Scaling Up and Modeling for Transport and Flow in Porous Media

Dubrovnik, Croatia, 13-16 October 2008

Analysis and simulation of a two phase flow model with phase apparition/disappearance

Application to gas migration in underground nuclear waste repository

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14 October 2008

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Context

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- Saturated/unsaturated global formulation ?

Outline

Unsaturated two phase flow

Physical assumptions of the model

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- Additional assumption : no water vapor

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Unsaturated flow equations

The unsaturated flow is described by :

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with usual primary variables : (p_l, S_l) ou (p_l, p_g).

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Where we denote fluxes :

$$\mathbf{q}_l = -\mathbb{K}\frac{kr_l}{\mu_l}\left(\nabla p_l - (\rho_l^{std} + C_h \rho_g^{std} p_g)\mathbf{g}\right),$$

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and constants :

$$C_h = \frac{H(T)M^h}{\rho_g^{std}}\ ,\ C_v = \frac{M^h}{RT\rho_g^{std}}\ ,\ G = \frac{\rho_l^{std}}{\rho_g^{std}},\ \ F = \frac{M^h \rho_l^{std}}{M^w \rho_g^{std}}\ .$$

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How to globally describe saturated and unsaturated flows ?

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Choice of suitable variables

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  unsaturated : $X > C_h(p_l + p_c(0))$

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  $X \equiv R_s$

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usual primary variables (p_l, S_l) and (p_l, p_g)

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Formulation in (p_l, X)

- The saturated/unsaturated flow may be described with primary variables (p_l, X) by only one couple of equations :

$$\Phi \frac{\partial}{\partial t}(X - GS_g) + \mathrm{div}\Big((G + R_s)\mathbf{q}_l + C_v p_g \mathbf{q}_g\Big) = G\frac{\mathcal{F}^w}{\rho_l^{std}} + \frac{\mathcal{F}^h}{\rho_g^{std}}$$

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- 1st equation is parabolic/elliptic in p_l,
  2nde equation is parabolic in X.

Analysis and simulation

Existence of solutions

- We consider the simplified formulation :

$$\begin{cases} \Phi \dfrac{\partial S_l}{\partial t} + \mathsf{div}\big(\mathbf{q}_l + 0\big) = \mathcal{F}^w / \rho_l^{std} \\ \\ \Phi \dfrac{\partial X}{\partial t} + \mathsf{div}\big(R_s \mathbf{q}_l + C_v p_g \mathbf{q}_g + \mathbf{J}\big) = \mathcal{F}^h / \rho_g^{std} \end{cases}$$

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Suppose $r_{min} \leq R_s \leq r_{max}$ and $p_l \geq 0$ and assume that initial and Dirichlet conditions are enough regular.
Then there is a weak solution to the simplified formulation.

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- A well chosen variable change allows to apply the Alt-Luckhaus theorem in order to prove existence of a solution.

Analysis and simulation

Numerical test : a simple configuration

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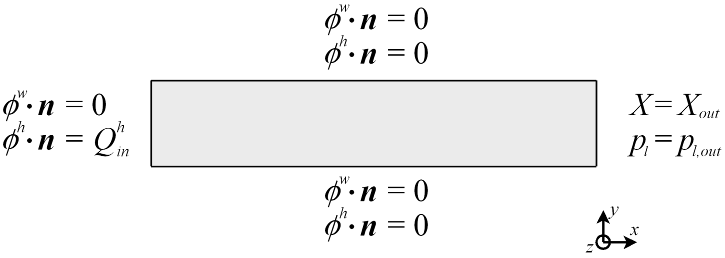

- Boundary conditions :
  - Injection of pure gas on left side
  - Impervious condition on top and bottom side
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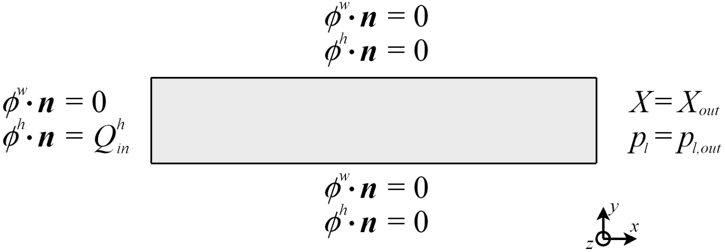

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  stationary state without injection ($Q^h_{in} = 0$)

