

PhD PROPOSAL FOR THE DOCTORAL SCHOOL

« Ecologie, Géosciences, Agronomie, Alimentation »

GENERAL INFORMATION

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|---|
| Thesis title: Structural and capillary trapping of CO ₂ in fractured reservoirs |
| Acronym: CO2stockRes |
| Disciplinary field 1: Geosciences |
| Disciplinary field 2: Select an element |
| Three keywords: Subsurface storage of CO ₂ , structural and residual trappings, fractured media |
| Research unit : Géosciences Rennes |
| Name of the thesis director HDR (Habilitation thesis to supervise research) required: Méheust Yves |
| Email address of the thesis director: yves.meheust@univ-rennes1.fr |
| Name of the thesis co-director (if applicable): HDR (Habilitation thesis to supervise research) required: Neuweiler Insa, Institute of Fluid Mechanics and Environmental Physics in Civil Engineering, Univ. Hannover, Hannover (Allemagne) |
| Email address of the thesis co-director (if applicable): neuweiler@hydromech.uni-hannover.de |
| Name of the thesis co-supervisor 1 (if applicable): |
| Email address of the thesis co-supervisor 1 (if applicable): |
| Thesis grant (funding origin and amount): Doctoral School Contract by Université Rennes 1 (“politique d’établissement”) |
| Contact(s) (mailing address and E-mail): Thesis director : Yves Méheust (yves.meheust@univ-rennes1.fr / 0223236251 /Géosciences Rennes, Université de Rennes 1, Campus Beaulieu, bât. 14B, 35042 Rennes) |
| Recruitment process: Recruitment process depends on thesis funding. To select the corresponding recruitment process, please visit the EGAAL website here . This information is needed for proposal publication. <input checked="" type="checkbox"/> Doctoral school contest <input type="checkbox"/> Interview <input type="checkbox"/> Other (indicate) : |

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All sections must be filled. Once filled, please save the proposal form in pdf format using the following naming: Supervisor Name_Unit_Subject Acronym_EN.pdf

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SCIENTIFIC DESCRIPTION OF THE PhD PROJECT

Socio-economic and scientific context : (10 lines)

Two thirds of the global warming of the atmosphere by greenhouse effect in the last 150 years is due to carbon dioxide (CO₂). To limit global warming, one can capture the CO₂ produced by industrial facilities and inject it in deep aquifers (of depth > 800 m), where it is supercritical and hence less dense than the resident brine. Upon injection, it goes up by buoyancy to the cap rock, and spreads horizontally under it (so-called *structural trapping*). During this displacement, the CO₂ must displace the brine, which gives rise to liquid-gas interface instabilities and thus to the so-called *residual trapping of CO₂*. Very few studies have addressed configurations of fractured aquifers so far. The characterization of (i) the circumstances under which such a procedure can maintain the CO₂ trapped for at least a millenium, (ii) the relative importance of the different trapping mechanisms, (iii) the quantity of CO₂ that can be trapped in this manner, and (iv) the time duration of the storage operation, remains a challenge.

Assumptions and questions (8 lines)

Spatial variation of the wall topographies of geological fractures, coupled to the physical instability of fluid-fluid interfaces, lead to a great complexity in the spatial distribution of the fluid phases. This complexity impacts both the saturation in CO₂, related to the overall amount of non-displaced resident fluids, and the amount of CO₂²⁰⁰⁷ which has been detached from the injected CO₂ phase and thus contributes to residual trapping. The relevant scientific questions are the following. What are the flow regimes in the fractures, depending on the injection flow rate, the fracture's orientation, and the relative viscosities/densities of the injected and resident fluids ? How do these regimes impact the amount of CO₂ that contributes to structural and residual trappings at the scale of the formation ? What is the time scale of these trapping mechanisms, and on which parameters does it depend ?

