A nonlinear Domain Decomposition Method to couple compositional liquid gas Darcy and free gas flows

Nabil Birgle[1], Roland Masson[1], Laurent Trenty[2]

[1] Université Côte d'Azur, LJAD, INRIA, CNRS
[2] Andra

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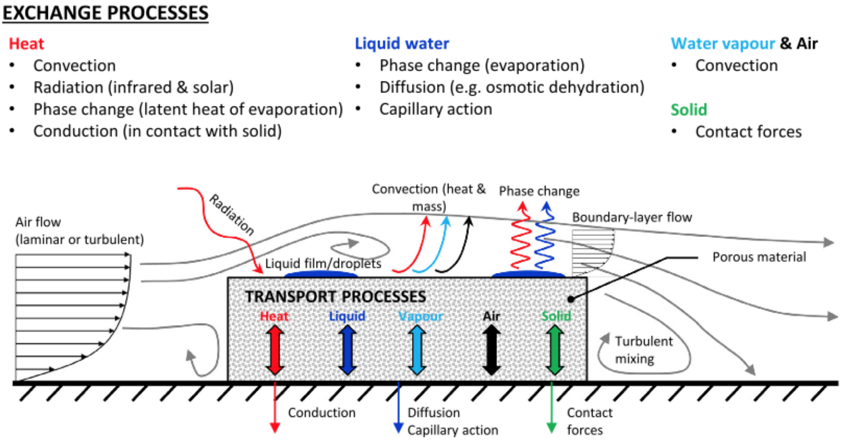
Drying problems

From Defraeye 2014

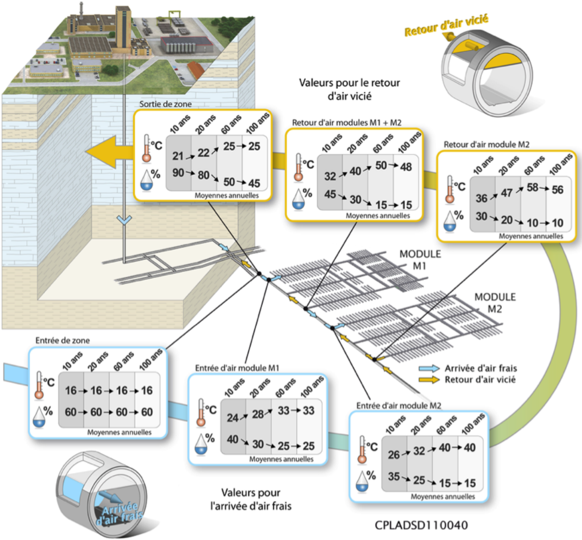


Motivations

- Land atmosphere interaction, soil evaporation and evapotranspiration
- Drying problems in engineering: food, wood, paper, ceramic
- Radioactive waste geological storage

Main motivation of this work: radioactive waste geological storage

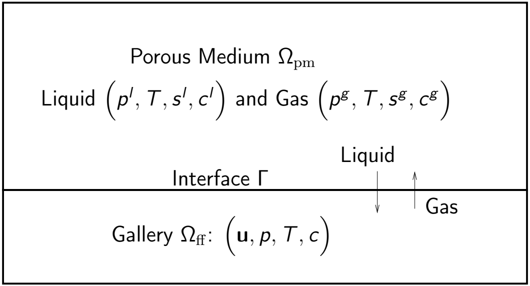
- Tens of kilometers of ventilated galleries
- Modelization of the mass and energy exchanges between the storage and the galleries
- Objectives
  - Guarantee safe air for workers
  - Study the desaturation induced by the ventilation



Outline

- Model
- Nonlinear domain decomposition for a simplified model
- Extension to the compositional model
- Numerical results

Model



- Starting point: model proposed by [Helmig et al. 2011]
- Liquid gas compositional Darcy flow
- RANS compositional free gas flow
- Non-isothermal model

Single phase Darcy flow

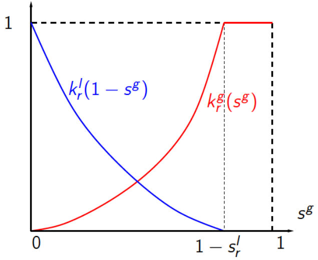
$$
\begin{cases}
\text{Darcy law:} & \mathbf{V} = -\dfrac{\mathbf{K}(\boldsymbol{x})}{\mu}(\nabla p - \rho(p)\mathbf{g}), \\
\text{Mole conservation:} & \phi \partial_t \zeta(p) + \operatorname{div}(\zeta(p)\mathbf{V}) = 0.
\end{cases}
$$

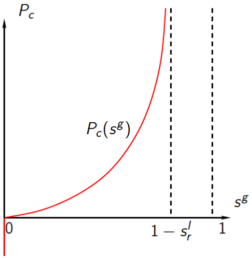
p: pressure (Pa)
$\mathbf{V}$: Darcy Velocity ($\mathrm{m}.s^{-1}$)
$\mathbf{K}$: permeability tensor of the porous medium (m^2) (1 Darcy $= 10^{-12}$ m^2)
ϕ: porosity of the porous medium
μ: viscosity of the fluid (Pa.s)
ζ: molar density of the fluid (mol. m^{-3})
ρ: mass density of the fluid (kg. m^{-3})

