Liquid metals as heat transfer fluid – experimental benchmark and instrumentation development

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1. Introduction

Concentrated solar power offers a solution to the common crossroads of renewable energy power plants: the non-equilibrium of electrical energy demand and its supply. By combining direct electrical energy generation and thermal energy storage, this electrical energy power plant concept appears to be the perfect solution for the energy-problem of those countries, which have abundant solar energy resources. Nevertheless, this electrical energy concept has not find its market breakthrough since the levelized cost of electricity (LCOE) still have to be reduced. However, the room for technical and technological innovations is enormous. This would eventually permit a considerable LCOE reduction. One of the possibilities is to augment the operational maximum temperature at the solar receiver in order to improve the global plant´s efficiency. This cannot be achieved with current heat transfer fluids (HTF), as for example, molten salts. Researchers at KIT [1] propose the use of liquid metals as a HTF, namely: sodium, since its material properties are very attractive for thermal-hydraulic purposes. And not only as a heat transfer media between solar receiver and the electrical energy power block, but also as the thermal energy storage fluid. In addition, new concepts related to the direct heat-to-electricity are also being developed at INR-KIT [2]. Regarding the safe use and operation with sodium, the perspectives are promising, since vast experiences can be transferred from the nuclear sector [3]. This is why at KIT, particularly at INR-KIT, the KASOLA (HTF: Na) and the DITEFA (HTF: GaInSn) experimental facilities with liquid metals are being built [4], in order to contribute to the nuclear-to-CSP liquid metal use, knowledge and know-how transfer.

2. KASOLA – backward facing step

The use of benchmark cases for computational fluid dynamics (CFD) code validation is one of the main reasons why computational simulations of physical phenomena have continuously improved and gained credibility along the years. One of the benchmark test cases for CFD code validation is the backward facing step. This benchmark case tests CFD codes against the separation of a flow in a sudden expansion of the duct as well as its reattachment. This sudden-expansion-geometry may also arise in the design of heat exchangers as for example, solar receivers. It is then necessary to study the influence of the buoyancy in the flow for the case where the reattachment zone of the backward facing step is heated. Considering the very particular thermal-hydraulic properties of liquid metals ($Pr \ll 1$), this buoyancy effect cannot be neglected. This experiment is currently being built within the Karlsruhe Sodium Laboratory (KASOLA) facility at INR-KIT. Besides the gained data (velocity-, temperature-profiles and turbulent heat fluxes), further operational experience and safety-related know-how with sodium is constantly being gained.

3. DITEFA

Safety and accident management are one of the most important aspects of every engineering project. In order to be able to successfully control this situation, all the underlying physical phenomena present in the process have to be understood. For example: the transition from forced to natural convection of the working fluid in an emergency shut down situation. In liquid metals, the comprehension – and most important: the prediction of this phenomena, imposes a major challenge due to their high thermal conductivity. This has a consequence the presence of anisotropic heat fluxes which are extremely complicated to predict. CFD offers the flexibility to analyze these kind of phenomena without the need of experimentation. Unfortunately, these codes still need experimental data for validation. To do so, experiments will be performed in the DIvertor TEst FAcility (DITEFA) at INR-KIT (Figure 1) besides the already mentioned experiments in KASOLA.

Figure 1: Test section of DITEFA with its 85 installed thermocouples prior to be pre-cleaned before filling.

4. Instrumentation technology development

In order to provide the scientific and industrial communities with high quality data, special care is being taken in the further development of measurement techniques and general instrumentation for liquid metals. Particularly, the optimization and miniaturization of a permanent magnet (PM) probe to simultaneously measure all velocity, temperature and turbulent heat fluxes is being developed at INR-KIT. This opens a new field for innovations for flow characterization instrumentation, as for example, high precision flow meters.

Figure 2: First prototype of the permanent magnetic probe.

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