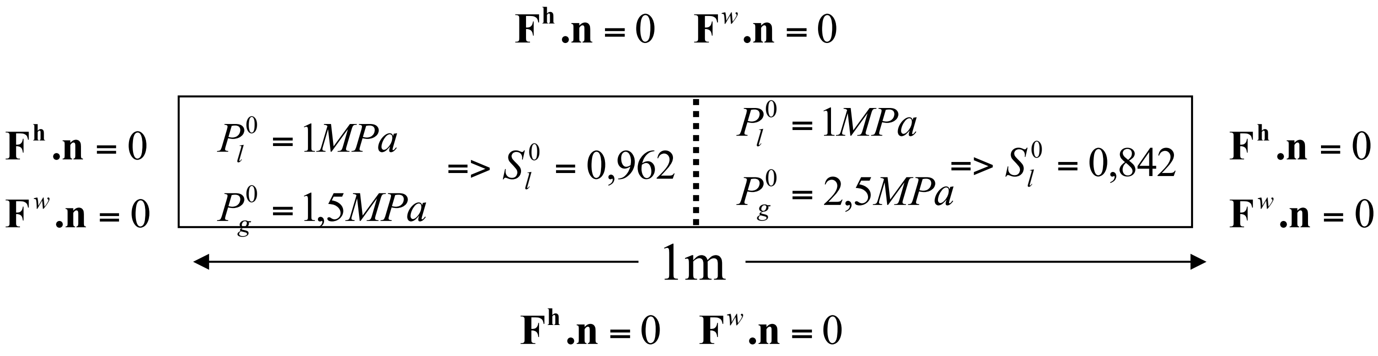








Test 3 : Compressible and miscible two-phase flow starting from non equilibrium state



Test proposed by F. Smaï

- **Time of simulation : 10^6s**
- **Homogeneous material**
- **Capillary pressure curve and relative permeability expressed with a Mualem Van-Genuchten Law (Pr = 2MPa ; n=1,54 ; S_{lr} = 0,01)**

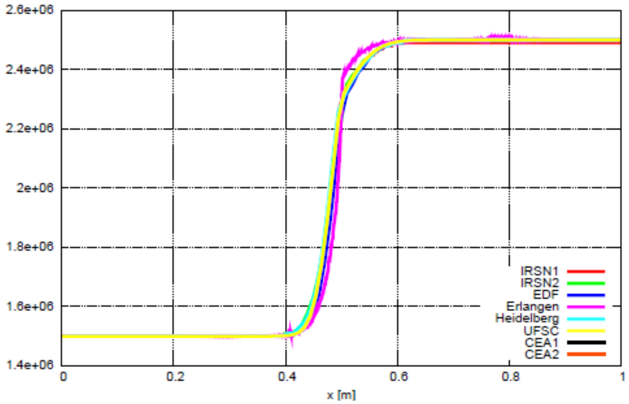
Test 3 : Hypothesis of each team (1/2)

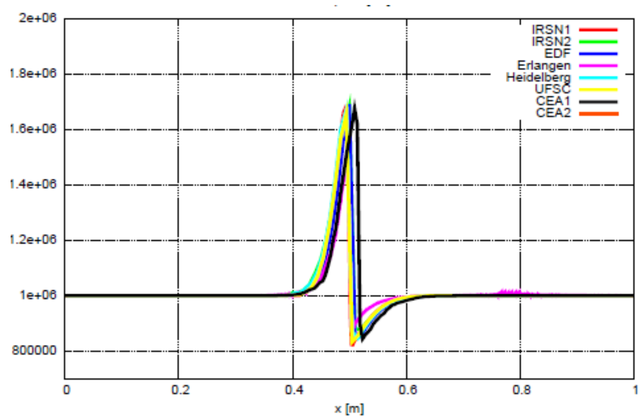
	Software	Spatial Scheme	Mesh	Time steps(s)
CEA (F. Caro)	MPCube	FV Diamants	200 triangles	0,17->833
CEA2 (B. Saad)	Scilab 1D	Finite Diffrence	500 1D el.	0,17->833
IRSN1 (F. Smaï)	Develop. IRSN soft.	FE P1	500*1*(1m*1m) quad	0,1->4000
IRSN2 (M. Dimitrowska)	MIgastra	FV for convection and EF for diffusion	Triangles Δx=0,01	1->16
EDF (S. Granet)	Code_Aster	FE P1 (VF)	100*1*(1m*1m) quad	2->15000
U. Erlangen (T. Mueller)	M++	Mixed Hybrid FE	4480 triangles	10->1000s
U. Heidelberg (R. Neumann)	Dune	FV with upstream scheme	40*20*(0,5*1m) quad	1->1000s
UFSC (I.Mozolezki)	Matlab	Discontinuous Galerkin	512*1D el.	0,3->31250