Two phase Darcy velocities

$\alpha = g, l$: phases
s^α: volume fractions
p^α: pressures

$$\left\{\begin{array}{l} \mathbf{V}^\alpha = -\dfrac{k_r^\alpha(s^\alpha)}{\mu^\alpha}\, \mathbf{K}(\boldsymbol{x}) \left(\nabla p^\alpha - \rho^\alpha \mathbf{g}\right), \\[2ex] P_c(s^g) = p^g - p^l, \\[2ex] s^g + s^l = 1. \end{array}\right.$$



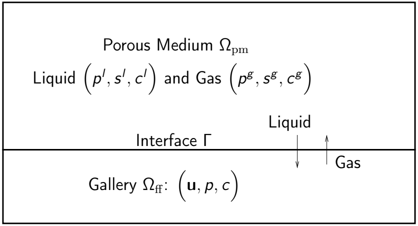


Porous medium model on Ω_{pm} (isothermal)

- Set of components $i \in \mathcal{C} = \{water, air\}$
- Unknowns: $p^\alpha, s^\alpha, c^\alpha = (c_i^\alpha)_{i\in\mathcal{C}}$, $\alpha = l, g$
- $n_i = \sum_{\alpha=l,g} \zeta^\alpha s^\alpha c_i^\alpha$
- Darcy velocities:

$$\mathbf{V}^\alpha = \frac{k_r^\alpha(s^\alpha)}{\mu^\alpha}\mathbf{K}(\nabla p^\alpha - \rho^\alpha \mathbf{g})$$

- $\mathbf{V}_i = \sum_{\alpha=l,g} c_i^\alpha \zeta^\alpha \mathbf{V}^\alpha$

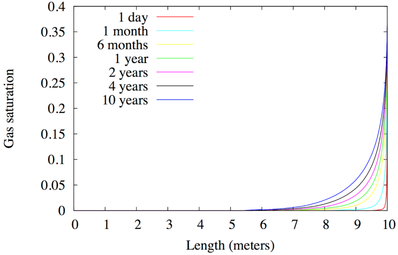


$$\begin{aligned}
&\phi \partial_t n_i + \mathrm{div}(\mathbf{V}_i) = 0,\ i \in \mathcal{C},\\
&s^l + s^g = 1,\\
&p^g - p^l = p_c(s^g),\\
&\sum_{i\in\mathcal{C}} c_i^\alpha = 1 \text{ if phase } \alpha \text{ present},\\
&\text{Thermodynamical equilibrium.}
\end{aligned}$$

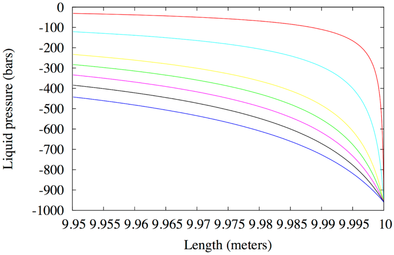
Example of uncoupled solution in 1D

- Two components: air (a) and H_2O (w)
- Initial condition: : $p^l = 4$ Mpa, $s^l = 1$, pure water
- Left boundary condition: $p^l = 4$ Mpa, $s^l = 1$, pure water
- Right boundary condition (interface Γ):
  - $p^g = 10^5$ Pa, relative humidity $H_r = \frac{p^g c_e^g}{p_{sat}(T_e)} = 0.5$
  - p^l, c^l, s^g computed using the gas liquid equilibrium

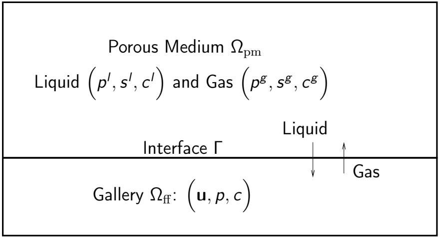
gas saturation s^g



Liquid pressure P^l



Free flow model on $\Omega_{\rm ff}$ (isothermal)



RANS model: find $(\mathbf{u}, p, c)$ such that

$$\begin{cases} \mathrm{div}(\mathbf{W}_i) = 0, i \in \mathcal{C}, \\ \mathrm{div}\mathbb{T} = \rho^g \mathbf{g}, \\ \mathbf{W}_i = \zeta^g \Big(c_i \mathbf{u} - D_t \nabla c_i \Big), i \in \mathcal{C}, \\ \mathbb{T} = \rho^g \mathbf{u} \otimes \mathbf{u} - \mu_t (\nabla \mathbf{u} + \nabla^t \mathbf{u}) + pI, \\ \sum_{i \in \mathcal{C}} c_i = 1. \end{cases}$$

