PhD position available at LEMTA, Université de Lorraine CNRS - FRANCE

starting on 1/10/2025

thesis title : Joint Analysis for Characterization of Kinematics of droplets Superheated Patterns using iA– advanced Research on Reflooding and Overheated Walls

Skills: experimental heat and mass transfer, multi-physics modelling, IA, machine learning, analytical skills and rigour, ability to tackle challenging problems, and the ability to work as part of a team.

Key words: Leidenfrost, DFFB, Droplet impact, Visualization, IA, Deep Learning

Applicant must send CV and motivation letter to professor Michel GRADECK, Université de Lorraine – France (michel.gradeck@univ-lorraine.fr) and copy to Dr Arthur Oliveira, EESC-USP – Brazil (avs.oliveira@usp.br)

Dead Line: 30th April **2025**

Context

This doctoral project is founded by Lorraine University of Excellence (LUE) and will be part of an existing research collaboration between LEMTA laboratory of Université de Lorraine (UL -France) and a research team (i.e. GOTAS team) of Sao Carlos School of Engineering at University of Sao Paulo (EESC-USP, Brazil) with which LEMTA's is collaborating since 2021. **The PhD student to be engaged will register to the doctoral school SIMPPÉ (ED SIMPPÉ of Université de Lorraine). He or she will be supervised by Prof. Michel Gradeck (UL – France), co-supervised by Dr Guillaune Castanet (CNRS – France) and Dr Arthur Oliveira (EESC-USP, Brazil).**

This thesis is part of a long-term project aiming at better understand the transient cooling of a fuel assembly during its reflooding after a loss of coolant accident. In the context of nuclear safety and in the event of a loss of coolant accident, there is a clear need for a better model in order to be able to accurately estimate the thermal transient of the fuel cladding far from the quenching front. The story starts while the security circuits are activated and these will feed the core with fresh water at very low speed from the bottom to the top. This fresh water coming into contact with the fuel cladding at high temperature induces a very strong boiling phenomena at what is called the quenching front, producing a huge amount of steam whose momentum enables it to tear off droplets and finally produces the DFFB regime (Dispersed Film Flow Boiling). This is a very complex two-phase flow even it looks simple because dispersed ; heat and mass transfer are described in figure 1

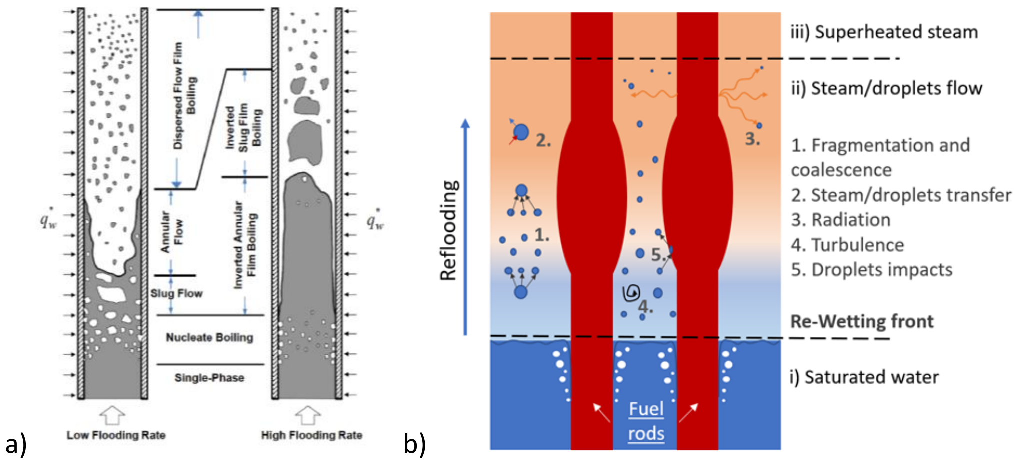


Figure 1: a) classical internal boiling regime in a heated tube ; b) multiphase flow during the reflooding of a nuclear core

Even if a huge amount of studies on droplet impact can be found in the literature, there are still some shortcomings concerning the DFFB in the post-dryout region which is the regime ending the process of steam production.

Steam production is the essential step in any electricity production process based on a Rankine cycle, not only in nuclear power plants but in every thermal power plant for electricity production, including solar and bio-source plants. Dispersed film flow boiling (i.e. DFFB) is also essential in the first time of reflooding in case of LOCA. In order to well estimate the thermal transient of a nuclear fuel assembly experiencing such an accident, we need a more reliable model for being able to ensure that the core will not melt in any situations (including severe degradations like ballooning of the cladding) and finally to better estimate the safety margins. The figure 1b describes the multiphase flows occurring during the reflooding phase after the shutdown of the reactor.

The situation under interest in this LUE thesis is the post-dryout regime and especially the modelling and measurement of the droplet mass flux to the wall.

Objectives of the thesis:

Even if we made serious efforts to better estimate the heat and mass transfer within this flow [1-3], there are still some keylocks that need to be overcome. Among them, the characteristics of the droplet's population produced at the quenching front must be better known, the mass flow of droplet impinging the wall is also the key model that needs also to be seriously improved. This will be the objective of this doctoral project.

