UNIVERSITÀ DEGLI STUDI DI MILANO

TO MAGNIFICO RETTORE OF UNIVERSITA' DEGLI STUDI DI MILANO **ID CODE 6621**

I the undersigned asks to participate in the public selection, for qualifications and examinations, for the awarding of a type B fellowship at **Dipartimento di FISICA**

Scientist- in – charge: Alberto VAILATI

[Paul FRUTON]

CURRICULUM VITAE

PERSONAL INFORMATION

Surname	Fruton
Name	Paul

PRESENT OCCUPATION

Appointment	**Structure**
2024: Full time physic teacher	CY Tech Pau, engineering school

EDUCATION AND TRAINING

Degree	**Course of studies**	**University**	**year of achievement of the degree**
PhD	Fluid Mechanics	Université de Pau et des Pays de l'Adour, Anglet	2022
Master	Fluid Mechanics and Non-Linear Physics	Aix-Marseille Université, Marseille	2018
Engineer degree	General engineering and specialisation in fluid mechanics	Centrale Marseille, Marseille	2018
Preparatory school for French engineering schools	Mathematics and Physics	Lycée Janson de Sailly, Paris	2014
French Baccalauréat	Scientific	Lycée François Joseph Talma, Brunoy	2011

FOREIGN LANGUAGES

Languages	level of knowledge
French	Native
English	B2/C1
Italian	Beginner

AWARDS, ACKNOWLEDGEMENTS, SCHOLARSHIPS

Year	Description of award
2019	Student grant for ELGRA 2019 participation
2020	E2S mobility grant for a three month stay in the Università degli Studi di Milano (finally cancelled due to COVID-19)

TRAINING OR RESEARCH ACTIVITY

Convection in both free and porous medium

Owing to the global warming and the need to reduce greenhouse gases emissions, in 2018 Fabrizio Croccolo launched the CO_2 Enhancement Storage (CO2ES) industrial chair supported by E2S-UPPA, TotalEnergies, the BRGM and the CNES (cf. "Project activity" section). The CO2ES chair will provide a multi-scale overview of the processes involved in CO_2 storage.

This topic is closely related to the fight against global warming and I started to work on that subject during my Master thesis at the "Research institute on out-of-equilibrium phenomena" (IRPHE, Marseille) under the supervision of Pr. Patrice Meunier. There, I performed experiments to observe convective dissolution of carbon dioxide in a transparent porous medium saturated with a solution of water and potassium thiocyanate (KSCN). This solution has been selected to match its refractive index with the one of glass beads that were used to model the porous medium. Then, using a laser sheet and fluorescent particles, we performed particle image velocimetry (PIV) to observe the flow induced by the dissolution of CO_2 in the solution. Experiments were conducted at relatively low pressures (up to 1.4 MPa) and observation was done from the lateral side, as conventional for Hele-Shaw cells.

Then, I had the opportunity to continue my investigations on this topic during a Ph.D. thesis, using a new experimental set-up and method. In October 2018, I joined the CO2ES team to develop an experimental set-up and perform convective dissolution experiments of CO_2 in water and brine using shadowgraphy as the optical method and observing the system in the vertical direction, i.e. parallel to the gravity vector. Here, we used a high-pressure cell that can hold pressures up to 30 MPa with two entries oriented towards the top and bottom of the sample. Thus, we could inject pure or salted water from the bottom and then pressurize the cell from the top by injecting CO_2 into the upper gaseous phase. When CO_2 dissolves inside the liquid phase, it creates a boundary layer at the horizontal gas-liquid interface. A CO_2-rich boundary layer grows diffusively in time due to diffusion of CO_2 towards the liquid phase, its density being larger than the bottom liquid bulk. Thus, the boundary layer could be destabilized by buoyancy once its thickness exceeds a critical value, as mirrored by a critical solutal Rayleigh number for the boundary layer.