The main steps of the thesis and scientific procedure (10-12 lines)

First year: We shall develop a new experimental setup of flow through a geological fracture, and we shall visualize optically and characterize the spatial distribution of phase for different values of the parameter space.
Second year: The analysis of these spatial phase distributions will allow characterizing the flow regimes depending on the various parameters. The experimental results will be compared to numerical results obtained in the framework of the PhD project launched in parallel at Univ. Hannover, and will be used to validate them.
Third year: The entire set of results (experimental and numerical) at the fracture scale will be upscaled to the 2007 scale of the geological formation using a large scale numerical model which will be developed in a collaboration between the two groups.

Methodological and technical approaches considered (4-6 lines)

The PhD work will be mostly experimental, and will require the development of a new experimental setup. The flow cell will reproduce the geometry of a geological fracture. The rough walls will be either milled, or printed in 3D. The flow will be controlled with a pump (for the liquid) or with a pressure controller (for the gas). Differential pressure sensors will allow measuring the pressure drop across the medium. An optical camera of large resolution and of acquisition frequency 100 Hz will image the spatial distribution of phases.

Scientific and technical skills required by the candidate

The applicants will hold a MSc in Earth sciences, water science, engineering (preferably, environmental or mechanical), or physics. Good knowledge of fluid mechanics will be required. Experimental skills relative to flow experiments will be appreciated. A good culture of, and interest for, natural subsurface permeable media, will be an asset. We are looking for curious and strongly motivated individuals, as autonomous as possible and willing to work in an inter-disciplinary environment.

THESIS SUPERVISION¹

| | |
|---|--|
| Unit name: Géosciences Rennes | Team name: DIMENV |
| Unit director name: Olivier Dauteuil | Team director name: Yves Méheust |
| Mailing address of the unit director: olivier.dauteuil@univ-rennes1.fr | Mailing address of the team director: yves.meheust@univ-rennes1.fr |
| <p>Thesis director</p> <p>Surname, first name: Méheust Yves</p> <p>Position: Distinguished Associate Professor</p> <p>Obtained date of the HDR (Habilitation thesis to supervise research): 2016</p> <p>Employer: Université de Rennes 1</p> <p>Doctoral school affiliation: EGAAL</p> <p>Rate of thesis supervision in the present project (%) : 60</p> <p>Total rate of thesis supervision in ongoing theses (supervisions and co-supervisions) (%) : 50</p> <p>Number of current thesis supervisions/co-supervisions: 1</p> | |
| <p>Thesis co-director</p> <p>Surname, first name: Neuweiler Insa</p> <p>Position: Professeur à l'institut de Mécanique de Fluides de l'Université d'Hannovre (Allemagne)</p> <p>Obtained date of the HDR (Habilitation thesis to supervise research): 2007</p> <p>Employer: Université d'Hannovre</p> <p>Doctoral school affiliation: <i>Non-applicable</i></p> <p>Rate of thesis supervision in the present project (%) : 40</p> <p>Total rate of thesis supervision in ongoing theses (supervisions and co-supervisions) (%) : 200</p> <p>Number of current thesis supervisions/co-supervisions: 4</p> | |
| <p>Professional status of previous PhD students supervised by both director and co-supervisors (from 5 years)</p> <p><i>Please provide the following information for <u>each</u> PhD students supervised</i></p> <p>Surname, first name : Turuban, Régis</p> <p>Date of PhD beginning and PhD defence : 2012-2017</p> | |

¹ In EGAAL Doctoral School, if only one scientist in thesis supervision = 100% of supervision rate; if 2 people involved in thesis supervision = from 50% to 70% of supervision rate for the director; if 3 people involved in thesis supervision = 40% / 30% / 30% of supervision rate distribution among supervisors.

Thesis supervision : Yves Méheust (directeur) et Tanguy Le Borgne (co-directeur)

Professional status and location : Postdoc, SISSA Trieste (Italie)

Contract profile (post-doc, fixed-term, permanent) : Postdoc (CDD)

List of publications from the thesis work :