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- Van Genuchten-Mualem model for capillary pressure and relative permeabilities
- Fixed temperature, $T = 303\ K$

Porous medium parameters			Fluid characteristics		
Parameter	Value		Parameter	Value	
k	$5\ 10^{-20}$	m^2	D_l^h	$3\ 10^{-9}$	m^2/s
Φ	0.15	$(-)$	μ_l	$1\ 10^{-3}$	$Pa.s$
P_r	$2\ 10^6$	Pa	μ_g	$9\ 10^{-6}$	$Pa.s$
n	1.49	$(-)$	$H(T=303K)$	$7.65\ 10^{-6}$	$mol/Pa/m^3$
S_{lr}	0.4	$(-)$	M_l	10^{-2}	kg/mol
S_{gr}	0	$(-)$	M_g	$2\ 10^{-3}$	kg/mol
			ρ_l^{std}	10^3	kg/m^3
			ρ_g^{std}	$8\ 10^{-2}$	kg/m^3

Parameter	Value	
L_x	200	m
L_y	20	m
Q^h	$1.5\ 10^{-5}$	$m/year$
$p_{l,out}$	10^6	Pa
T_{simul}	$5\ 10^5$	$years$

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- Implementation with the modular code Cast3m

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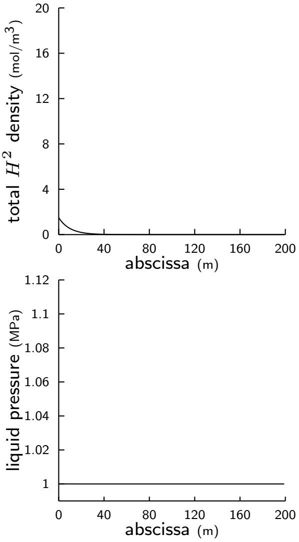

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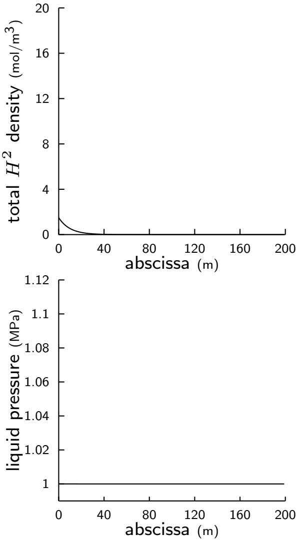

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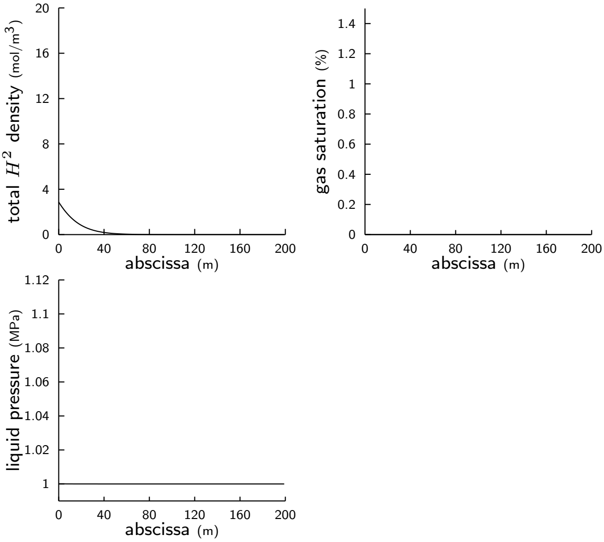

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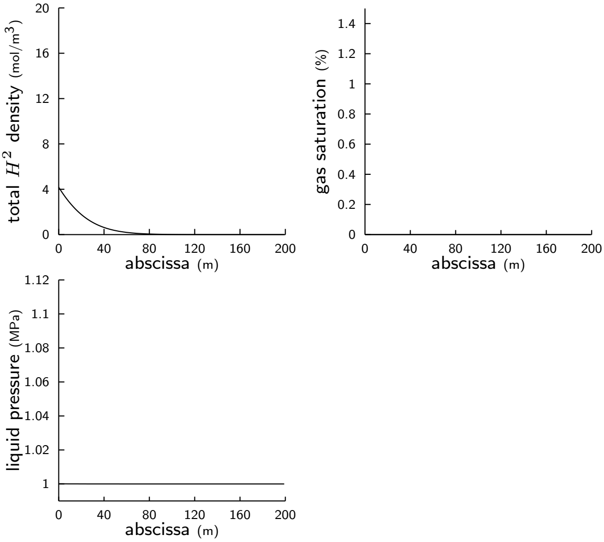