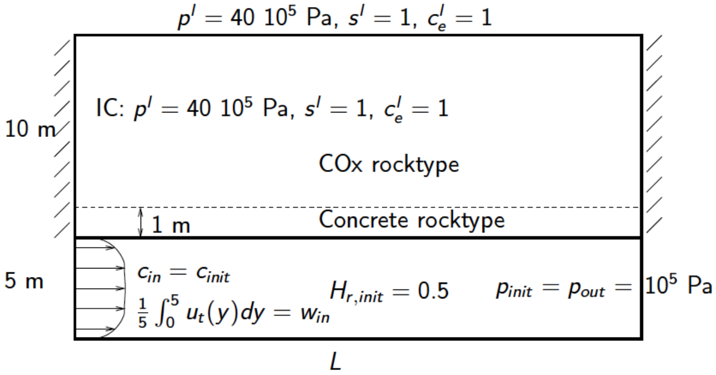
- μ_t, D_t: turbulence closure
- Quasi stationary solutions (porous medium time scale)

Coupling conditions at the interface Γ [Helmig et al. 2011] (isothermal)

$$\begin{cases} \mathbf{V}_i \cdot \mathbf{n} = \mathbf{W}_i \cdot \mathbf{n}, \quad i \in \mathcal{C}: \text{ molar flux continuity,} \\ c_i^g = c_i, \quad i \in \mathcal{C}: \text{ gas molar fractions continuity,} \\ \text{ Liquid Gas thermodynamical equilibrium,} \\ p^g = \mathbf{n} \cdot \mathbb{T}\mathbf{n}, \\ \mathbf{u} \cdot \tau = 0: \text{ no slip condition.} \end{cases}$$

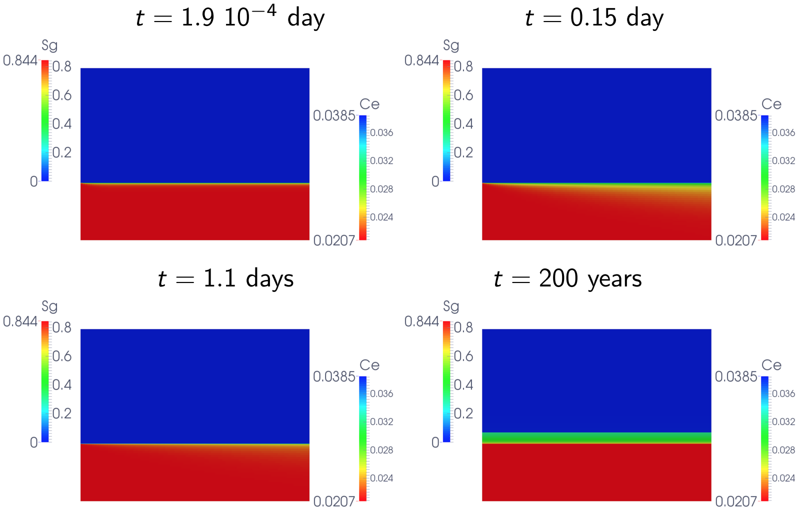
Andra test case

- Two components: H2O (w) and air (a), $T = 303$ K



Andra test case: evolution of c_w and s^g

- $L = 100$ m, $w_{in} = 0.5$ m/s
- Simulation time: 200 years



Andra test case: evolution of c_w and s^g

- $L = 100$ m, $w_{in} = 0.5$ m/s
- Simulation time: 200 years

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State of the art

- One way coupling algorithms using convective transfer coefficients
- Dirichlet Neumann sequential algorithms [Defraeye 2014]
- Fully coupled algorithms [Helmig et al 2011–2017]
- Domain Decomposition Methods
  - Many works for single phase Darcy - Navier Stokes coupling [Discacciati, Quarteroni et al 2003–]

Richards model in the Darcy flow domain

Assumptions: $p^g \simeq p_{atm}$, $\zeta^l >> \zeta^g$, $c_e^l \sim 1$.

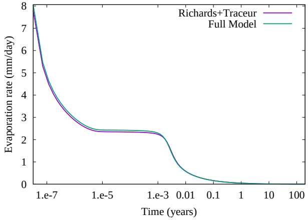
$$
\left\{
\begin{array}{ll}
\text{Liquid saturation:} & s^l(p^l) = 1 - P_c^{-1}(p^{atm} - p^l), \\
\text{Liquid Darcy velocity:} & \mathbf{V}^l = -\dfrac{k_r^l(s^l(p^l))}{\mu^l} \mathbf{K}(\boldsymbol{x}) \left(\nabla p^l - \rho^l \mathbf{g}\right), \\
\text{Conservation of H2O:} & \phi \partial_t \left(\zeta^l s^l(p^l)\right) + \mathrm{div}(\zeta^l \mathbf{V}^l) = 0
\end{array}
\right.
$$

Approximate coupled model: Richards + Tracer

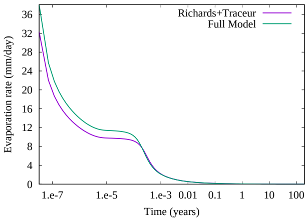
$\mathbf{u}_t$: given uncoupled velocity with $\mathrm{div}(\zeta^g \mathbf{u}_t) = 0$ on Ω_{ff} and $\mathbf{u}_t \cdot \mathbf{n} = 0$ on Γ.

