Modeling melting/solidification processes in the Molten Salt Fast Reactor (MEP)

The most innovative aspects of the Molten Salt Fast Reactor (MSFR), one of the six Generation IV nuclear reactors, are that the fuel is dissolved in a liquid salt, and that it can be passively drained in an Emergency Safety Tank placed underneath the core, via the melting of plugs made of frozen salt (see Figure 1). Hence, new phenomena involving multiphase flows must be taken into account when simulating accidental transients in such a reactor: the freeze-plugs melting (does it happen sufficiently fast?), the potential salt solidification along the pipe during drainage (does it block the fluid flow?), or in the heat-exchanger channels during over-cooling accidents (does this lead to the formation of hot-spots?).

Modeling solidification/melting phenomena is numerically challenging due to the presence of a moving solid-liquid interface. The enthalpy-porosity method is often employed, because of its versatility and convenience: it is easy to adapt to complex geometries, and, in it, the solid-liquid interface is implicitly tracked, by smearing the phase-change region over several grid cells and implicitly accounting for the latent heat. In this way, conservation of mass, momentum, and energy is guaranteed, but computationally expensive local mesh refinements at each time step (required for an explicit tracking of the interface) are avoided.

Recent work in our section showed that the enthalpy-porosity method can be successfully applied to model the freeze-plug melting (see Figure 2). A second design of the plug, wedge-shaped and relying on the phenomenon of contact-melting, was also proposed (see Figure 3). With this project, we want to continue the investigation of phase-change processes inside the MSFR. The student will do so by first implementing an enthalpy-porosity method in an existent CFD code (written in Fortran), based on the Discontinuous Galerkin Finite Element Method for the spatial discretization of the governing equations. The second goal will be to investigate the possibility of extending the model to simulate the contact-melting mechanism.

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Figure 1: Schematic view of freeze-plug and draining pipe
Figure 2: simulation of freeze-plug melting
Figure 3: Wedge-shaped freeze plug
An Approach to Model the SEEDS Facility empirically Using Proper Orthogonal Decomposition (BEP)

The objective of this project is to develop a reduced model for the SEven rods bundle Experiments in Delft for SESAME (SEEDS) facility. This experiment aims at measuring the flow field in a 7-rods hexagonal rod bundle geometry (Figure 1) modelling the real fuel assembly of a Liquid Metal Fast Breeder Reactor (LMFBR), which is one of the designs for the next generation (Gen-IV) of nuclear reactors. The experiment is providing experimental evidence on the physics of large coherent vortices which develop in the flow among the rods, as they move along the setup without vanishing (hence coherent). These eddies have the potential of enhancing the heat transfer inside the core of a LMFBR. The student will first conduct literature review of the facility and the method of reduced order modelling. Then, operational data of the facility are collected and treated for noise and glitches. These data are used to develop a reduced order model in an empirical manner using the Proper Orthogonal Decomposition method with the use of Radial Basis Functions. The model is then validated and tested for accuracy and performance.

Figure 1: (Left) SEEDS experimental setup during measurements with Laser Doppler Anemometry; (Right) Hexagonal nuclear fuel assembly.

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Multigroup acceleration of radiation transport (MEP) Danny Lathouwers

The calculation of radiation fields is very expensive owing to various reasons: (i) great geometric detail may be required such as in fuel assemblies with many fuel pins present (ii) iterative methods used for radiation transport calculations suffer from slow convergence in the case of strong scatter and/or when scatter is highly anisotropic. The first problem is usually tackled by homogenizing the geometry such that less geometric detail is present. Unfortunately there appears no easy cure for the second problem. Multigroup methods for the angular variable are generally believed to be the cure for this problem. The basic principle of multigroup methods is that it is easy to remove high frequency components from the error but the low frequencies are persistent. By transferring the problem to a set of multiple coarser grids make it possible to remove all error components efficiently.

![Hierarchy of angular meshes on a sphere used for angular discretization combined with multigrid](image)

Although this has been investigated, they are not in widespread use for radiation transport yet. This is partially because the multigroup method is not directly compatible with the often-used angular discretization. In our group we have developed another angular approach, which is highly suited for multigroup. The goal of this project will be to investigate the construction of an efficient multigroup method for highly anisotropic scattering particles based on this new approach.

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Spectral ocean wave modeling (MEP) Danny Lathouwers

Spectral wave modeling is used in the field of ocean and coastal modeling. In this approach one recognizes that the sea surface elevation is composed of a superposition of harmonic wave components and the energy spectrum represents the energy over the frequencies and the wave direction. Important characteristics such as average wave height can be derived from this spectrum.

![Fig. Snapshot of wave height as function of location calculated by a spectral wave model (Adam et al, J. Comp Phys. 305, pp.521-538, 2016)](image)

Although this topic appears unrelated to nuclear reactor physics, the model describing this wave energy spectrum is very similar to that of (neutron) radiation transport. The numerical techniques used in nuclear can therefore be transferred almost directly to the ocean modeling field. In general it is fair to say that nuclear techniques are more advanced and the idea of this project is to apply such modern techniques to ocean modeling. The project will consist of two parts: (i) adapt a finite element radiation transport model to spectral wave modeling and (ii) study possible improvements necessary for obtaining high-resolution such as local adaptivity to capture local details without excessive computational power.

Collaboration with the CITG department is envisaged in this work.

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