WTN123 - Appearance/disappearance of phase in a diphasic flow: Gas injection around a gallery in a saturated field

Summary:

This test represents the simulation of the gas injection in a geological medium. It is a question of modelling and of simulating the appearance and the evolution of a diphasic water/hydrogen flow in one porous environment initially saturated with pure water. A situation is considered $2D$ where the effects of gravity are neglected.

It is about a miscible purely hydraulic calculation. The geometry represented corresponds to a square field whose zone was withdrawn. The terms of transfers are described by a model of Mualem Van-Genuchten. With the problem is dealt by the various diagrams available for the modeling of the diphasic flows: finite elements classiqueset Volumes Finis Décentrés Arête.

This case test is an extension in $2D$ case test WTNP120.

1 Problem of reference

1.1 Geometry

The field is a square of size $[0\text{m},10\,m]\times[0\text{m};10\text{m}]$ with a hole of $[1\text{m},1\,m]$ in bottom on the left.

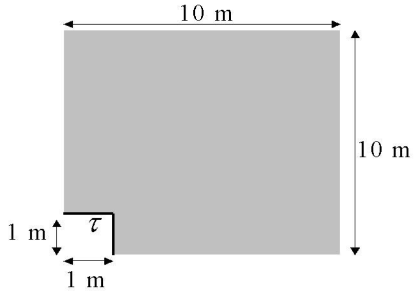

Figure 1.1-a: Representation of the field

1.2 Properties of materials

One gives here only the properties whose solution depends, knowing that the command file contains other data of material which do not play any part in the solution of with the dealt problem.

Liquid water	Density $(kg.m^{-3})$	1000
	Molar mass $(kg.mol^{-1})$	10^{-2}
	Viscosity $(kg.m^{-1}.s^{-1})$	10^{-3}
Gas	Density $(kg.m^{-3})$	$8\,10^{-2}$
	Molar mass $(kg.mol^{-1})$	$2\,10^{-3}$
	Viscosity $(kg.m^{-1}.s^{-1})$	$9\,10^{-5}$
Dissolved gas	Coefficient of Henry $(Pa.mol^{-1}.m^{3})$	130719
Vapor	Density $(kg.m^{-3})$	10^{-4}
Homogenized parameters	Permeability k (m^{2})	$5\,10^{-20}$
	Porosity	0.15
	Fick gas $(m^{2}.s^{-1})$	0
	Liquid Fick $(m^{2}.s^{-1})$	$0,45\,10^{-9}$
Parameters of Van-Genuchten	N	$1,49$
	P_r MPa	2
	S_{rl}	0
	S_{gr}	0

	$Smax$	0,999
Initial state	Capillary pressure (Pa) Gas pressure (Pa)	$\begin{cases} P_l^0 = 10^{-6} \\ S_l = 1 \end{cases} \Leftrightarrow \begin{cases} P_c^0 = -10^{-6} \\ P_g^0 = 0 \end{cases}$

Table 1.2-1 : properties of materials

The curves of saturation and permeabilities obey the Mualem-Van-Genuchten model (`HYDR_VGM`). It is thus necessary to define in materials the parameters $n, Pr, Sr, Smax$.

It is pointed out that these models are: $S_{le} = \frac{S_l - S_{lr}}{1 - S_{lr}}$ and $m = 1 - \frac{1}{n}$

$$S_{we} = \frac{1}{\left[1 + \left(\frac{P_c}{P_r}\right)^n\right]^m}$$

The permeability relating to water is expressed by integrating the model of prediction proposed by Mualem (1976) in the model of capillarity of Van Genuchten.

$$k_r^l = \sqrt{S_{le}}\left(1 - \left(1 - S_{le}^{\frac{1}{m}}\right)^m\right)^2$$

The permeability to gas is formulated in a similar way by a law of Parker:

$$k_r^g = \sqrt{(1 - S_{le})}\left(1 - S_{le}^{\frac{1}{m}}\right)^{2m}$$

One recalls that for $S > Smax$, these curves are interpolated by a polynomial of degree 2 $C1$ in $Smax$.

For modeling E, the law of Parker for the permeability relating to gas is replaced by a cubic law (me '`HYDR_VGC`'):

$$k_r^g = (1 - S_l)^3$$

1.3 Boundary conditions and initial

The limiting conditions are the following ones:

- conditions of Neumann on the right-hand side and the left of the field:

$$(\boldsymbol{F}_l^w + \boldsymbol{F}_g^w).\boldsymbol{n} = 0$$
$$(\boldsymbol{F}_l^c + \boldsymbol{F}_g^c).\boldsymbol{n} = 0$$

- conditions of Neumann in the hole τ :

  If $0 < t < TSIM$ then $(\boldsymbol{F}_l^w + \boldsymbol{F}_g^w).\boldsymbol{n} = 0$

  If $0 < t < TINJ$ then $(\boldsymbol{F}_l^c + \boldsymbol{F}_g^c).\boldsymbol{n} = Q$