$$\begin{cases} \phi \partial_t \Big(\zeta^l s^l(p^l) \Big) + \mathrm{div}(\zeta^l \mathbf{V}^l) = 0 & \text{on } \Omega_{\mathrm{pm}} \quad \text{(Richards equation for } p^l\text{)}, \\ \mathrm{div}\Big(\zeta^g c_w \mathbf{u}_t - \zeta^g D_t \nabla c_w \Big) = 0 & \text{on } \Omega_{\mathrm{ff}} \quad \text{(tracer equation for } c_w\text{)}, \\ \zeta^l \mathbf{V}^l \cdot \mathbf{n} = -\zeta^g D_t \nabla c_w \cdot \mathbf{n} & \text{on } \Gamma \quad \text{(flux continuity)}, \\ c_w = f(p^l) = \frac{p_{sat}(T)}{p_{atm}} e^{\frac{p^l - p_{atm}}{\zeta^l R T}} & \text{on } \Gamma \quad \text{(liq. vap. equilibrium)}. \end{cases}$$

$T = 303$ K



$T = 333$ K



Robin Robin Schwarz method

Given $\beta_{\rm pm}(x) \geq 0$ and $\beta_{\rm ff}(x) \geq 0$, $\beta_{\rm pm}(x)\beta_{\rm pm}(x) \neq 0$, $x \in \Gamma$, solve for $k = 1, \cdots$ until convergence:

$$\begin{cases} \phi\zeta^l \dfrac{s^l(p^{l,k})}{\Delta t} + \mathrm{div}(\zeta^l \mathbf{V}^{l,k}) = \phi\zeta^l \dfrac{s^l(p^{l,n-1})}{\Delta t} & \text{on } \Omega_{\rm pm}, \\ \beta_{\rm pm} f(p^{l,k}) - \zeta^l \mathbf{V}^{l,k} \cdot \mathbf{n}_{\rm pm} = \beta_{\rm pm} c_w^{k-1} - \zeta^g D_t \nabla c_w^{k-1} \cdot \mathbf{n}_{\rm pm} & \text{on } \Gamma, \end{cases}$$

$$\begin{cases} \mathrm{div}\Big(\zeta^g c_w^k \mathbf{u}_t - \zeta^g D_t \nabla c_w^k\Big) = 0 & \text{on } \Omega_{\rm ff}, \\ \beta_{\rm ff} c_w^k - \zeta^g D_t \nabla c_w^k \cdot \mathbf{n}_{\rm ff} = \beta_{\rm ff} f(p^{l,k}) - \zeta^l \mathbf{V}^{l,k} \cdot \mathbf{n}_{\rm ff} & \text{on } \Gamma. \end{cases}$$

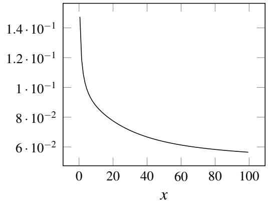
Computation of β_{pm}: diagonal approximation of the DtN operator in Ω_{ff}

Given two constants $c_{w,\Gamma} \neq c_{w,in}$, solve

$$\begin{cases} \mathrm{div}\Big(c_w \zeta^g \mathbf{u}_t - \zeta^g D_t \nabla c_w\Big) = 0 \text{ on } \Omega_{\mathrm{ff}}, \\ c_w = c_{w,\Gamma} \text{ on } \Gamma, \\ c_w = c_{w,in} \text{ on } \Gamma_{in}, \\ \nabla c_w \cdot \mathbf{n} = 0 \text{ on } \partial\Omega_{\mathrm{ff}} \setminus (\Gamma \cup \Gamma_{in}) \end{cases}$$

and compute

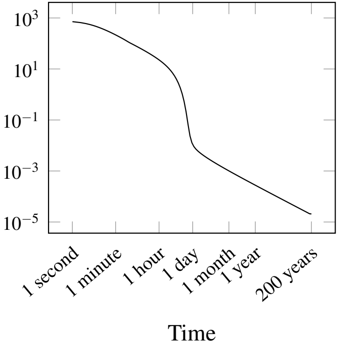
$$\beta_{\mathrm{pm}}(x) = \frac{-\zeta^g D_t \nabla c_w \cdot \mathbf{n}(x)}{c_{w,\Gamma} - c_{w,in}} > 0 \text{ on } \Gamma.$$



which is independent of $c_{w,\Gamma}$ and $c_{w,in}$

Computation of $\beta_{\rm ff}$: diagonal approximation of the DtN operator in $\Omega_{\rm pm}$

- Linearized Richards equation with frozen coefficients at the interface Γ
- $\beta_{\rm ff}(x,t)$ = order 0 Taylor approximation of the DtN operator



Plot of $\frac{\int_\Gamma \beta_{\rm ff}(x,t)dx}{\int_\Gamma dx}$ function of time.