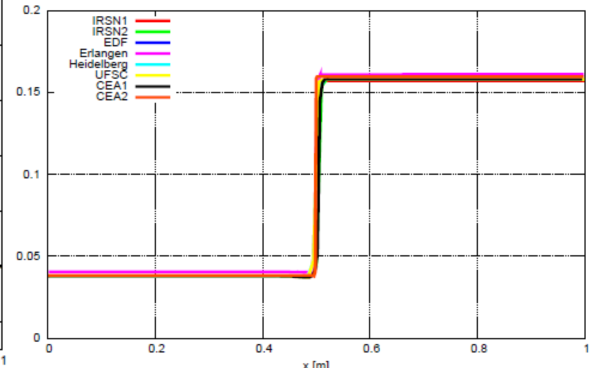
Test 3 : Results (1/2)

10 s

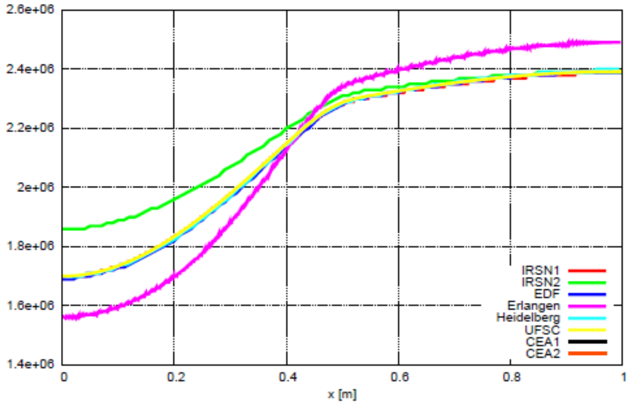
Gas pressure | **Liquid pressure** | **Saturation**