The system behaviour is observed by means of a shadowgraph and the whole system can be mounted either horizontally or vertically. Then, two observation approaches are available. Looking from the side, we observe the evolution of downward fingers that emerge at the top interface and induce the mixing inside the bulk. This approach is similar to the one used in literature, notably the two-dimensional experiments conducted in Hele-Shaw cells. Looking from the top, we observe how these patterns are spatially (x-y) distributed. As far as we know, this method has not been used before and it allowed us highlighting a first new result: the fingers are not isolated, as witnessed by the lateral observation, but interconnected by falling sheets that appear before the eventually breaking into plumes. This research work led to the publication of the article entitled "Convective dissolution of carbon dioxide into brine in a three-dimensional free medium" [1].

From the shadowgraph images, we observed darker areas that correspond to convective patterns more concentrated in CO_2 than the bulk. By computing the variance of image differences, we provided a quantitative analysis of the experiment evolution. From this, we were able to derive the onset time of convection that accelerates the mixing inside the fluid bulk, and, thus, increases the dissolution rate of CO_2. The onset time of convection has been measured for many different values of initial and final CO_2 pressure as well as different salt concentration of the brine. This allowed us to verify that the dimensionless onset times follow a unique master curve, confirming the theoretical development similar to the one derived by Howard et al. [2] for thermal convection. This puts in evidence that the onset time of convection is completely determined by the solutal Rayleigh number and does not depend on the nature of the gaseous and liquid phase.

Starting from the beginning of 2022, with the help of a PhD candidate that I co-supervise, we developed a new set-up to study convective dissolution in a transparent porous medium. The porous matrix is modelled by glass beads. The liquid phase is a mixture of 1-hexanol and toluene that matches the refractive index of the solid phase allowing optical methods involving visible light, as shadowgraphy. In the article [3], we showed that we were able to clearly visualize the flow through the porous medium. We also developed an analysing method to determine the plume velocity as they propagate through the porous matrix. This investigation relates the intensity of the convective mixing with the speed of the convective front, and especially demonstrates the compatibility of shadowgraphy with the observation of convective flow through a solid porous medium.

After this preliminary study, we are currently going further by performing a real convective dissolution experiment. It means that we initiate convection by the dissolution of CO_2 inside a liquid phase. This required a new refractive index matching analysis with another pair of fluids that has thermophysical properties available in the literature, such as the solubility of CO_2 inside the mixture. This is mandatory to properly quantify the process with dimensionless numbers such as the Rayleigh, Peclet and Reynolds numbers. Experiments are currently performed and their analysis will lead to further discussion on the convective dissolution of CO_2 in porous media.

Investigation of complex fluids under both terrestrial and reduced gravity

My research work also focused on the study of the transport properties of pure and complex fluids. First, at the beginning of my thesis, I took part in the development of post-process methodologies, especially to perform a proper concatenation of structure functions to study the behaviour of non-equilibrium fluctuations (NEFs) at short and long terms [4]. This has specific interest for the study of multicomponent mixtures.

Related to the work on CO_2 storage, we performed preliminary experiments using pure CO_2 at supercritical state (s-CO_2), stressed by a thermal gradient that is applied around the Widom line of CO_2. Using the non-equilibrium fluctuations that spontaneously emerge inside the bulk, we investigated the s-CO_2 behaviour to understand if it acts more like a liquid or a gas. Preliminary results clearly show that, in the presence of gravity, the fluid stratifies in two quasi-phases with different densities. This has been understood after the analysis of the structure functions of NEFs that, in certain conditions, clearly show propagating modes that are characteristic of multicomponent mixtures.

To relate non-equilibrium fluctuations and convection, we also studied the transport phenomena occurring in a mixture of CO_2 and 1-hexanol during thermodiffusion experiments under both terrestrial and reduced gravities. Experiments have been performed on ground at terrestrial gravity, and during two parabolic flight campaigns (VP154-59 & VP161-61) that provided us periods of reduced and hyper gravity. Data have been analysed only partially and we still need to complete the analysis in order to obtain a clear indication about the effect of different gravity levels (1g, 2g, 0g) on the convective patterns observed at different conditions of CO_2 concentration and fluid pressure. A preliminary analysis shows a clear influence of the gravity level on convection that is enhanced during hyper gravity phases and stops during reduced gravity phases.