Extension to the compositional model - Coupling conditions at the interface Γ (isothermal)

$$
\begin{cases}
\mathbf{V}_i \cdot \mathbf{n} = \mathbf{W}_i \cdot \mathbf{n}, \quad i \in \mathcal{C}: \text{ molar flux continuity,} \\
c_i^g = c_i, \quad i \in \mathcal{C}: \text{ gas molar fractions continuity,} \\
p^g = \mathbf{n} \cdot \mathbb{T}\mathbf{n}, \\
\mathbf{u} \cdot \tau = 0: \text{ no slip condition.}
\end{cases}
$$

$$
\sum_{i \in \mathcal{C}} \mathbf{V}_i \cdot \mathbf{n} = \sum_{i \in \mathcal{C}} \mathbf{W}_i \cdot \mathbf{n} = \zeta^g \mathbf{u} \cdot \mathbf{n}.
$$

Extension to the compositional model (isothermal)

- Porous medium flow on Ω_{pm} with Robin and Dirichlet boundary conditions on Γ

$$\beta_{\mathrm{pm}} c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\mathrm{pm}} - c_i^{g,k} \zeta_{\mathrm{pm}}^{g,k} \delta_{\mathbf{u}}^k = \beta_{\mathrm{pm}} c_i^{k-1} - \mathbf{W}_i^{k-1} \cdot \mathbf{n}_{\mathrm{pm}}, \quad i \in \mathcal{C},$$

$$p^{g,k} = \mathbf{n} \cdot \mathbb{T}^{k-1} \mathbf{n}.$$

- RANS flow on Ω_{ff} with Dirichlet boundary condition on Γ

$$\zeta_{\mathrm{ff}}^{g,k} \mathbf{u}^k \cdot \mathbf{n}_{\mathrm{ff}} = \sum_{i \in \mathcal{C}} \mathbf{V}_i^k \cdot \mathbf{n}_{\mathrm{ff}} = \zeta_{\mathrm{ff}}^{g,k-1} \mathbf{u}^{k-1} \cdot \mathbf{n}_{\mathrm{ff}} + \zeta_{\mathrm{pm}}^{g,k} \delta_{\mathbf{u}}^k,$$

$$\mathbf{u}^k \cdot \tau = 0.$$

- Convection diffusion equations on Ω_{ff} with Robin boundary conditions on Γ

$$\beta_{\mathrm{ff}} c_i^k - \mathbf{W}_i^k \cdot \mathbf{n}_{\mathrm{ff}} = \beta_{\mathrm{ff}} c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\mathrm{ff}}, \quad i \in \mathcal{C}.$$

Extension to the compositional model (isothermal)

Porous medium flow on Ω_{pm} with Robin boundary conditions on Γ: compute $p^\alpha, s^\alpha, c^\alpha, \delta_{\mathbf{u}}$ such that

$$\frac{\phi}{\Delta t}(n_i^k - n_i^{n-1}) + \nabla\cdot \mathbf{V}_i^k = 0, \qquad \text{in } \Omega_{\mathrm{pm}},$$

$$\beta_{\mathrm{pm}} c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\mathrm{pm}} - c_i^{g,k} \zeta_{\mathrm{pm}}^{g,k} \delta_{\mathbf{u}}^k = \beta_{\mathrm{pm}} c_i^{k-1} - \mathbf{W}_i^{k-1} \cdot \mathbf{n}_{\mathrm{pm}}, \qquad \text{on } \Gamma,$$

$$p^{g,k} = \mathbf{n} \cdot \mathbb{T}^{k-1}\mathbf{n}, \qquad \text{on } \Gamma,$$

+ thermodynamical equilibrium and other closure laws,

with $\zeta_{\mathrm{pm}}^{g,k} = \zeta^g(p^{g,k}, c^{g,k})$.

Extension to the compositional model (isothermal)

RANS flow on Ω_{ff} with Dirichlet boundary condition on Γ: compute the pressure p^k and the gas velocity $\mathbf{u}^k$ such that

$$\nabla\cdot(\rho_{\mathrm{ff}}^{g,k}\mathbf{u}^k \otimes \mathbf{u}^k - \mu_t(\nabla\,\mathbf{u}^k + \nabla^t\,\mathbf{u}^k)) + \nabla\,p^k = \rho_{\mathrm{ff}}^{g,k}\mathbf{g}, \qquad \text{in } \Omega_{\mathrm{ff}},$$

$$\nabla\cdot(\zeta_{\mathrm{ff}}^{g,k}\mathbf{u}^k) = 0, \qquad \text{in } \Omega_{\mathrm{ff}},$$

$$\zeta_{\mathrm{ff}}^{g,k}\mathbf{u}^k = \zeta_{\mathrm{ff}}^{g,k-1}\mathbf{u}^{k-1} + \zeta_{\mathrm{pm}}^{g,k}\delta_{\mathbf{u}}^k\,\mathbf{n}_{\mathrm{ff}}, \qquad \text{on } \Gamma,$$

with $\zeta_{\mathrm{ff}}^{g,k} = \zeta^g(p^k, c^{k-1})$ and $\rho_{\mathrm{ff}}^{g,k} = \rho^g(p^k, c^{k-1})$.

Extension to the compositional model (isothermal)

Convection diffusion equations on $\Omega_{\rm ff}$ with Robin boundary conditions on Γ: compute c^k such that for all $i \in \mathcal{C}$

$$\nabla \cdot \mathbf{W}_i^k = 0, \qquad \text{in } \Omega_{\rm ff},$$

$$\beta_{\rm ff}\, c_i^k - \mathbf{W}_i^k \cdot \mathbf{n}_{\rm ff} = \beta_{\rm ff}\, c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\rm ff}, \qquad \text{on } \Gamma,$$

with $\mathbf{W}_i^k = \zeta_{\rm ff}^{g,k}(c_i^k \mathbf{u}^k - D_t \nabla c_i^k)$.