1. P. de Anna, J. Jimenez-Martinez, H. Tabuteau, R. Turuban, T. Le Borgne, M. Derrien & Y. Méheust (2014), Mixing and reaction kinetics in porous media: an experimental pore scale quantification, *Environ. Sci. Tech.* **48**, 508-516.
2. J. Jimenez-Martinez, P. de Anna, H. Tabuteau, R. Turuban, T. Le Borgne, & Y. Méheust (2015), Pore-scale mechanisms for the enhancement of mixing in unsaturated porous media and implications for chemical reactions, *Geophys. Rev. Lett.* **42**(13), 5316-5324.
3. R. Turuban, D. R. Lester, T. Le Borgne & Y. Méheust (2018), Space-Group Symmetries Generate Chaotic Fluid Advection in Crystalline Granular Media, *Phys. Rev. Lett.* **120**, 024501.
4. R. Turuban, D. R. Lester, H. Heyman, T. Le Borgne & Y. Méheust (2019), Chaotic Mixing in Crystalline Granular Media, *J. Fluid Mech.* **871**, 562-594.
5. J. Heyman, D. R. Lester, R. Turuban, Y. Méheust, & T. Le Borgne (2020), Stretching and folding sustain microscale chemical gradients in porous media., *Proc. Nat. Acad. Sci.* **117** (24), 13359-13365.

Surname, first name : Hubert, Antoine

Date of PhD beginning and PhD defence : 2016-2020

Thesis supervision : Tanguy Le Borgne (directeur) et Yves Méheust (co-directeur)

Professional status and location : Ingénieur en recherche et développement

Contract profile (post-doc, fixed-term, permanent) : CDI

List of publications from the thesis work :

1. A. Hubert, T. Aquino, H. Tabuteau, Y. Méheust & T. Le Borgne & (2020), Enhanced and non-monotonic effective kinetics of solute pulses under Michaelis–Menten reactions, *Adv. Water Resour.* **146**, 103739.
2. A. Hubert, J. Jimenez-Martinez, H. Tabuteau, J. Heyman, T. Le Borgne & Y. Méheust (2020), Micro-model experiments of solute transport, mixing and reactions in subsurface environments: a review, in revision for *J. Hydrol.*
3. A. Hubert, J. Farasin, H. Tabuteau, A. Dufresne, Y. Méheust & T. Le Borgne (2020), Shear-induced switching between active growth and dormancy in *E. coli* dynamics, in revision for *Nature Com.*

Surname, first name : Fernandez Visentini, Alejandro

Date of PhD beginning and PhD defence : 2018-2021

Thesis supervision : Niklas Linde (directeur), Tanguy Le Borgne (co-directeur) et Yves Méheust (co-encadrant)

Professional status and location : Thèse en voie de complétion

Contract profile (post-doc, fixed-term, permanent) : Bourse de thèse

List of publications from the thesis work :

1. A. F. Visentini, P. de Anna, D. Jougnot, T. Le Borgne, Y. Méheust & N. Linde (2021), Electrical signature of diffusion-limited mixing: Insights from a milli-fluidic tracer experiment, submitted to *Transport Porous Med.*

Surname, first name : Izimoto, Satoshi

Date of PhD beginning and PhD defence : 2017-2021

Thesis supervision : Sander (directeur), Tanguy Le Borgne (co-directeur) et Yves Méheust (co-encadrant)

Professional status and location : Thèse en voie de complétion

Contract profile (post-doc, fixed-term, permanent): Bourse de thèse

List of publications from the thesis work :

1. S. Izumoto, J. A. Huisman, E. Zimmermann, J. Heyman, F. Gomez, H. Tabuteau, R. Laniel, H. Vereecken, Y. Méheust & T. Le Borgne (2021), Spectral induced polarization of calcite precipitation in a 2D porous medium, submitted to *Environ. Sci. & Tech.*

Surname, first name : Lenci, Alessandro

Date of PhD beginning and PhD defence : 2017-2021

Thesis supervision : Vittorio Di Federico (directeur) et Yves Méheust (co-directeur)

Professional status and location : Thèse en cours

Contract profile (post-doc, fixed-term, permanent): Bourse de thèse

List of publications from the thesis work : aucune publication soumise pour le moment

Surname, first name : Tecklenburg, Jan

Date of PhD beginning and PhD defence : 2012 - 2017

Thesis supervision : Insa Neuweiler (directeur)

Professional status and location : Ingénieur modélisateur

Contrat (post-doc, CDD, CDI) : CDI

List of publications from the thesis work :

1. Tecklenburg, J., I. Neuweiler, M. Dentz, J. Carrera, S. Geiger, C. Abromowski and O. Silva (2013): A non-local two-phase flow model for immiscible displacement in highly heterogeneous porous media and its parameterization. *Advances in Water Resources* **62**: 475-487.
2. Tecklenburg, J., I. Neuweiler, J. Carrera and M. Dentz (2016): Multi-rate mass transfer modeling of two-phase flow in highly heterogeneous fractured and porous media, *Advances in Water Resources* **91**, 63-77.