This will be achieved after several challenging step using experimental bench available at LEMTA (France) or EESC-USP (Brazil), developing a deep learning code for picture analysis purpose and finally, at the end, it will be possible to propose a new modelling of droplet mass flow to the wall that will be implemented in a system code aiming at estimate the cooling of a nuclear core after a Loss of Coolant Accident (LOCA). The thesis works is divided in three main tasks:

Task 1: data base of a wide variety of droplet impacts
This task is dedicated to the building of the database of a wide variety of impact in the Leidenfrost regime (fig 1). Based on an existing set-up available at LEMTA laboratory (fig 3), we will build a database of the **thermal pattern of each droplet impact depending on Weber number (We) based on droplet diameter (d_d) and velocity normal to the wall but also on the tangential velocity (u_t).** Hence, while impacting the wall, a droplet will also slide on it before bouncing (figure 2) and the temperature field at the wall surface should be depend on that parameters (We, d_d and u_t) like it has been observed in similar situations (see fig 3a and 3b). The building of that database will be compulsory to be used in the next steps. The doctoral student will also have access to previous data available in the research team.

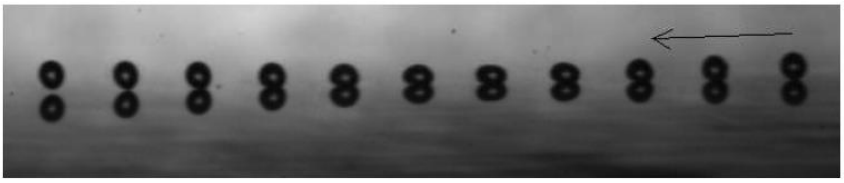


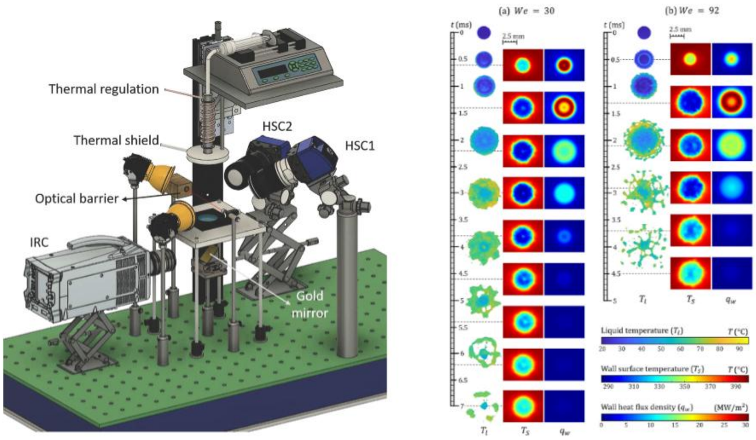
Figure 2: droplet interacting with a wall in the Leidenfrost state (from [1]

Task 2: building of the deep learning code to identify the characteristics of each impingement
To achieve that we will need to develop a strategy to identify efficiently the characteristics of droplet dynamics through the temperature field modification during the interaction with the wall (see figure 3b). In fact, each temperature field modification will depend on the droplet dynamics (and also the temperature of it) that it is to say its Weber number. But in the case of a droplet carried by a vapour flow, it will also depend on the tangential velocity. These parameters will produce a unique modification of temperature field at the wall. In our previous experiments [1], we cannot catch it because the wall was too thick. So, taking advantage of the database of LEMTA, improve during this project (see task 1), we will train a deep learning code to be able **to identify any droplet to wall interaction and recover its main characteristics**. To achieve that, we need well time and spaced resolved data obtained in task 1.

Task 3: Apply the previous code in a more complex situation : droplet to wall interaction in a DFFB
To be able to catch each droplet impact at the wall at different wall temperature in the DFFB regime (like the one described in fig 1), we will build a new set-up allowing the Infrared visualization of the droplet impact to the wall. This set-up will be similar to the COLIBRI experiment develop during PhD thesis of [2]. A full characterization of the flow including the measurements of the droplet's distribution (size and velocity), coupled with the detection of droplet impact (using infrared measurements and deep learning), will allow to estimate droplet mass flow to the wall and its

characteristics. In that new experiment, we will use a heated wall coated with TiAlN[1] which will allow infrared measurement of droplet impact with IR images taken at high frequencies. These experiments will be performed in the same experimental conditions of thesis [2] and [3] but using also high-speed camera to control the flow conditions as well as dual PDA.

All of this will be the basis of the development of a new model of droplet mass flux.



(a) (b)

Figure 3: (a) Experimental set-up ; (b) droplet spreading dynamics and heat transfer performances of droplet impacting on sapphire substrate coated with TiAlN (from [4] and [5]).

Simplified thesis scheduled :

- first year, building of the data (task one) as well as coding the deep learning (task 2) code based on python library that be found on open source website like Anomalib (https://arxiv.org/abs/2202.08341 or others). At the end, test of the code on some known experiments
- second year, building of the new set-up for task 3 and analysis of the droplet mass flux
- third year, building of a new model of droplet mass flux and writing of article and thesis document.

Working team : On the French side, the PhD candidate will be part of a very active team in the field of heat and mass transfer. The team of professor Gradeck is engaged in several national and international program aiming at providing knowledge in the context of energy transition and safe energy production. This team belongs to LEMTA, one of the reference laboratories of Université de Lorraine in fluid mechanics and thermal science. The PhD candidate will also interact with the young Brazilian team GOTAS leads by assistant professor Arthur Oliveira. This team is located at Sao Carlos School of Engineering in the state of Sao Paulo (Brazil). The two teams host a lot of PhD thesis which are all in the field of heat and mass transfer.

REFERENCES

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[1] Titanium aluminium nitride