During my post-doctoral duties in the LFCR, I also developed a two-wavelength shadowgraph in the scope of the NEUF-DIX project (cf. “Project activity” section). This set-up will strongly enhance the resolution capacity of the shadowgraph. Indeed, in ternary mixtures, two solutal modes with very close decay times emerge inside the sample during thermodiffusion experiments. By adding a second wavelength, we are able to invert the contrast factor matrix and then separate the two solutal modes. Thus, within a single experiment, we are able to retrieve all the transport properties of the fluid mixtures. I developed the setup during my post-doctoral duties and ot is currently used to performed experiments to verify its capability.

References

[1] P. Fruton, A. Nauruzbaeva, H. Bataller, C. Giraudet, A. Vailati, F. Croccolo, Convective dissolution of carbon dioxide into brine in a three-dimensional free medium, Physical Review Fluids, 8(2), 023503. DOI: https://doi.org/10.1103/PhysRevFluids.8.023503

[2] L. N. Howard. Convection athigh rayleigh number. In Heidelberg Springer Berlin Heidelberg Imprint Springer, Berlin, editor, Applied Mechanics : Proceedings of the Eleventh International Congress of Applied Mechanics Munich (Germany) 1964, 1966.

[3] H. Imuetinyan, P. Fruton, C. Giraudet, F. Croccolo, Convective plume spreading in model transparent porous media, Transport in porous media, Transport in Porous Media (Accepted: 2 May 2024). DOI: https://doi.org/10.1007/s11242-024-02090-z

[4] L. Garcia-Fernandez, P. Fruton, H. Bataller, A. Vailati, J.H. Ortiz de Zarate, F. Croccolo, Coupled non-equilibrium fluctuations in a polymeric ternary mixture, European Physical Journal E, 2019, 42, 1-13. DOI: https://doi.org/10.1140/epje/i2019-11889-4

PROJECT ACTIVITY

Year	Project
2018-Now	CO2ES: In 2018 Fabrizio Croccolo launched the CO_2 Enhancement Storage (CO2ES) industrial chair supported by E2S-UPPA, TotalEnergies, the BRGM and the CNES. The chair was hosted at the "Laboratory of complex fluids and their reservoirs" (LFCR) of the Université de Pau et des Pays de l'Adour (UPPA), within the team "Geomechanics of porous media" (G2MP) in Anglet. The chair CO2ES aims at better understanding the processes involved in the storage of carbon dioxide in saline aquifers. For that, several work packages have been developed, including the experimental investigation of phenomena occurring inside the aquifers after the injection of carbon dioxide: convective dissolution, salt precipitation and crystallization. The experimental studies made at the laboratory scale are completed with numerical modelling at the basin scale. Thus, the CO2ES chair will provide a multi-scale overview of the processes involved in CO_2 storage. During my PhD thesis and my post-doctoral duties, my research activities were enrolled within this chair. They were focused on experimental investigations using the shadowgraph method to observe convective motions and non-equilibrium fluctuations in fluid mixtures.
2018-Now	CO2EX: The CO_2 storage experiment (CO2EX) project is included in the industrial chair of Fabrizio Croccolo CO2ES. The project CO2EX focuses on the experimental investigations of some of the processes involved in CO_2 storage technologies under microgravity conditions. In the scope of the CO2EX project, I took part in two parabolic flight campaigns (VP154-59& VP161-61 at Novespace, Mérignac, France) with the CNES (French national center of spatial studies) to study non-equilibrium fluctuations induced by the Soret effect under various gravity levels. I had a central role in the building of the two experimental setups that has been specially developed for each of these campaigns. It was a precise work to meet all the requirements of Novespace. I was also the software responsible of the project.
2022-Now	NEUF-DIX: This project aims to investigate non-equilibrium fluctuations during diffusion in complex fluids (NEUF-DIX), especially under micro gravity conditions. This project addresses several challenges that came out during the study of NEFs of complex fluids, notably on the predictions of Casimir forces emerging with the confinement of NEFs, or the behaviour of NEFs in multicomponent mixture and concentrated colloidal suspensions. In the scope of this project, I participated in the development of analysis methods of the NEFs and on the development of a two-wavelength shadowgraph (cf. "Training or research activity" section).