Surname, first name : Cremer, Clemens

Date of PhD beginning and PhD defence: 2012 - 2017

Thesis supervision : Insa Neuweiler (directeur)

Professional status and location : Ingénieur modélisateur

Contract profile (post-doc, fixed-term, permanent) : CDI

List of publications from the thesis work :

1. Cremer, C., I. Neuweiler, M. Bechtold and J. Vanderborcht (2016): Solute transport in heterogeneous

- soil with time-dependent boundary conditions, *Vadose Zone Journal* **15**(6)
2. Cremer, C., C. Schuetz, I. Neuweiler, P. Lehmann and E.H. Lehmann (2017): Unstable infiltration experiments in dry porous media, *Vadose Zone Journal* **16**(7).
 3. Cremer, C., and I. Neuweiler (2019): How dynamic boundary conditions induce solute trapping and quasi-stagnant zones in laboratory experiments comprising unsaturated heterogeneous porous media, *Water Resources Research* **55**(12), 10765-10780.

Surname, first name : Feng, Dianlei

Date of PhD beginning and PhD defence : 2013 - 2017

Professional status and location : Insa Neuweiler (directeur)

Emploi actuel, lieu : Tenure track position

Contract profile (post-doc, fixed-term, permanent) : CDD

List of publications from the thesis work :

1. Feng, D., I. Neuweiler and U. Nackenhorst (2017), A spatially stabilized TDG based finite element framework for modeling biofilm growth with a multi-dimensional multi-species continuum biofilm model, *Computational Mechanics* **59**(6), 1049-1070
2. Rath, H., D. Feng, I. Neuweiler, N.S. Stumpp, U. Nackenhorst and M. Stiesch (2017), Biofilm formation by the oral pioneer colonizer *Streptococcus gordonii*: an experimental and numerical study, *FEMS Microbiology Ecology* **93**(3), Nr. Fix010
3. Feng, D., I. Neuweiler, U. Nackenhorst and T. Wick (2019), A time-space flux corrected transport finite element formulation for solving multi-dimensional advection-diffusion-reaction equations, *Journal of Computational Physics* **396**, 31-53.

Five main recent publications of the supervisors on thesis subject:

- Z. Yang, I. Neuweiler, Y. Méheust, F. Fagerlund & A. Niemi (2016), Fluid trapping during capillary displacement in fractures, *Advances Water Resour.* **95**, 264-275.
- M. Dentz, I. Neuweiler, Y. Méheust & D. M. Tartakovsky (2016), Noise-Driven Interfaces and Their Macroscopic Representation, *Phys. Rev. E* **94**, 052802.
- Z. Yang, Y. Méheust, I. Neuweiler, R. Hu, A. Niemi, Y.-F. Chen (2019), Modeling immiscible two-phase flow in rough fractures from capillary to viscous fingering, *Water Resour. Res.* **55**(3), 2033–2056.

THESIS FUNDING

Origin(s) of the thesis funding: Doctoral School Contract by Université Rennes 1 (“politique d’établissement”)

Gross monthly salary: 1770

Thesis funding state : Acquired

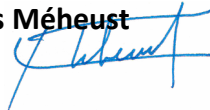
Funding beginning date/Funding ending date: 01/09/2021 / 3 years

Date: 26/03/2021

Name, signature of unit director: Olivier Dauteuil


Olivier DAUTEUIL
Directeur de Géosciences
Rennes UMR6118

Name, signature of team director: Yves Méheust



Name, signature of thesis project director: Yves Méheust



2007