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Editorial: Experimental and numerical studies on liquid metal cooled fast reactors

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Editorial on the Research Topic
Experimental and numerical studies on liquid metal cooled fast reactors

Liquid metal cooled fast reactors (LMFRs) use liquid metal as a coolant instead of water commonly used in commercial nuclear power plants. This allows the coolant to operate at a higher temperature and a lower pressure than current reactors, thus improving the efficiency and safety of the reactor system. They also use the fast neutron spectrum, which means that neutrons can cause fission without having to be slowed down first, as in current reactors. This allows liquid metal cooled fast reactors to use fissile materials and spent fuels from the current reactor to generate electricity. Due to their much higher power density, higher thermodynamic efficiency, and higher temperature, liquid metal cooled fast reactors have become more and more attractive among different countries for improving reactor designs, power outputs, and nuclear waste management (Alemberti et al., 2014; Ohshima and Kubo, 2016). Understanding physical phenomena in liquid metal cooled fast reactors is thus vital in increasing innovation for reactor design and operation optimization. To address the challenges related to liquid metal cooled fast reactors, the team of editors organizes the Research Topic "Experimental and Numerical Studies on Liquid Metal Cooled Fast Reactors" in the journal *Frontiers in Energy Research*. Finally, 16 articles are collected, covering different yet essential aspects of liquid metal cooled fast reactors, including neutronics, thermal hydraulics and severe accident analysis, and nuclear fuels/materials performance. Both experimental and computational approaches have been collected to significantly contribute to advances in liquid metal cooled fast reactors.

There are eleven original research articles about nuclear thermal hydraulics and severe accident analysis for liquid metal cooled fast reactors. Low-Prandtl number liquid metal is a promising candidate coolant for various designs of advanced nuclear systems such as liquid metal–cooled fast reactors and accelerator-driven sub-critical systems (ADS) due to their high thermal conductivity. Huang et al. proposed a turbulent Prandtl number model for the Reynolds-averaged Navier–Stokes approach on the modeling of turbulent heat transfer of low-Prandtl number liquid metal, which is validated with the LES/DNS results available. To increase the accuracy of low Prandtl flow prediction in a bare 19-rod bundle, Li et al. used a four-equation model, consisting of a two-equation turbulence model and a two-equation heat transfer model, in OpenFOAM. Its effectiveness and feasibility are validated through the comparison with the empirical correlations. Yi et al. develop a methodology to predict CEFR core thermal hydraulic parameters based on the adaptive radial basis function neural network. The proposed RBF neural network model can provide real-time forecasting in a short time under unstable flow conditions. Bubble columns represent an extreme case of gas-liquid two-phase flow. Wang et al. develop drift-flux correlation for vertical forward bubble column-type gas-liquid lead-bismuth two-phase flow. The statistical analysis results show that the new correlation gives the best prediction for gas-LBE two-phase flow in the void fraction range of 0. 018–0.313. In order to research and compare the effect of wire-wrapped on the sub-channels and inner flow field of the fast reactor annular fuel assembly, Guo et al. investigate the thermal-hydraulic characteristics in inner and outer wire-wrapped for a fast reactor annular fuel assembly, providing a reference for the optimization design of the fuel assembly. Duan and Huang. perform an unsteady RANS study of thermal striping in a T-junction with sodium streams mixing at different temperatures. To better understand the mechanisms of stainless-steel corrosion behavior in the LBE flow, Chen and Wan. numerically investigate the iron mass transfer phenomenon on roughened walls under various LBE pipe flow conditions. Liu et al. numerically study the heat transfer characteristics of a liquid lead–bismuth eutectic in a D-type channel, and the simulation results lay a good foundation for the development of printed circuit heat exchanger (PCHE) with an LBE as the working fluid.

When a sodium leakage accident occurs in the sodium-cooled fast reactor, the leaked sodium reacts violently with the air in the form of droplets, resulting in a sodium spray fire. Zou et al. proposed a semi-empirical model of sodium spray droplet size distribution based on the theory of the maximum entropy principle, which shows good agreement with the experimental data. Under postulated severe accidents, the fuel rod of LFR may be damaged, which would cause the release of fission gas, and the migration of fission gas bubbles in the reactor molten pool will affect the release and absorption of radioactive substances in the reactor. Mai et al. perform a three-dimensional numerical study on the release and migration behavior of fission gas in a molten LBE pool based on the VOF method. Fuel-coolant interaction (FCI) has a pivotal role in the development of core disruptive accidents in a sodium-cooled fast reactor. Wang et al. present an improved multiphase smoothed particle hydrodynamics (SPH) algorithm corrected with kernel gradient correction (KGC) technique is presented for multiphase flow with large density ratio and complex interfacial behaviors.

One paper discusses the power optimization methodology of the natural circulation lead-bismuth cooled fast reactor SPALLER-100 design, considering different constraint parameters such as neutronics, materials, and thermal-hydraulics. Xiao et al. develop a platform to calculate the maximum neutronic power produced by the reactor at different core heights using Latin hypercube sampling and the Kriging proxy model. The cooling power of the reactor at different core heights is calculated by considering its natural circulation capacity. Finally, a design scheme that meets the requirements of neutronic and thermal-hydraulic assessments while producing maximum power is obtained.

Three articles focus on reactor fuels/materials performance, trying to overcome the challenges from the materials aspect of liquid metal cooled fast reactors. Mun et al. successfully modify the fuel performance code FRAPCON-4.0 for normal operation of light water reactors (LWRs) to evaluate the thermal and mechanical performance of the highest linear power rod of MicroURANUS, an innovative ultra-long-life lead-bismuth eutectic (LBE)-cooled fast reactor. Cai et al. successfully model and simulate an annular uranium-plutonium mixed oxide (MOX) fuel operating in a liquid lead/lead-bismuth cooled fast reactor to predict its behavior under transient and steady-state operation based on COMSOL Multiphysics. Oxide Dispersion Strengthened (ODS) steels with nano-scale oxides have become one of the potential candidate materials used in advanced nuclear reactor systems. Yun et al. irradiate a novel MX-ODS steel with uniformly distributed Y_2O_3 nano-precipitates and extremely low carbon content under 3 MeV Fe ions at 550°C and peak damage up to 70 dpa. The MX-ODS steel exhibits good irradiation tolerance.

Finally, this Research Topic also includes one review article to overview state-of-the-art research approaches on liquid metal cooled fast reactors. A specific type of sloshing motion may occur in the molten pool during core disruptive accidents (CDAs) of sodium-cooled fast reactors due to local neutronic power excursion or pressure developments, thereby significantly influencing recriticality. Recognizing the importance of improving the evaluation of CDAs of SFRs, Xu and Cheng contribute a comprehensive review of experimental and numerical investigations into molten-pool sloshing motion for severe accident analysis of sodium-cooled fast reactors, which is valuable not only for improving and verifying SFR safety analysis codes but also for providing reference data for studies of sloshing motion in other fields of engineering.

After almost 1 year's revisions and updates, this Research Topic finally selected those 16 articles and published them in the journal *Frontiers in Energy Research*. The collection shows the ongoing research on liquid metal cooled fast reactors from different perspectives and also allows us to exhibit the high-quality work to the public. More high-quality topics and articles are welcomed at this open platform in the future. All the editors are open to further information and communications.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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