Extension to the compositional model (non-isothermal)

Porous medium flow on Ω_{pm} with Robin boundary conditions on Γ: compute $p^\alpha, T_{\mathrm{pm}}, s^\alpha, c^\alpha, \delta_{\mathbf{u}}$ such that for all $i \in \mathcal{C}$:

$$\frac{\phi}{\Delta t}(n_i^k - n_i^{n-1}) + \nabla\cdot \mathbf{V}_i^k = 0, \qquad \text{in } \Omega_{\mathrm{pm}},$$

$$\frac{E^k - E^{n-1}}{\Delta t} + \nabla\cdot \mathbf{V}_e^k = 0, \qquad \text{in } \Omega_{\mathrm{pm}},$$

$$\beta_{\mathrm{pm}} c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\mathrm{pm}} - c_i^{g,k}\zeta_{\mathrm{pm}}^{g,k}\delta_{\mathbf{u}}^k = \beta_{\mathrm{pm}} c_i^{k-1} - \mathbf{W}_i^{k-1}\cdot \mathbf{n}_{\mathrm{pm}}, \qquad \text{on } \Gamma,$$

$$\gamma_{\mathrm{pm}} T_{\mathrm{pm}}^k - \mathbf{V}_e^k \cdot \mathbf{n}_{\mathrm{pm}} - h_{\mathrm{pm}}^{g,k}\zeta_{\mathrm{pm}}^{g,k}\delta_{\mathbf{u}}^k = \gamma_{\mathrm{pm}} T_{\mathrm{ff}}^{k-1} - \mathbf{W}_e^{k-1}\cdot \mathbf{n}_{\mathrm{pm}}, \qquad \text{on } \Gamma,$$

$$p^{g,k} = \mathbf{n}\cdot \mathbb{T}^{k-1}\mathbf{n}, \qquad \text{on } \Gamma,$$

+ thermodynamical equilibrium and other closure laws,

with $\zeta_{\mathrm{pm}}^{g,k} = \zeta^g(p^{g,k}, T_{\mathrm{pm}}^k, c^{g,k})$, $h_{\mathrm{pm}}^{g,k} = h^g(p^{g,k}, T_{\mathrm{pm}}^k, c^{g,k})$.

Extension to the compositional model (non-isothermal)

RANS flow on $\Omega_{\rm ff}$ with Dirichlet boundary condition on Γ: compute the pressure p^k and the gas velocity $\mathbf{u}^k$ such that

$$\nabla\cdot(\rho_{\rm ff}^{g,k}\mathbf{u}^k \otimes \mathbf{u}^k - \mu_t(\nabla \mathbf{u}^k + \nabla^t \mathbf{u}^k)) + \nabla p^k = \rho_{\rm ff}^{g,k}\mathbf{g}, \qquad \text{in } \Omega_{\rm ff},$$

$$\nabla\cdot(\zeta_{\rm ff}^{g,k}\mathbf{u}^k) = 0, \qquad \text{in } \Omega_{\rm ff},$$

$$\zeta_{\rm ff}^{g,k}\mathbf{u}^k = \zeta_{\rm ff}^{g,k-1}\mathbf{u}^{k-1} + \zeta_{\rm pm}^{g,k}\delta_{\mathbf{u}}^k\, \mathbf{n}_{\rm ff}, \qquad \text{on } \Gamma,$$

with $\zeta_{\rm ff}^{g,k} = \zeta^g(p^k, T_{\rm ff}^{k-1}, c^{k-1})$ and $\rho_{\rm ff}^{g,k} = \rho^g(p^k, T_{\rm ff}^{k-1}, c^{k-1})$.

Extension to the compositional model (non-isothermal)

Convection diffusion equations on $\Omega_{\rm ff}$ with Robin boundary conditions on Γ: compute c^k, $T^k_{\rm ff}$ such that for all $i \in \mathcal{C}$

$$\begin{aligned} \nabla\cdot \mathbf{W}_i^k &= 0, \qquad \text{in } \Omega_{\rm ff}, \\ \nabla\cdot \mathbf{W}_e^k &= 0, \qquad \text{in } \Omega_{\rm ff}, \end{aligned}$$

$$\begin{aligned} \beta_{\rm ff}\, c_i^k - \mathbf{W}_i^k \cdot \mathbf{n}_{\rm ff} &= \beta_{\rm ff}\, c_i^{g,k} - \mathbf{V}_i^k \cdot \mathbf{n}_{\rm ff}, \qquad \text{on } \Gamma, \\ \gamma_{\rm ff}\, T_{\rm ff}^k - \mathbf{W}_e^k \cdot \mathbf{n}_{\rm ff} &= \gamma_{\rm ff}\, T_{\rm pm}^k - \mathbf{V}_e^k \cdot \mathbf{n}_{\rm ff}, \qquad \text{on } \Gamma, \end{aligned}$$

with $\mathbf{W}_i^k = \zeta_{\rm ff}^{g,k}(c_i^k \mathbf{u}^k - D_t \nabla c_i^k)$ and $\mathbf{W}_e^k = \sum_{i\in\mathcal{C}} h_i^{g,k}(p^k, T_{\rm ff}^k)\mathbf{W}_i^k - \lambda_t \nabla T_{\rm ff}^k$.

where we have used that $h^g(p, T, c) = \sum_{i\in\mathcal{C}} h_i^g(p, T) c_i$.