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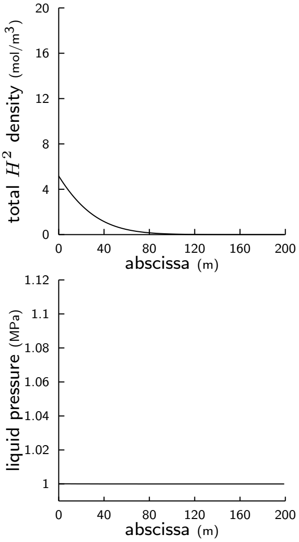

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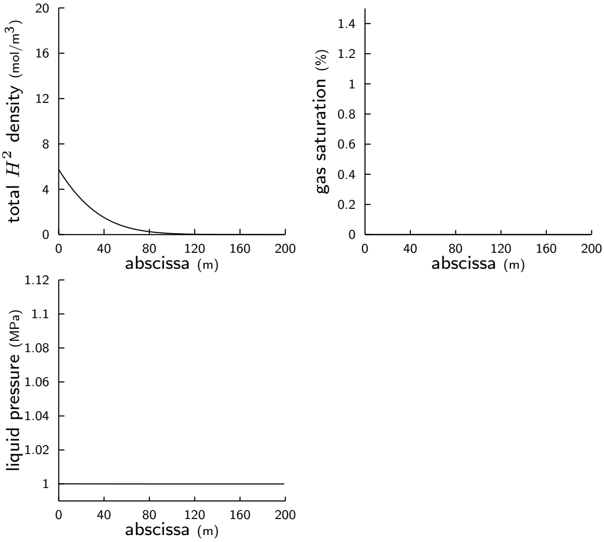

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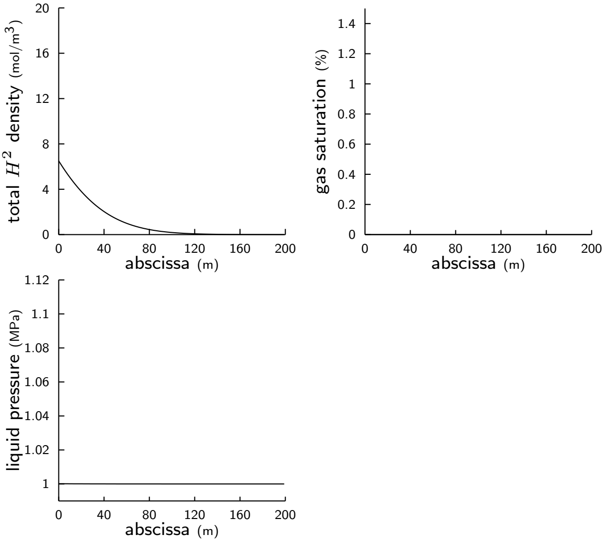

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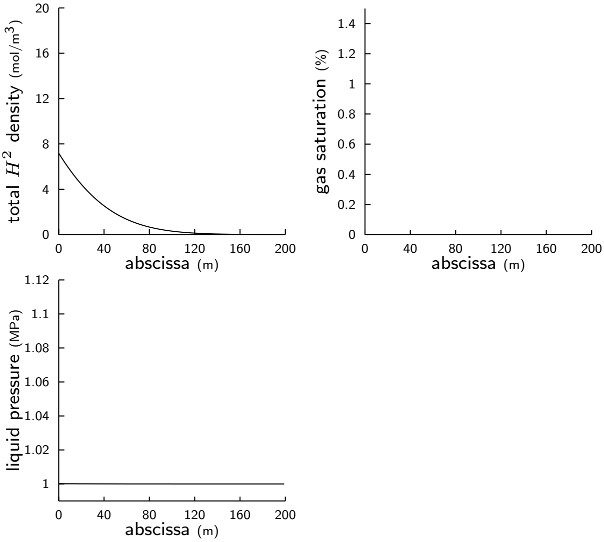

