Nuclear Engineering and Design 369 (2020) 110826

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Preliminary design and analysis of Liquid Fuel Molten Salt Reactor using multi-physics code GeN-Foam

Muhammad Ramzy Altahhan[a], Sandesh Bhaskar[a], Devshibhai Ziyad[a], Paolo Balestra[a], Carlo Fiorina[b], Jason Hou[a], Nicholas Smith[c], Maria Avramova[a]

[a] Department of Nuclear Engineering, North Carolina State University, Raleigh, NC 27695, USA
[b] Department of Physics, Ecole Polytechnique Fédérale de Lausanne, Lausanne 1015, Switzerland
[c] Southern Company, Birmingham, AL 35203, USA

ARTICLE INFO

Keywords:
Molten Salt Reactor
CFD
Multiphysics
GeN-Foam
OpenFOAM
Nuclear energy
Liquid fuel

ABSTRACT

In this study, a hypothetical fast spectrum Liquid Fuel Molten Salt Reactor (LFMSR) core is modeled using the multiphysics C++ code GeN-Foam (General Nuclear Foam). GeN-Foam is based on OpenFOAM, a C++ open-source library for solution of continuum mechanics problems. The code utilizes a unified fine/coarse mesh approach, modeling different physics such as neutron kinetics, thermal-hydraulics based on porous fluid equations, and structural thermal-mechanics. A steady state analysis of a simplified two-dimensional (2D) LFMSR model has been performed assuming rotational symmetry to cross verify the code with the commercial ANSYS Computational Fluid Dynamics (CFD) code Fluent. The calculations showed very good agreement between the two codes allowing progression to a three-dimensional (3D) model simulation. A coupled neutron kinetics and CFD steady state analysis of a right-cylindrical 3D LFMSR core has been performed modeling one quarter of the core while using symmetry boundaries to reduce the computational time. Mixed uranium and plutonium chloride fuel has been selected in this preliminary study. Both 2D and 3D simulations showed appearance of recirculation zones within the right-cylinder core. These zones can be a challenge for LFMSR control and materials. A new hyperboloid design is proposed to remove recirculation zones, which is based on eight symmetrical loops. An Unprotected Loss of Flow accident (ULOF), in which the pump head is instantaneously reduced to zero, has been selected to demonstrate the safety characteristics of the reactor in one of the most challenging possible situations for LFMSR. The obtained results (e.g., reduced total precursors concentration at the core inlet and reduction of the core nominal power following the transient) confirm that GeN-Foam is capable of performing coupled LFMSR transient analysis and can be used for design analysis and optimization. Although the current design needs further assessment and development, it shows encouraging performance under ULOF conditions paving the way to the next step in the optimization process.

1. Introduction

The Liquid Fuel Molten Salt Reactor (LFMSR) is recognized as one of the Generation IV reference reactors due to its inherent safety and expected good performance. This includes low pressure operation, high boiling temperature, and for chloride-based salt reactors no hydrogen is produced during normal operations or an accident (Dolan, 2017). It is the only liquid fuel reactor among the Generation IV nuclear reactors concepts and the US Nuclear Regulatory Commission (NRC) has defined near- and long-term implementation action plans for new reactors concepts that include Molten Salt Reactors (MSRs) (Betzlera et al., 2019).

The LFMSRs use liquid molten salt as both coolant and fuel solvent; hence, the conventionally used methods to analyze the reactor characteristics cannot be applied to LFMSRs. It is necessary to develop dedicated design and analysis tools where Computational Fluid Dynamics (CFD) calculations are coupled with a neutron kinetics solver.

Lately, more research funding is going towards LFMSRs because of their significant safety and economic advantages over solid fueled designs. From a safety point of view, there is no risk of fuel melting as the fuel is already in a molten state. Furthermore, LFMSRs can operate at atmospheric pressure, and there is no risk of hydrogen accident scenarios. Economically, the overall cycle efficiency is on the order of 44% (which is a significant increase over the typical 33% Light Water Reactor (LWR) Rankine cycle efficiency); and there is no necessity of fuel pellets and rods manufacturing. Moreover, online refueling ensures that the reactor does not have to be shut down, making it different from most of the conventional reactors (Dolan, 2017). LFMSRs can also be designed as breeder reactors, as can be seen in the paper-design of the Molten Salt Breeder Reactor (MSBR) in the 1970s (Haubenreich and Engel, 1970).

LFMSRs are characterized by having the fuel flowing out of the core

https://doi.org/10.1016/j.nucengdes.2020.110826
Received 30 January 2020; Received in revised form 17 August 2020; Accepted 24 August 2020
Available online 14 September 2020
0029-5493/