LOCIE

Towards close-to-zero CO_2 emission for energy systems: study of a novel heat and mass exchanger for water-based heat-pump

Context:

The overall transformation of the energy supply towards close-to-zero CO_2 emissions leads to a significant electrification of the energy sector whereas the electricity production capacity is limited and cannot cover all uses, especially thermal uses. In addition, there is still a huge amount of unused thermal energy releases to the atmosphere whereas the massive demand for heat and refrigeration in industry and housing **will not be environmentally satisfied without a significant increase in the efficiency of systems in the broadest sense**, including a **recovery of the still very under-exploited waste energy**. At last, thermal energy systems based on mechanical compression like usual **cooling systems and heat-pumps often require the use of hydrochlorofluorocarbons fluids (HCFC) whereas their use leads to a significant amount of CO_2 emissions**[1]**.** Hopefully, environmental regulations like the F-gas planed their faced out so that in 2030 only working fluids with low GWP will be allowed (GWP <150). Among the possible replacement fluids, natural fluids can offer interesting performance and are a long-term and sustainable solution. If one considers water, water also offers the advantage to be commonly used in sorption systems like in Lithum-bromide absorption systems, which combined storage capability and allow to upgrade the heat provided by the source with a low temperature level at a higher temperature level with a negligible amount of mechanical work input. Thus, these systems present an interesting option to faster the decrease of CO_2 emission while increasing the efficiency of energy systems in the broadest sense, by a recovery of the under-exploited waste energy and renewable sources.

However, although water is an apparently well-known fluid, its behavior in conditions representative to conditions encounter in thermal energy systems is not yet perfectly apprehended. The particularity of exchangers, used in water-based systems in contact with a low exergetic level energy sink, is the working pressure: at the lowest-pressure stage, the working pressure could be 100 times lower than the atmospheric pressure (around 10 mbar). Phase-change phenomena are different than the ones observed at higher pressure due to the change of thermophysical properties (Fig.1 to 3). The topology of two-phase flows is completely transformed (Fig.2). As a consequence, commercialized water-based systems (based on mechanical and thermal compressions) are at least two times bigger than conventional commercialized systems based on HCFC fluids. But, to allow the deployment of water-based systems, and thus faster the decrease of CO_2 emission, **the cost and the size of these systems must be reduced**, which means to **improve the compactness of key components like exchangers**.

[1] In France, leaks of refrigerant in closed thermal system for refrigeration and excluding automotive air-cooling is responsible for 3,5 million tons equivalent CO2 release to the atmosphere per year. *CODA Stratégies, ADEME (2021), La climatisation dans le bâtiment.*

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The aim of this project is thus to **study a novel subatmospheric heat and mass exchangers** for water-based system which include boiler for Lithium-Bromide (LiBr) absorption heat-pumps and heat-exchanger for R-718 systems.

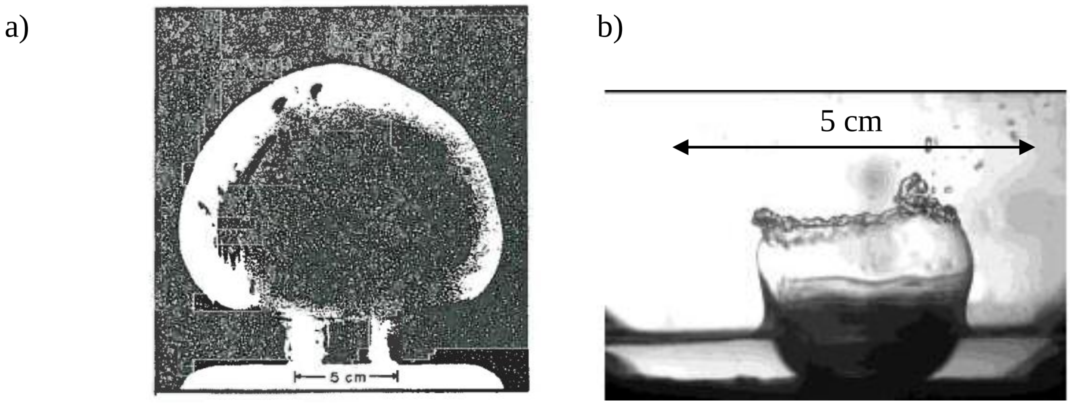

Figure 1: Example a water bubble growth a) at 2.04 kPa in a large pool of water [1] b) in a liquid layer of 3 mm with a breaking of the bubble at the interface liquid/vapor (Pv = 3 kPa, Tl = 24 °C, hl = 3 mm, q = 1.6 $W.cm^{-2}$) [2]