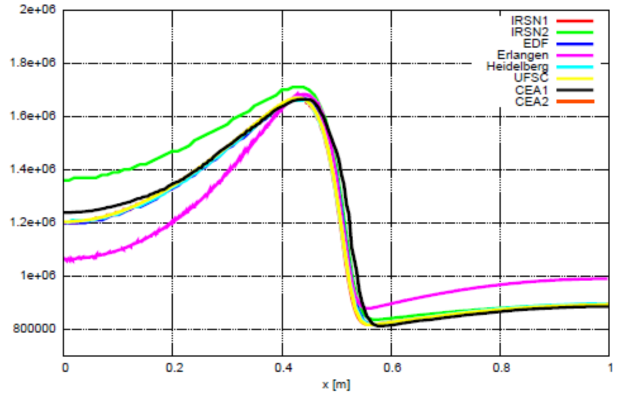


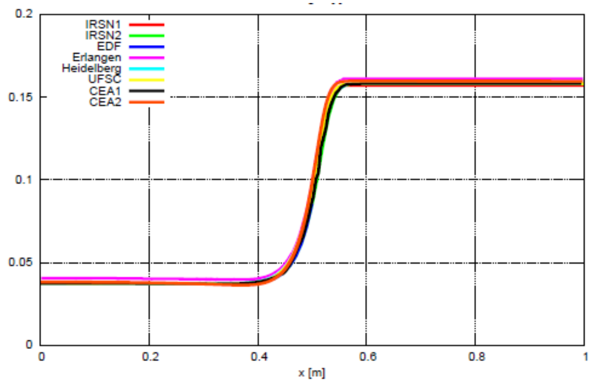




1000 s

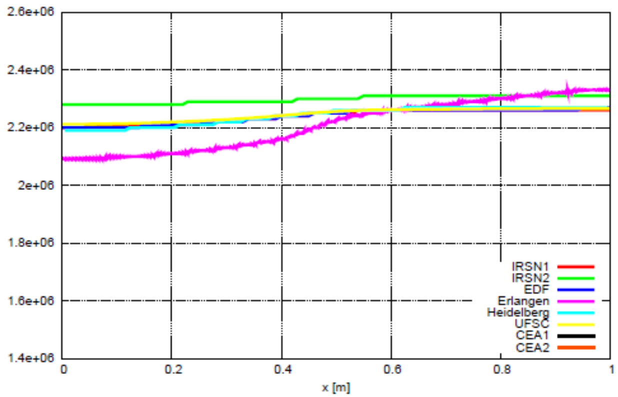


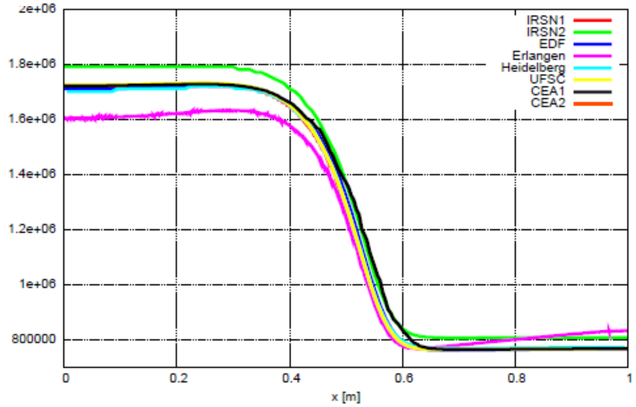


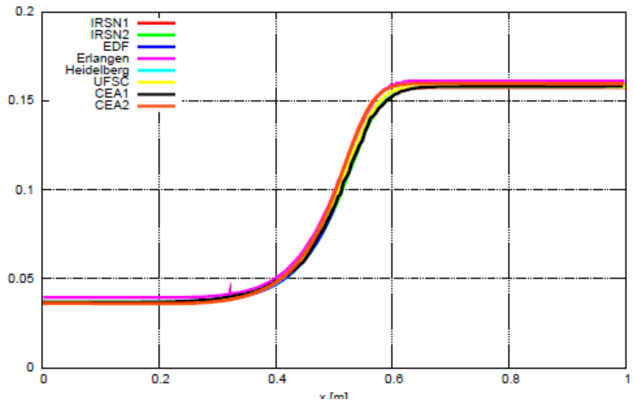


Test 3 : Results (2/2)

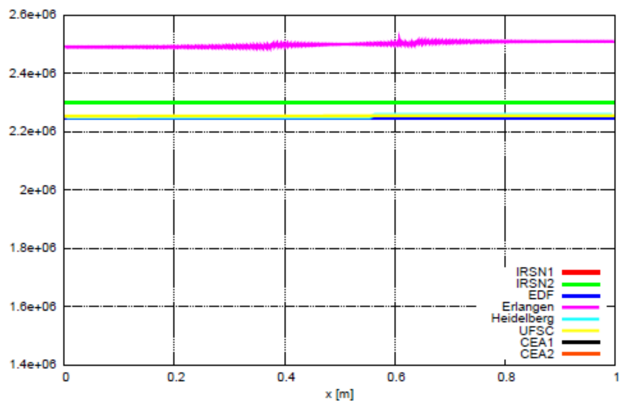
5000 s **Gas pressure** **Liquid pressure** **Saturation**

