PhD course of National Interest in Technologies for Fundamental Research in Physics and Astrophysics

Annual report

Name and surname: Francesca Valentini
Cycle and a.a.: 39th academic year 2024/2025
Supervisor: Simone Mancin

- **Research activity carried out during the year**

During the second year of my PhD, I mainly continued working on the LoCoMoSa project, a European project in which DIAM-INFN is one of the leading partners. The project aims to develop an additive manufactured steam generator for thermal energy storage systems using molten salt as the storage medium. My focus this year was on the design and simulation of the steam generator, while also laying the groundwork for future experimental validation.

My research explored two possible design solutions. The first aimed at enabling operation at high temperature while maintaining low pressure steam production at stable nucleate boiling, thereby avoiding efficiency losses caused by transition or film boiling. The second solution focused on a topology-optimized finned surface to enhance heat transfer in the laminar regime.

For the first solution, I developed a custom Python model to predict heat transfer along a discretized tube. The model accounts for different boiling regimes and pressure levels. Based on this, I proposed an innovative design made of three-layer additive-manufactured tube: high-temperature molten salt flows inside, low-temperature water boils on the outer side, and an inert gas stream circulates through the wall in an intermediate micro-finned layer. The model was used to study how tube geometry, thermal resistance, and operating parameters affect the stability of nucleate boiling. Results showed that by tailoring the number of fins and regulating the inert gas flow rate, it is possible to ensure safe and efficient operation of the steam generator. This approach helps prevent both salt solidification and transition to film boiling, while highlighting the importance of tailored thermal resistance and geometric design.

The second solution focused on heat transfer–enhancing designs made by additive manufacturing, specifically forced-convection internal fins generated through topology optimization (TO). These geometries were created and analyzed in COMSOL Multiphysics, using its mathematical interface to set up multiphysics PDE problems. The optimized designs showed a clear improvement in laminar heat transfer, though with the drawback of an increased pressure drop.

On the experimental side, I designed a diathermic oil hydraulic loop to allow preliminary validation of the numerical models and testing of the topology-optimized prototypes. In parallel, the full-scale LoCoMoSa steam generator was drafted, with the understanding that it will be refined once experimental results from the small-scale loop are available.

This year presented several challenges. Validating numerical models of boiling proved particularly complex, as the phenomenon is highly variable and influenced by many factors, such as wall material and geometry, heating method, liquid composition, and flow conditions. Relying on literature data was often impossible, since most tests were conducted under different conditions. For this reason, a dedicated hydraulic loop was designed and is now under construction with the collaboration of the University of Padova. Another difficulty was the application of topology optimization to fluid dynamics. While TO is well established in structural design, the application to Navier–Stokes equations is not so straightforward and requires some level of approximation and some assumptions to be made. Therefore, to deepen my knowledge in this area, I am currently on a research stay at DTU Construct, one of the most renown groups in topology optimization.

- **List of attended courses and passed exams**
  - Python for numerical heat transfer modelling and building physics (3 CFU)
  - Life Cycle Assessment of Energy Systems: fundamentals and applications (3 CFU)
  - Generative Design for Smart Additive Manufacturing (3CFU)

- **List of attended conferences, workshops and schools, with mention of the presented talks**
  - Clima 2025 4-6 June 2025 (https://climaworldcongress.org/), coauthor in two poster presentations: “Analysis on passive cooling strategies for buildings as supporting elements for climate change” and “On the use of latent thermal energy storage for sustainable residential space cooling”.
  - Summer Heat Transfer Conference 8-10 July 2025 (https://event.asme.org/SHTC), author for a technical presentation titled: “Simulation And Optimization Of A Novel Three-layer Steam Generator For The Process Industry”.

- **List of published papers/proceedings**
  - Yazdanpanah, A.; Zin, V.; Valentini, F.; Pezzato, L.; Brunelli, K. Tribocorrosion and Stress Corrosion Cracking Risk Assessment of Novel Hybrid Stainless Steel–Carbon Fibre Tubes. *Corros. Mater. Degrad.* 2025, *6*, 22. https://doi.org/10.3390/cmd6020022
  - Valentina Candela, Marialaura Tocci, Gloria Ischia, Francesca Valentini, Antti Mutanen, Silvia Candela, Hanna Lehtonen, Janne Hongisto, Tatu Syvänen, Razvan Dima, Juha Ottelin, Maija Nyström, Massimo Pellizzari, Simone Mancin, Adriano Pepato, Piergiorgio Sonato, Understanding microstructure and properties evolution in additively manufactured CuCrZr alloy to obtain a high-performance material, Materials Characterization, Volume 222, 2025, 114811, ISSN 1044-5803, https://doi.org/10.1016/j.matchar.2025.114811.j.matchar.2025.114811
  - Divertor Tokamak Test facility project: status of design and implementation, Francesco Romanelli*, on behalf of DTT Contributors, D. Abate, E. Acampora, D. Agguiaro, R. Agnello,...., Valentini, F., et al, 2024

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- **Thesis title (even temporary): Multiphysics Design Strategies for Heat Transfer Enhancement Using Additive Manufacturing.**

Date, 15/09/2025 **Signature…**

Seen, the supervisor