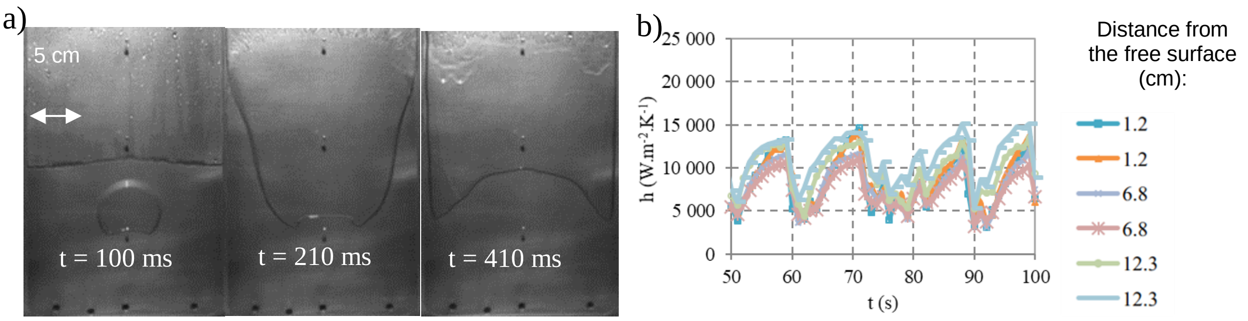

Figure 2: Example a) of two-phase flow observed in a flat plate evaporator and b) of evolution of the heat transfer coefficient (secondary fluid temperature 21°C, pressure 1.4 kPa) [3]

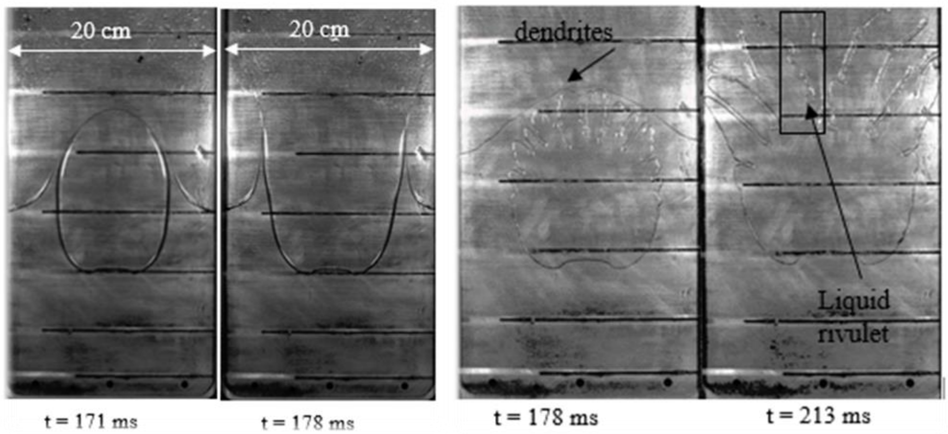

Figure 3: Example of two-phase flow observed in a flat plate evaporator for a confinement of the narrow channel of a) 6 mm and b) 2 mm [3]

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Content of the PhD thesis and main tasks:

Experimental and numerical studies will be conducted to understand and quantify observed phenomena occurring inside the novel heat and mass exchanger designed for water-based systems. In this novel heat-exchanger, growth and bursting of bubbles are expected to be observed. These bubbles will allow the deposition of a thin liquid film that will be drained and/or vaporised. The local heat-transfer coefficient are thus expected to be significantly improved compared to conventional falling-film heat-exchanger since the deposited liquid film thicknesses by the burst of bubble could be significantly thinner than falling film thicknesses usually obtained in traditional exchangers (for water, the estimated deposited film thicknesses observed in the two-phase flow heat exchanger studied in [3] range from 66 µm to 155 µm vs. falling film thicknesses higher than 500 µm measured in [4]).