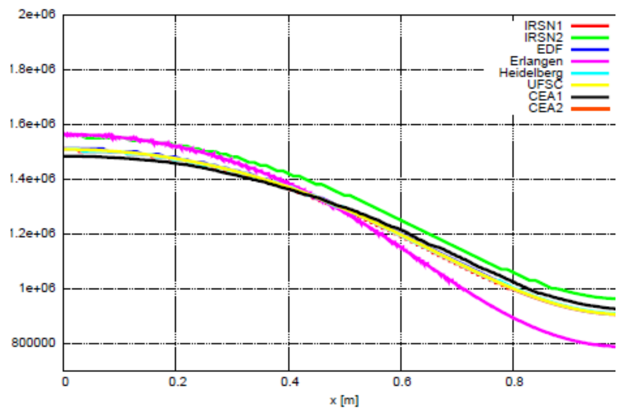


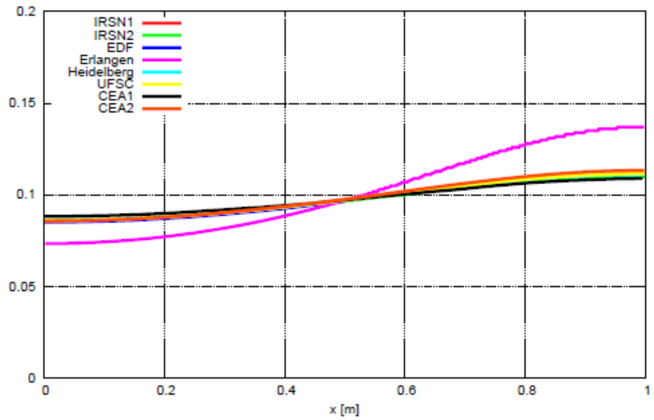




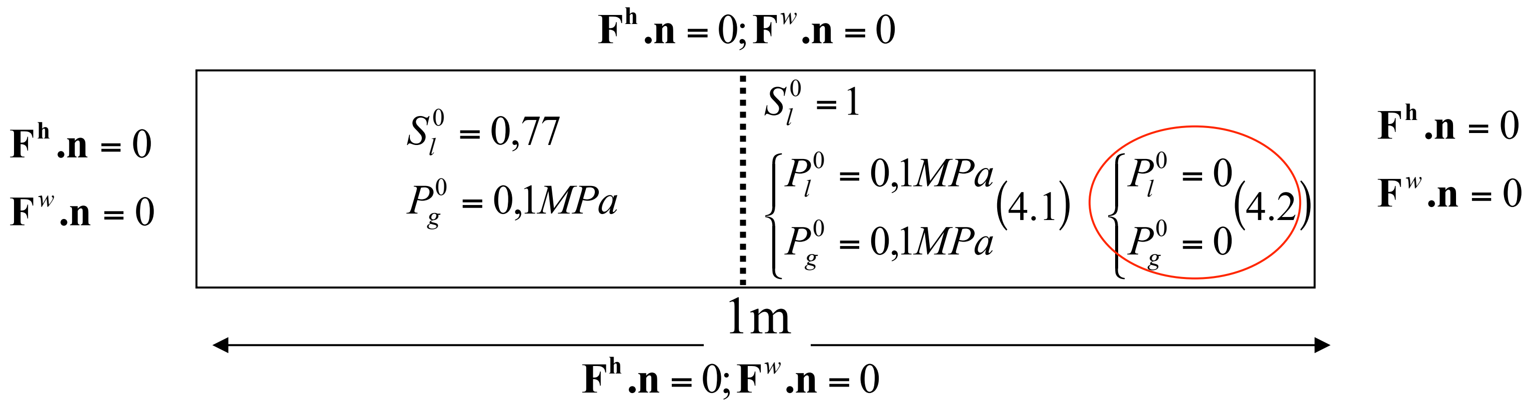
500000 s







Test 4 : immiscible two-phase flow starting from non equilibrium state in a heterogeneous media



Test proposed by C. Chavant

- **Immiscible fluid : 1 component in each phase (no dissolution)**
- **100 elements (h=10^{-2} m)**
- **heterogeneous material :**

S(PC) : VG (n=0,06 ; Pr = 1,5MPa)

$$k_{rel}^l = \left(1 + \frac{\left(S^{-16,67} - 1\right)^{1,88}}{4}\right)^{-0,5}$$

$$\phi = 0{,}3$$

$$K^{\text{int}} = 10^{-20} m^2$$

S(PC) : VG (n=0,412 ; Pr = 1MPa)