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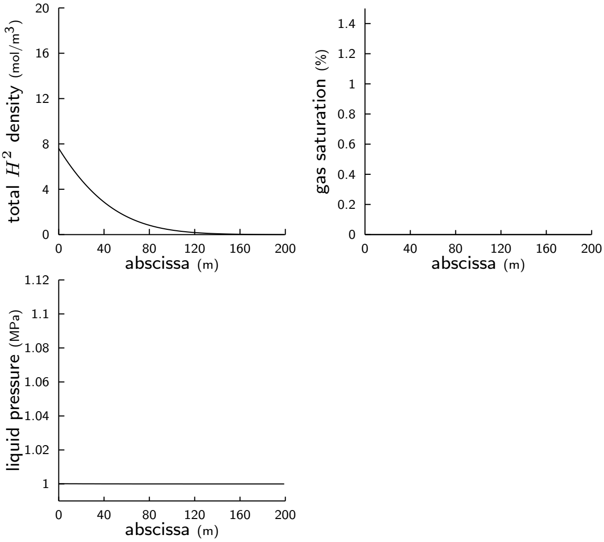

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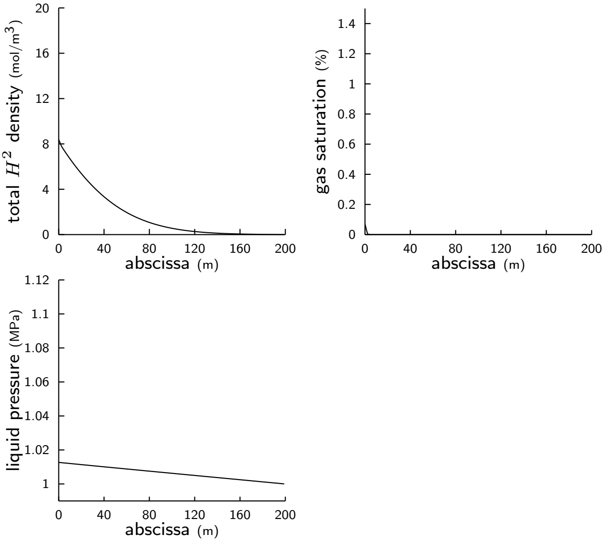

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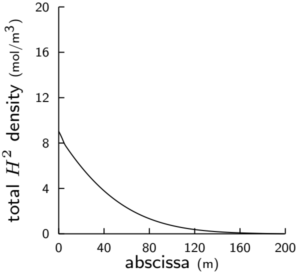

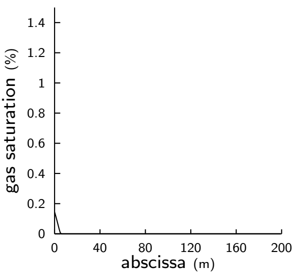

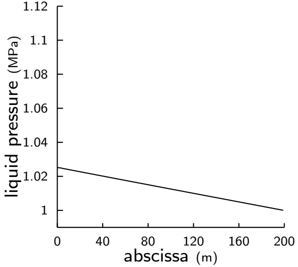

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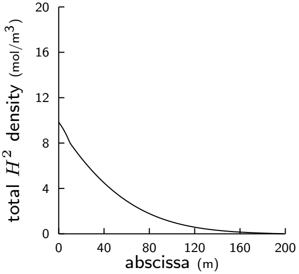

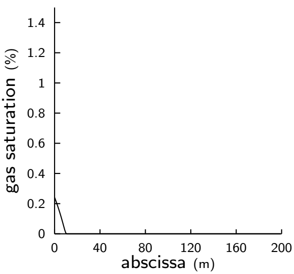

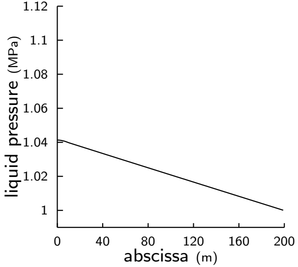

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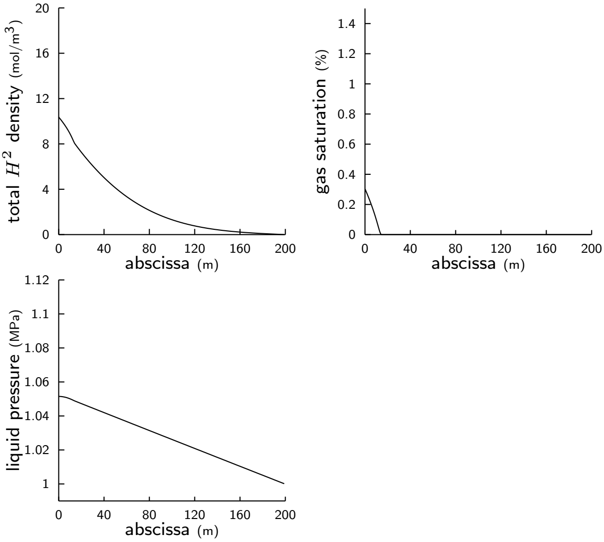