To provide experimental information required to conduct these analyses, **a new optical measurement technique will be developed** at LEMTA (Nancy) to measure the temperature and the concentration of LiBr. The focus will be on laser-induced fluorescence (LIF) using fluorescent dyes that are sensitive to temperature and to the presence of Br-/ Li+ ions.

Thus, in addition to the valorisation and dissemination of the obtained results, the main tasks of the PhD student will be:

- To design and develop a simplified experimental set-up to adjust the concentration of LiBr and the temperature at atmospheric pressure. This prototype will be used for the validation of the measurement technique develop at LEMTA.
- To develop a novel measurement technique to characterize the volumetric mean of the temperature and the concentration of the working fluid (LEMTA Laboratory);
- To conduct phenomenological and thermal studies of heat and mass transfer occurring in the novel exchanger (already designed) with water and (water + LiBr) solution (LOCIE Laboratory);
- To develop simple physical models for the main heat and mass transfer phenomena.

At the end of the project, the following major results are expected:

- Characterization of the novel heat and mass exchanger in term of simple models and performances maps;
- Development of innovative measurement techniques to access the volumetric mean temperature and concentration in LiBr.

The 1st and 3rd year of the PhD thesis will take at the LOCIE Laboratory (Savoie Technolac / 73370 Le Bourget-Du-Lac), the second year will be spent at the LEMTA Laboratory (2 avenue de la Forêt de Haye/ 54505 Vandoeuvre-lès-Nancy).

Equipment provided to conduct the research:

At LOCIE:

- 2 existing low-pressure experimental test benches with their acquisition chains
- 1 high-speed high-resolution camera (Photron FastCam Mini)
- 1 confocal device
- Support of the technical team

At LEMTA:

- photomultipliers, USB spectrometers, laser diodes
- dyes

Skills required:

- Strong knowledge on thermal and energy systems, **heat and mass transfer, fluid mechanics**, thermodynamics;
- **Aptitude for experimental manipulation;**
- Basics skills on Python or other programming language.

Practical information:

- **Localisation of the PhD thesis:**

1st and 3rd years : LOCIE /Université Savoie Mont Blanc, CNRS UMR 5271/ Bâtiment Hélios – 60 rue du Lac Léman – Savoie Technolac / 73370 Le Bourget-Du-Lac – France
www.univ-smb.fr/locie/
2nd year **:** LEMTA/ 2 avenue de la Forêt de Haye / BP 90161 / 54505 Vandoeuvre-lès-Nancy cedex
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- **Supervision teams:** DR CNRS Guillaume Castanet, MCF. Florine Giraud
- **Starting of the PhD position:** September 2024
- **Founding**: National French Agency – Research project NEWS -

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References :

[1] Van Stralen S. J. D., Cole R., Sluyter W. M., Sohal M. S., 1975. Bubble growth rates in nucleate boiling of water at subatmospheric pressures. Int. J. Heat Mass Transfer. Vol. 18, p. 655-669.

[2] **Giraud, F.**, Toublanc, C., Rullière, R., Bonjour, J., & Clausse, M. (2016). Experimental study of water vaporization occurring inside a channel of a smooth plate-type heat exchanger at subatmospheric pressure. Applied Thermal Engineering, 106, 180-191.

[3] Giraud, F., Rullière, R., Toublanc, C., Clausse, M., & Bonjour, J. (2015, August). Preliminary experimental investigation on water boiling phenomena in a liquid layer at subatmospheric pressure. In *24th International Congress of Refrigeration (ICR 2015)*.

[4] Collignon, R., & **Stutz, B**. (2022). Numerical simulation and modeling of the heat and mass transfer in a grooved flat falling film evaporator. Int. J. Heat Mass Transf.