CONGRESSES AND SEMINARS

Date	Title	Place
September 24th-27th, 2019	Poster presentation: Shadowgraph investigations of free-diffusion of glycerol and water under micro-gravity conditions using a cylindrical flowing-junction cell	26th biennial symposium and general assembly of the European low gravity research association, Granada, Spain
July 15th-17th, 2020	Oral presentaiton (Cancelled) Convective dissolution of CO_2 in brine in transparent model porous media	Concreep11+ 2020 conference, Northwestern University, Evanston, IL, USA (Cancelled due to health situation)
May 25th-27th, 2021	Oral presentation (remotely): Characterization of the convective dissolution of CO_2 in brine	14th International meeting on thermodiffusion
June 1st-3rd, 2021	Oral presentation (remotely): Characterization of the convective dissolution of CO_2 in brine	Biot-Bazan conference
June 24th, 2021	Oral presentation (remotely): Characterization of the convective dissolution of CO_2 in brine	21st symposium on thermophysical properties
September 6th-9th, 2022	Oral presentation: Thermal diffusion experiments in CO_2-1-hexanol mixtures at different gravity levels – Design and overview of a parabolic flight campaign	27th biennial symposium and general assembly of the European low gravity research association, Lisbon, Portugal
May 29th-June 1st, 2023	Oral presentation: Thermal diffusion experiments in CO_2-1-hexanol mixtures at different gravity levels – Design and overview of a parabolic flight campaign	15th International Meeting on Thermodiffusion, Tarragone, Spain

PUBLICATIONS

Articles in reviews
H. Imuetinyan, P. Fruton, C. Giraudet, F. Croccolo, Convective plume spreading in model transparent porous media, Transport in porous media, Transport in Porous Media (Accepted: 2 May 2024). DOI: https://doi.org/10.1007/s11242-024-02090-z
P. Fruton, A. Nauruzbaeva, H. Bataller, C. Giraudet, A. Vailati, F. Croccolo, Convective dissolution of carbon dioxide into brine in a three-dimensional free medium, Physical Review Fluids, 8(2), 023503. DOI: https://doi.org/10.1103/PhysRevFluids.8.023503
L. Garcia-Fernandez, H. Bataller, P. Fruton, A. Vailati, F. Croccolo, Stabilized convection in a ternary mixture with two Soret coefficients of opposite sign, European Physical Journal E, 2022, 45(6), 52. DOI: https://doi.org/10.1140/epje/s10189-022-00202-5
L. Garcia-Fernandez, P. Fruton, H. Bataller, A. Vailati, J.H. Ortiz de Zarate, F. Croccolo, Coupled non-equilibrium fluctuations in a polymeric ternary mixture, European Physical Journal E, 2019, 42, 1-13. DOI: https://doi.org/10.1140/epje/i2019-11889-4

OTHER INFORMATION

Dissemination activities
2024: Speech at the secondary school Albert Camus in Bayonne for a class of 9th grade students similar to the one given at "Nuit européenne des chercheurs 2023" Collège Albert Camus, Bayonne, France
2023: Scientific Village Stand at the « Village des sciences » of Hendaye as part of the science celebration. Introduction of shadowgraphy, experiments around CO_2 and the greenhouse effect to introduce the carbon capture and storage technology, explications on parabolic flights.
2023: European searchers night Stand entitled « Observe the invisible » to introduce the shadowgraphy, the diffusion and convection. Château d'Abaddia, Hendaye, France
2023: Speech at the secondary school Albert Camus in Bayonne for a class of 9th grade students similar to the one given at "Nuit européenne des chercheurs 2022" Collège Albert Camus, Bayonne, France
2022: European searchers night Conference entitled « Decarbonation: Why? For who? How? » given with F. Croccolo and A.T Ndjaka in the scope of the "European researchers' night". Dissemination on carbon lifecycle, with an explanation of the link between carbon and climate disruption and an overview of the academic research efforts to optimize carbon storage processes. IUT Mont-de-Marsan, France

Declarations given in the present curriculum must be considered released according to art. 46 and 47 of DPR n. 445/2000.

The present curriculum does not contain confidential and legal information according to art. 4, paragraph 1, points d) and e) of D.Lgs. 30.06.2003 n. 196.

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Place and date: Bayonne (France), May 28th 2024