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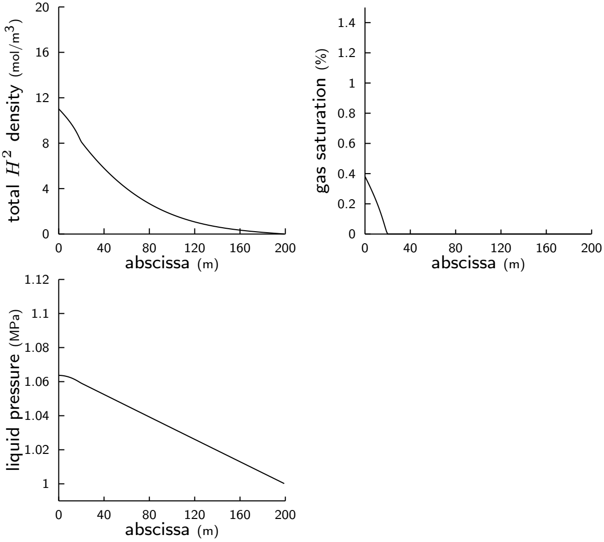

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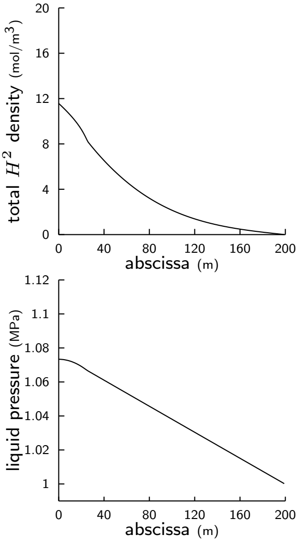

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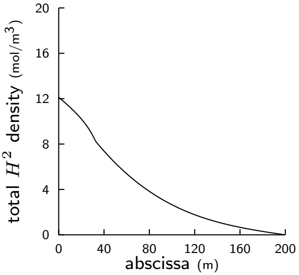

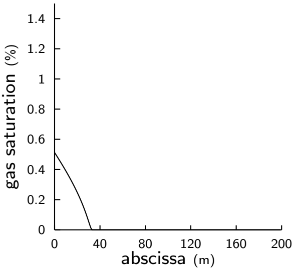

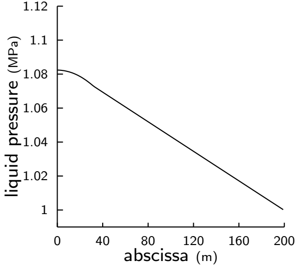

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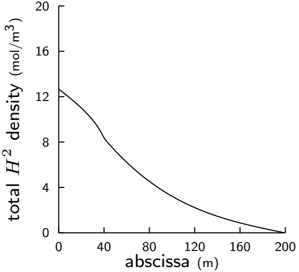

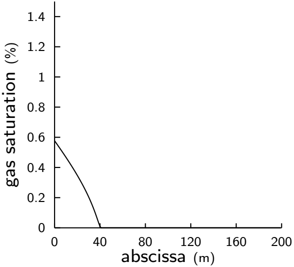

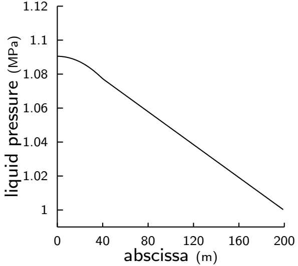

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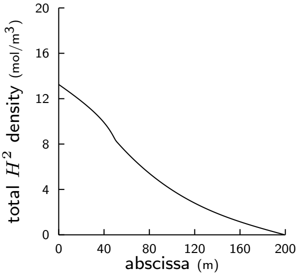