  If $TINJ < t < TSIM$ then $(\boldsymbol{F}_l^c + \boldsymbol{F}_g^c).\boldsymbol{n} = 0$

- condition of Dirichlet on the part in top on the right of field:

  $P_l(9 \le x \le 10, y = 10, t) = 10^6 \ Pa$

  $P_g(9 \le x \le 10, y = 10, t) = 0 \ Pa$

The initial conditions are the following ones:

$$P_l(x, y, t = 0) = 10^6 \ Pa$$
$$P_g(x, y, t = 0) = 0 \ Pa$$

The hydrogen flow imposed on the left part, Q , is worth:

$$Q=0{,}44.10^{-11}kg.m^{-2}.s^{-1}$$

The time of injection, $TINJ$ is of 5.10^{5} years and the time of simulation is of 10^{6} years.

2 Modeling A

2.1 Characteristics of modeling

Modeling `D_PLAN_HH2SUDA`. This modeling corresponds to modeling Volume Finis Décentrés Arêtes. Coupling `LIQU_AD_GAZ`.

2.2 Characteristics of the grid

One uses a grid made up of 1632 elements `TRIA7`.

2.3 Sizes tested and results

One traces the profiles of pressure of gas and capillary pressure on the bottom of the field at various times:

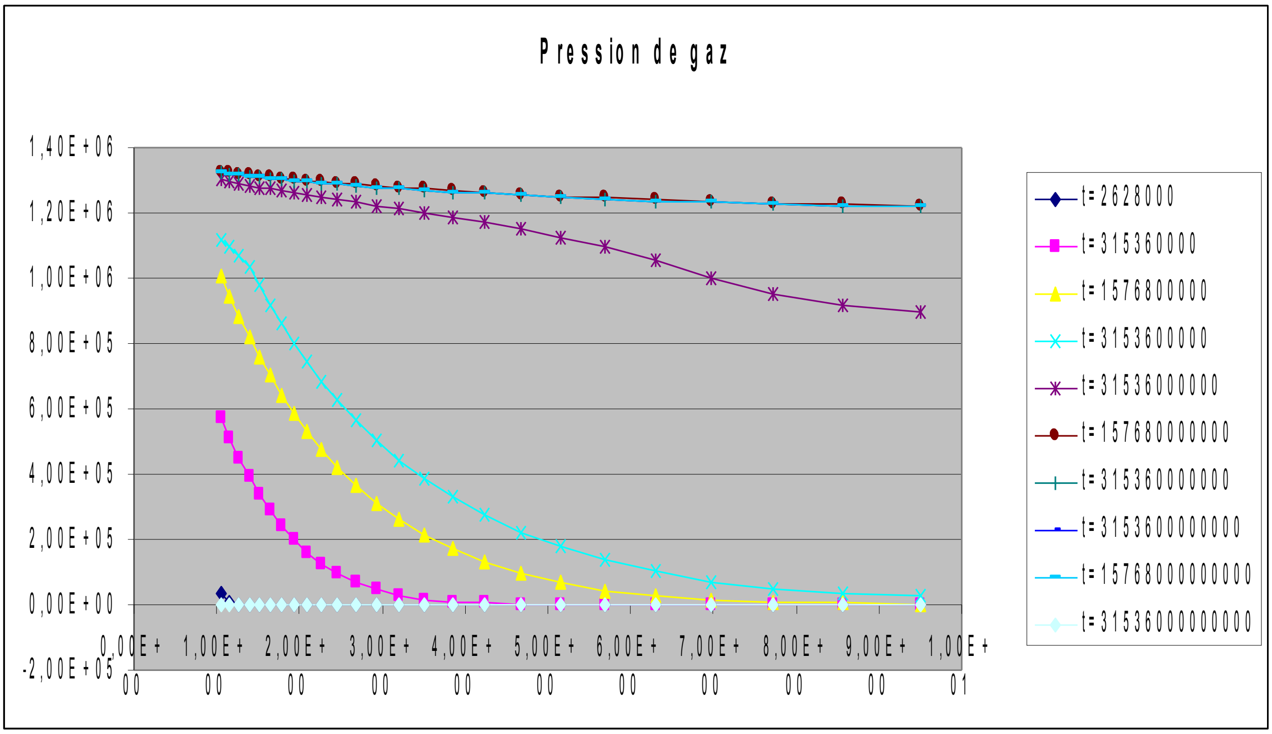

Illustration 1: Profiles of gas pressure, $Y=0$

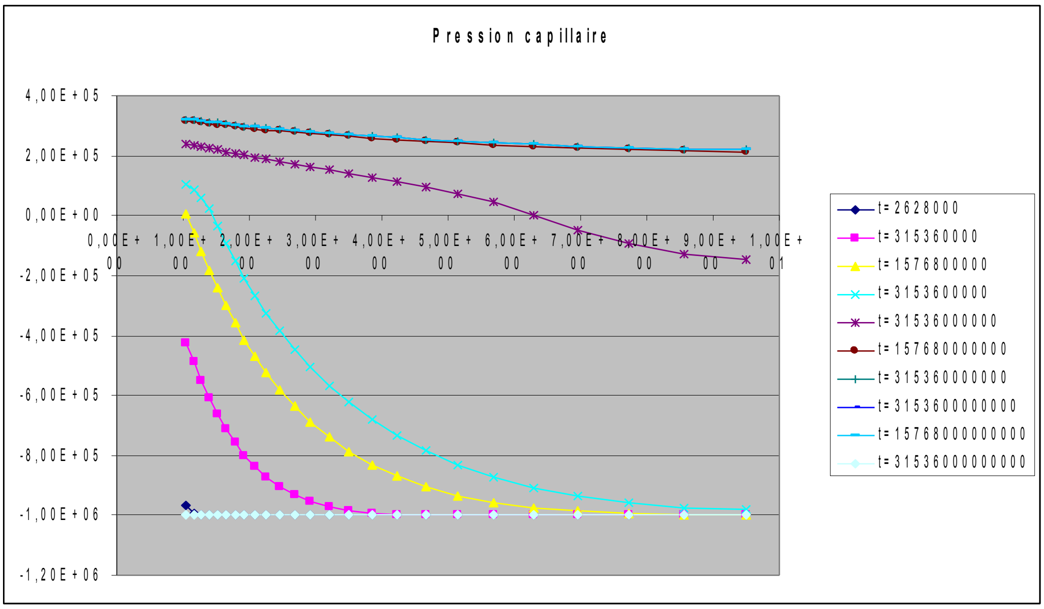

Illustration 2: Profiles of capillary pressure, $Y=0$

One initially notes a progressive increase in the gas pressure by dissolution (when the medium is saturated, i.e. when the capillary pressures are negative) then in gas form since the desaturation starts after 50 years. The medium goes then désaturé over all its length. Spent the time of injection, the resaturé medium and the gas pressure decreases. These results are in conformity with those expected.

This case test does not have a value of reference, one thus makes of them a case of nonregression.

Size	Points (x,y)	Time (s)	Reference	Tolerance
`PRE1`	(1.02; 0.947) NT335	1 month	-9.55974E+05	1.0%
`PRE1`	(5.05; 5.25) NT551	1 month	-9.99999E+05	1.0%
`PRE1`	(9.86; 9.7) NT566	1 month	-9.99999E+05	1.0%
`PRE2`	(1.02; 0.947) NT335	1 month	44025.7	1.0%
`PRE2`	(5.05; 5.25) NT551	1 month	1.63287E-13	1.0%
`PRE2`	(9.86; 9.7) NT566	1 month	3.477E-15	0,010

Table 2.3-1: Values tested

3 Modeling B

3.1 Characteristics of modeling