$$k_{rel}^l = \left(1 + \left(S^{-1,429} - 1\right)^{1,88}\right)^{-1}$$

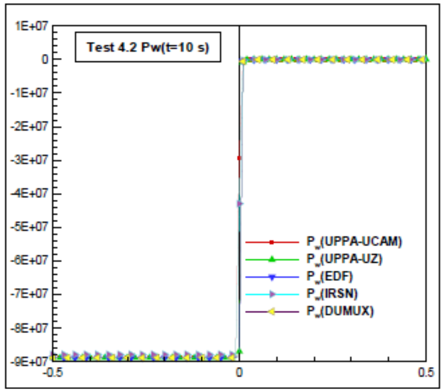
$$\phi = 0{,}05$$

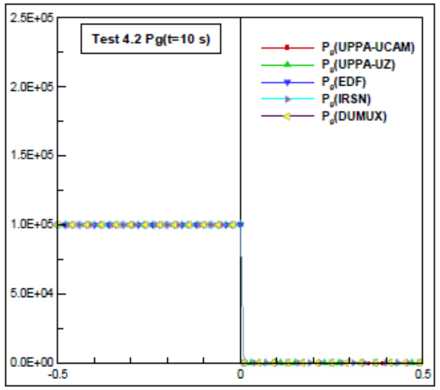
$$K^{\text{int}} = 10^{-19} m^2$$

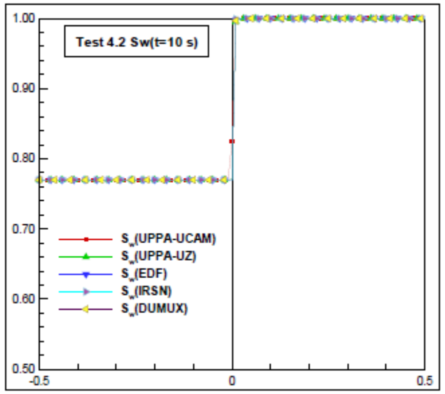
Test 4 : Hypothesis of each team

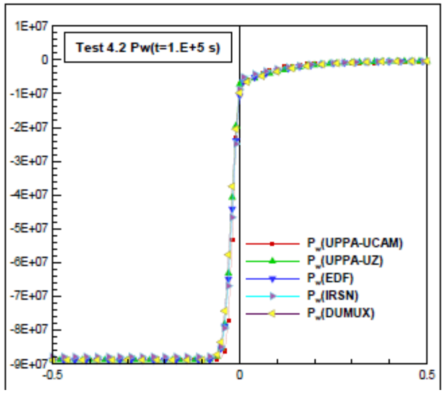
	Software	Unknowns	Spatial Scheme
UPPA-UCAM Marrakech (Ahusborde, Afif)	C++ 1D software	(P_g, S)	Vertex center FV
UPPA-U Zagreb (Amaziane, Jurak, Zgaljic-Keko)	C++ 1D software	(P_{glob}, S)	Vertex center FV
UPPA(Ahusborde)	DuMuX	(P_g, S)	Vertex center FV
IRSN (M. Dimitrowska)	MIgastra	(P_g, S)	FV for convection and FE for diffusion
EDF (S. Granet)	Code_Aster	$\left(P_l, \frac{\rho_l^h}{H.M^h}\right)$	FV Sushi

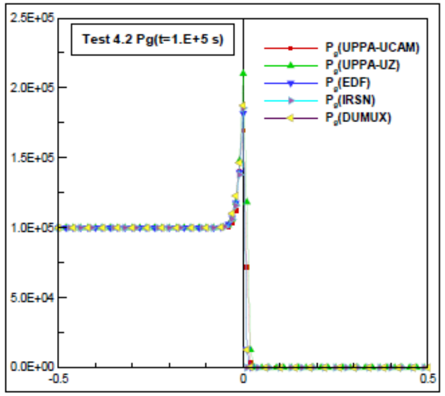
Test 4 : results (1/2)