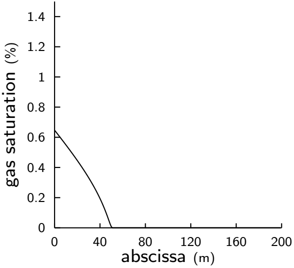

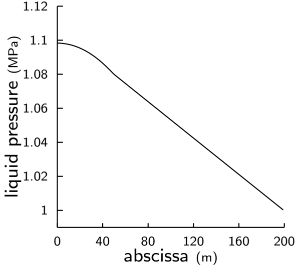

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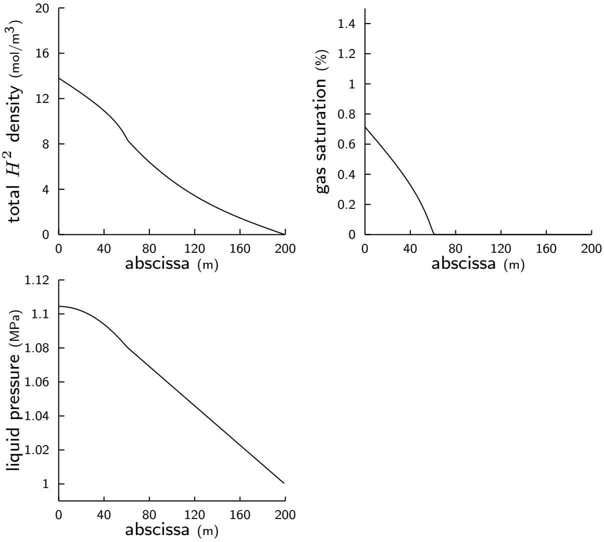

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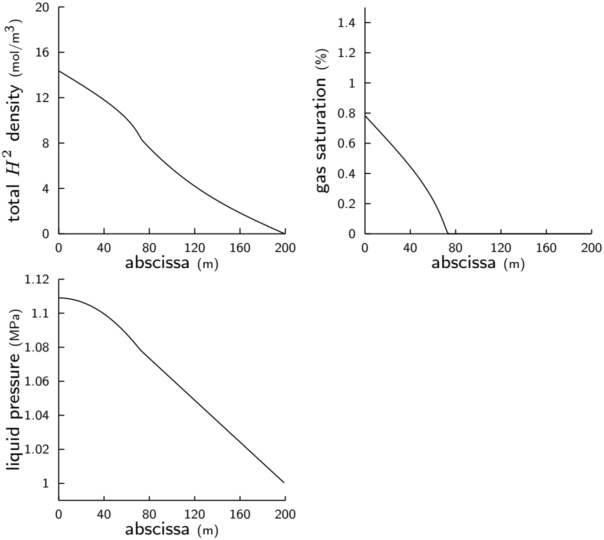

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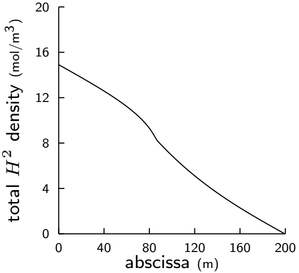

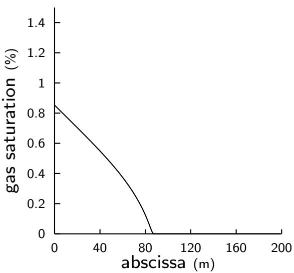

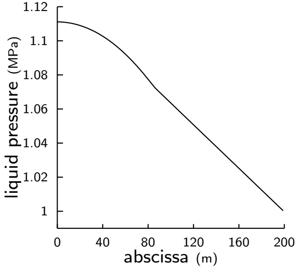

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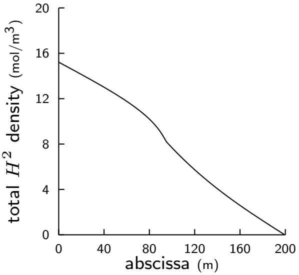