Computation of γ_{pm}: diagonal approximation of the DtN operator in Ω_{ff}

Given two constants $T_\Gamma \neq T_{in}$ and $C_{p,i} =< \partial_T h_i^g(p,T) >_\Gamma$, solve

$$\left\{\begin{array}{l} \mathrm{div}\Big(\sum_{i\in\mathcal{C}} C_{p,i} T\mathbf{W}_i - \lambda_t \nabla T\Big) = 0 \text{ on } \Omega_{\mathrm{ff}}, \\ T = T_\Gamma \text{ on } \Gamma, \\ T = T_{in} \text{ on } \Gamma_{in}, \\ \nabla T \cdot \mathbf{n} = 0 \text{ on } \partial\Omega_{\mathrm{ff}} \setminus (\Gamma \cup \Gamma_{in}) \end{array}\right.$$

and compute

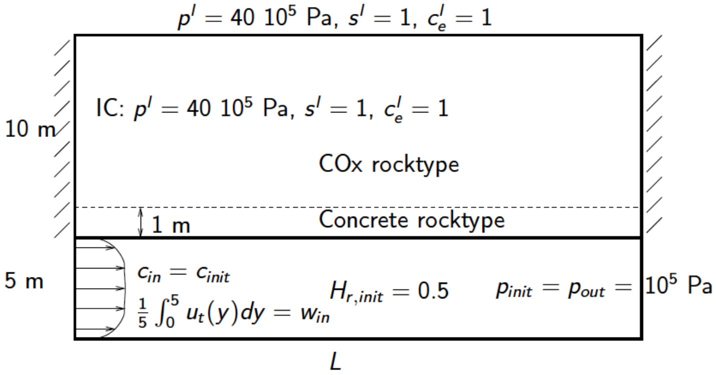
$$\gamma_{\mathrm{pm}}(x) = \frac{\Big(\sum_{i\in\mathcal{C}} C_{p,i} T_\Gamma \mathbf{W}_i - \lambda_t \nabla T\Big)\cdot \mathbf{n}(x)}{T_\Gamma - T_{in}} > 0 \text{ on } \Gamma.$$

which is independent of T_Γ and T_{in}

Computation of γ_{ff}: diagonal approximation of the DtN operator in Ω_{pm}

- Linearized energy conservation equation with frozen coefficients at the interface Γ
- $\gamma_{\mathrm{ff}}(x, t)$ = order 0 Taylor approximation of the DtN operator

Andra test case



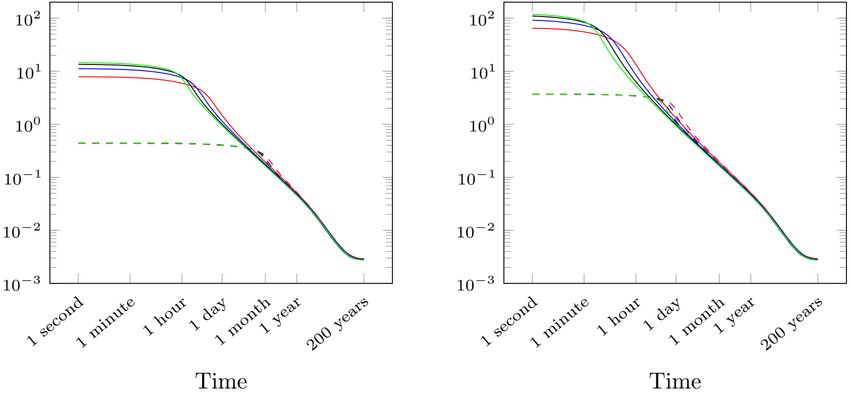
- Two components: H2O (w) and air (a)
- $L = 100$ m
- Input gas: $T_{in} = 303$ and $H_{r,in} = 0.5$
- $w_{in} = 5$ m/s or 0.05 m/s
- Initial temperature in Ω_{pm}: $T_{init} = 303$ or 333 K.
- Simulation time: 200 years

Andra test case: evaporation rates in mm/day/m^2

——— : $w_{in} = 5$ m/s,
– – – : $w_{in} = 0.05$ m/s

(a) $T^0 = 303\,\mathrm{K}$

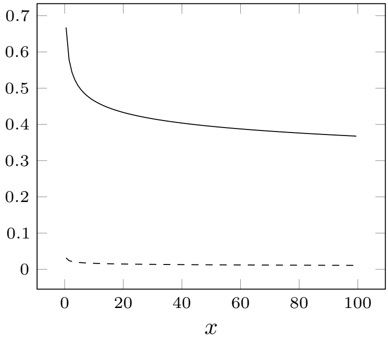
(b) $T^0|_{\Omega_{\mathrm{pm}}} = 333\,\mathrm{K}$