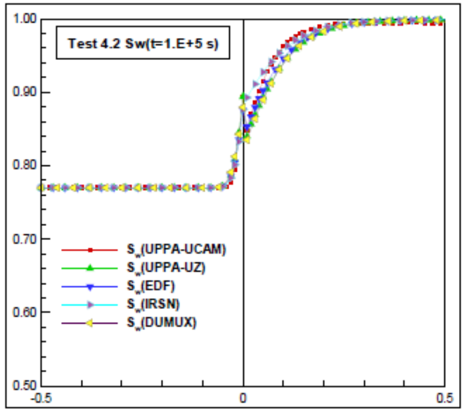




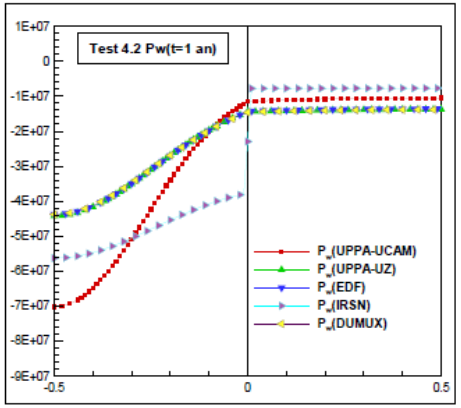


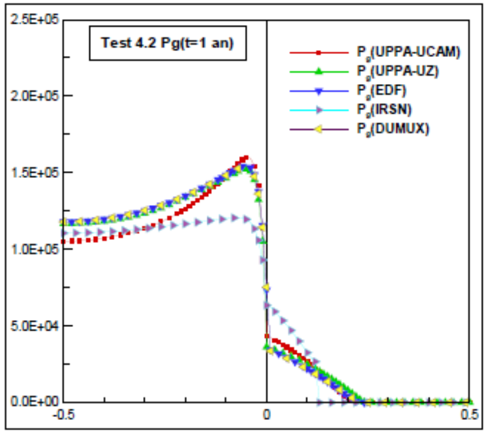


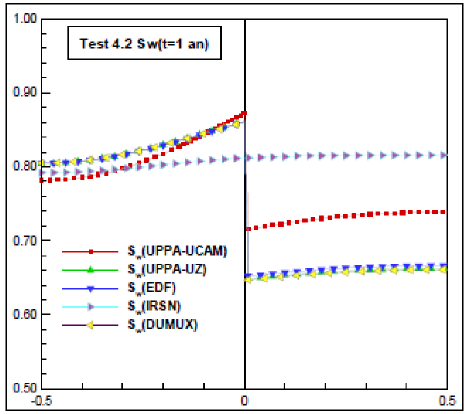


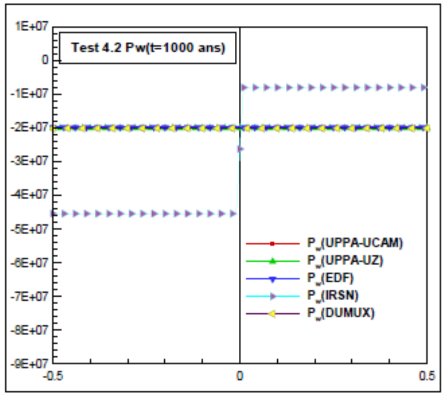


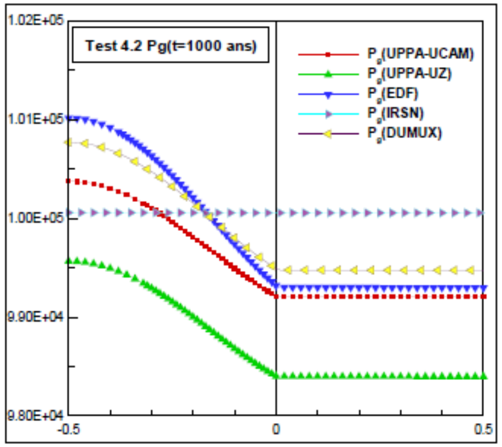
Test 4 : results (2/2)

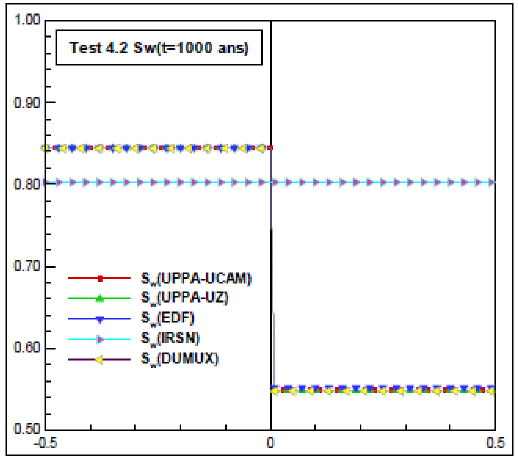












Conclusion and perspective

- **Participation of 12 teams : CEA (2 answers), EDF, INRIA, IRSN (2 answers), U. Erlangen, UFSC Santa Catarina, U. Heidelberg, UPPA&CNRS Pau, UCAM Marrakech, U. Zagreb**
- **6 teams for Test 1a; 8 teams for Test 3 ; 5 teams for test 4**
- **All the tests : very useful to understand the different mechanism of classical two-phase flow problem, and the solutions to solve them**

- **Most of results are qualitatively similar**
- **Little differences to investigate**
- **Importance in the choice of the unknowns (1a)**
- **Importance to take into account miscible phenomena**
- **Choice of scheme doesn’t seams to be discriminating**
- **Perpective : vaporization, gravity …etc.**

Selected references

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