Modeling `D_PLAN_HH2S`. This modeling corresponds to modeling Finite elements. Coupling `LIQU_AD_GAZ`.

3.2 Characteristics of the grid

One uses a grid made up of 1632 elements `TRIA6`.

3.3 Sizes tested and results

The results are identical to those obtained with modeling eccentric finished volumes nets.

This case test does not have a value of reference, one thus makes of them a case of nonregression.

Size	Points (x, y)	Time (s)	Reference	Tolerance
`PRE1`	(1; 1) N6	1 month	-9.59793E+05	1.0%
`PRE1`	(5.33; 5.30) N292	1 month	-9.99999E+05	1.0%
`PRE1`	(9.6; 9.6) N577	1 month	1.42195E-13	0,010
`PRE2`	(1; 1) N6	1 month	40206.9	1.0%
`PRE2`	(5.33; 5.30) N292	1 month	-9.99999E+05	1.0%
`PRE2`	(9.6; 9.6) N577	1 month	6.93178E-15	0,010

Table 3.3-1 : Values tested

4 Modeling C

4.1 Characteristics of modeling

Even modeling that modeling B but with a cubic law (‘`HYDR_VGC`‘) for the permeability relating to gas instead of a law of Parker.

4.2 Characteristics of the grid

One uses a grid made up of 1632 elements `TRIA6`.

4.3 Sizes tested and results

For short times when are carried out the test, saturation remains equal to one, also the choice of the law of permeability relating to gas does not influence the results which are identical to those obtained with modeling B.

This case test does not have a value of reference, one thus makes of them a case of nonregression.

5 Summary of the results

This case test makes it possible to have a classical problem of the digital modeling of underground storage: gas injection in a medium saturated with $2D$. We do not have reference solutions with which to compare to us, however the values and the pace of the results are classical of this kind of problem. We thus make of them a case test of nonregression. This test is treated with the 2 digital diagrams available for the modeling of the diphasic flows:

- the diagram eccentric finished volumes edge.
- Classical finite elements.

The got results are the same ones. In term of performance and reliability, one will strongly privilege the diagrams Finished volumes Decentred Edge (*`_HH2SUDA)`.