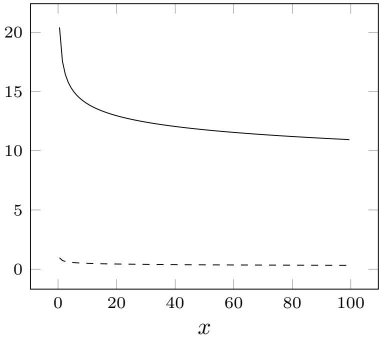
Andra test case: Robin coefficients β_{pm} and γ_{pm}

——— : $w_{in} = 5$ m/s,
– – – : $w_{in} = 0.05$ m/s

(a) β_{pm}

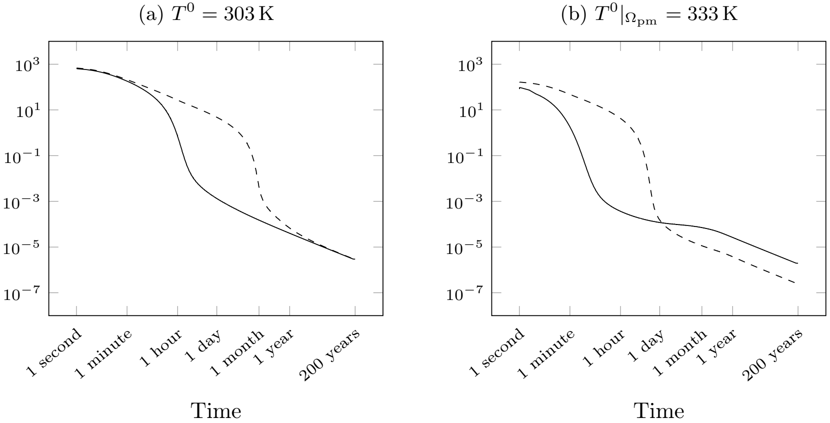


(b) γ_{pm}



Andra test case: Robin coefficients β_{ff}

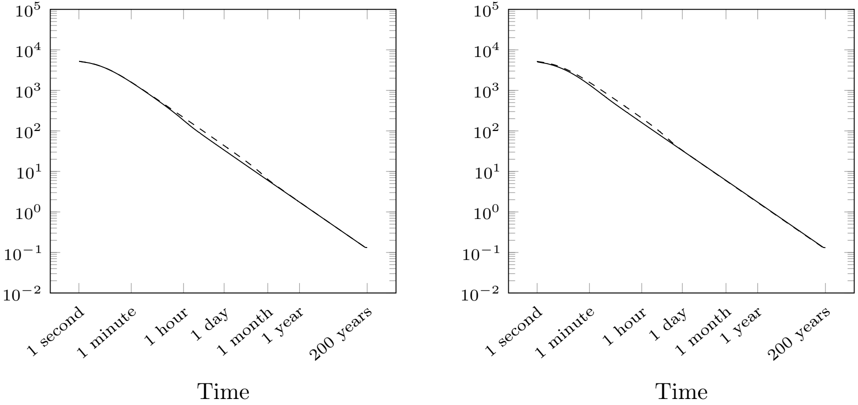
——— : $w_{in} = 5$ m/s,
– – – : $w_{in} = 0.05$ m/s



Andra test case: Robin coefficients γ_{ff}

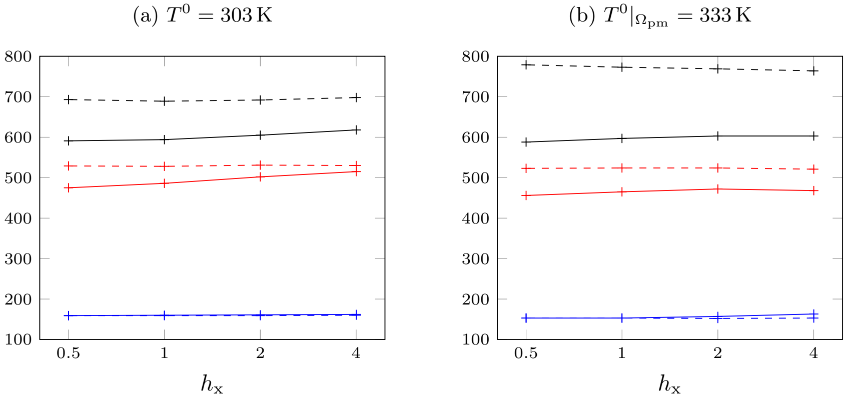
——— : $w_{in} = 5$ m/s,
– – – : $w_{in} = 0.05$ m/s

(a) $T^0 = 303\,\mathrm{K}$ (b) $T^0|_{\Omega_{\mathrm{pm}}} = 333\,\mathrm{K}$



Andra test case: total number of DDM iterations for 115 time steps

———— : $w_{in} = 5$ m/s,
– – – : $w_{in} = 0.05$ m/s



Conclusions and perspectives

Conclusions

- Algorithm to solve the coupling between a liquid gas Darcy and a free gas flow
  - Provide an efficient nonlinear solver
  - Allow the use of separate codes in the porous and free flow domains

Perspectives

- Code coupling
- Test cases with more complex geometries
- Acceleration by Newton method
- Convergence analysis

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Thanks for your attention!