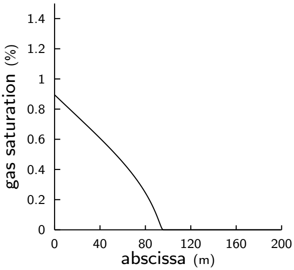

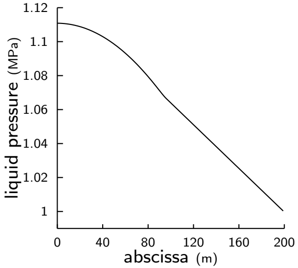

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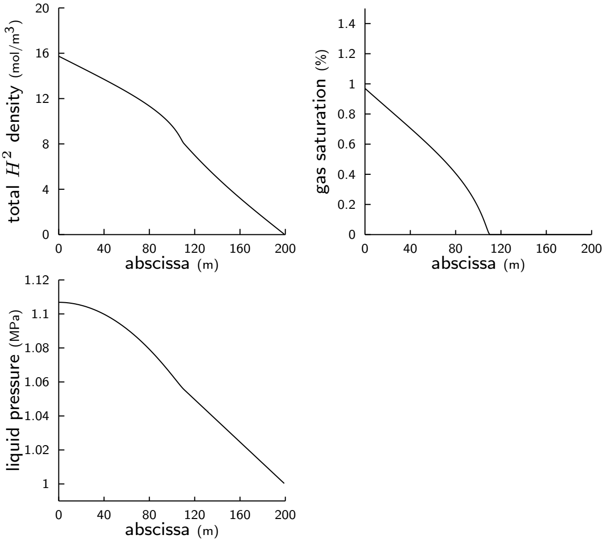

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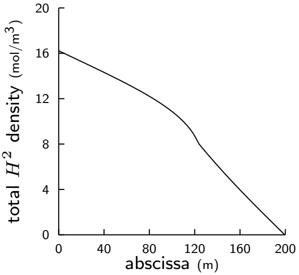

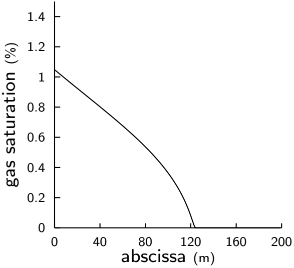

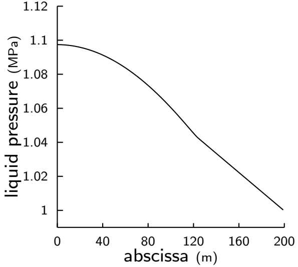

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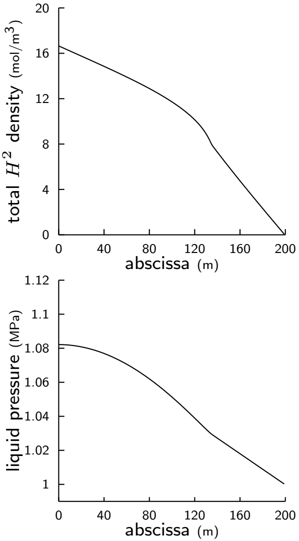

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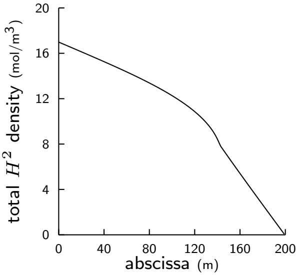

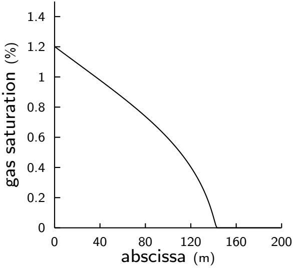

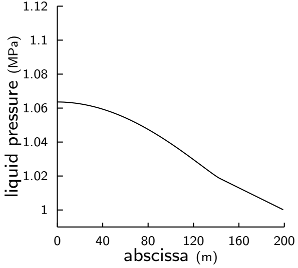

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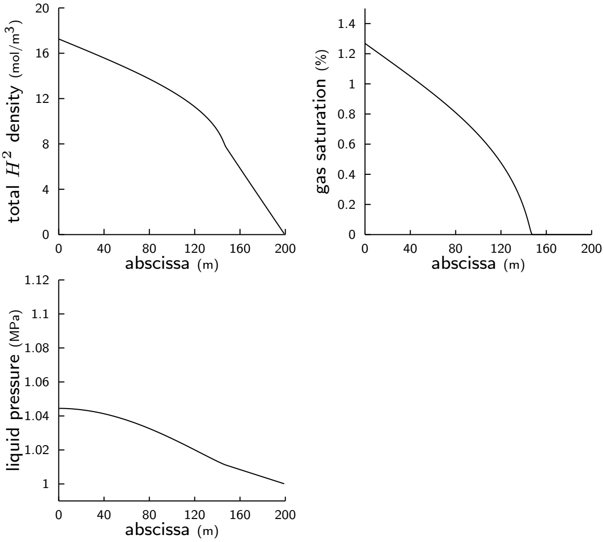

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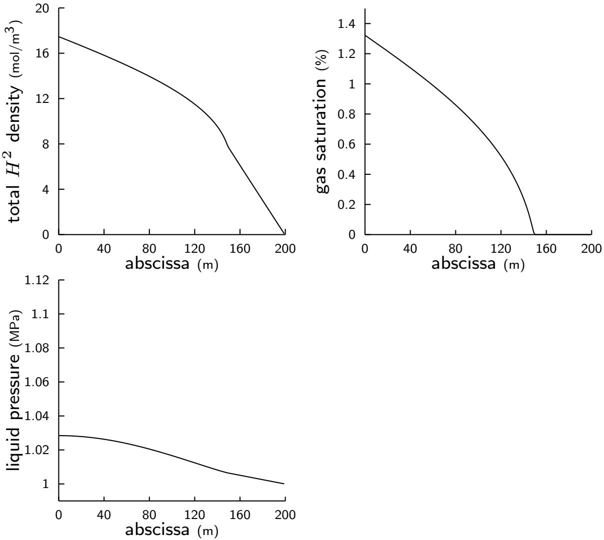

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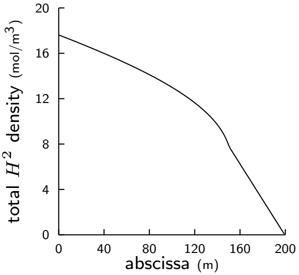

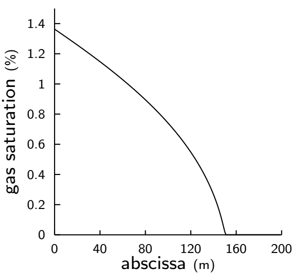

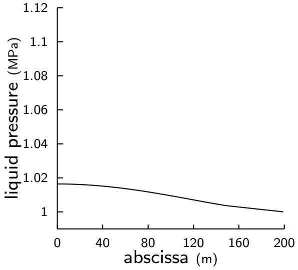

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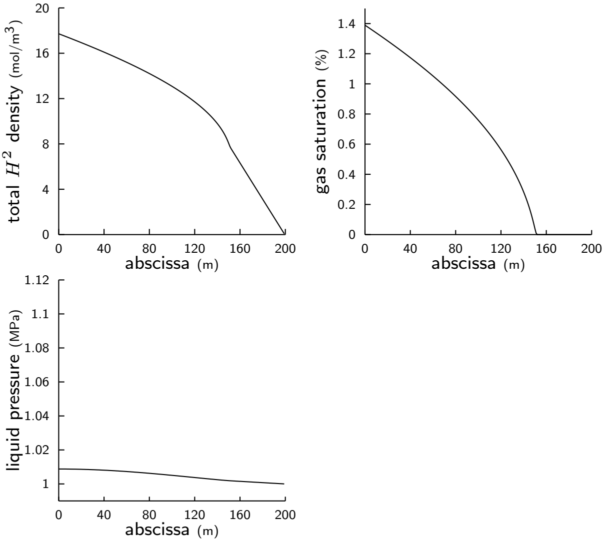

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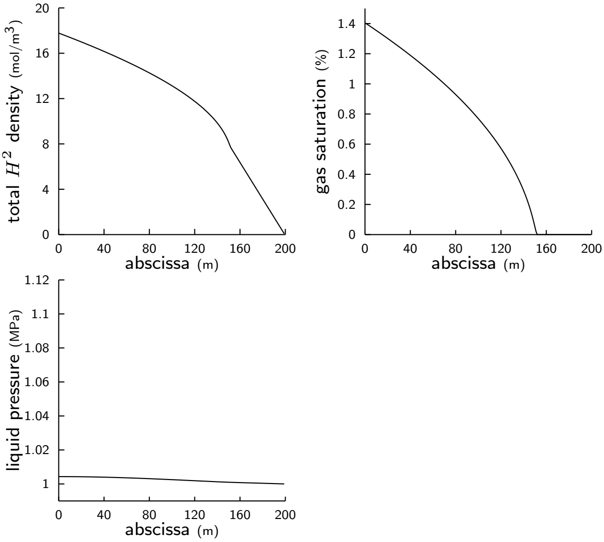

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References

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