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Steady thermal hydraulic analysis for a molten salt reactor

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Abstract The Molten Salt Reactor (MSR) can meet the demand of transmutation and breeding. In this study, theoretical calculation of steady thermal hydraulic characteristics of a graphite-moderated channel type MSR is conducted. The DRAGON code is adopted to calculate the axial and radial power factor firstly. The flow and heat transfer model in the fuel salt and graphite are developed on basis of the fundamental mass, momentum and energy equations. The results show the detailed flow distribution in the core, and the temperature profiles of the fuel salt, inner and outer wall in the nine typical elements along the axial flow direction are also obtained.

Key words Molten salt reactor, Thermal hydraulics, Steady characteristics, Numerical simulation

CLC number TL426

1 Introduction

The concept of Molten Salt Reactor (MSR) was first proposed by Bettis and Briant of Oak Ridge National Laboratory in late 1940s to develop a nuclear engine for a military jet aircraft. In 1954, the 2.5 MW Aircraft Reactor Experiment (ARE) was carried out successfully, and then the Molten Salt Reactor Experiment (MSRE) followed at 8MW for 13 000 equivalent full-power hours from 1956 to 1968[1]. The two prototype reactors established basic technologies for MSR, which have advantages of excellent neutron economy, inherent safety features and continuous or in-batch reprocessing.

The advantages make the MSR attractive to the Generation IV International Forum (GIF), and have drawn attention of many researchers again. In the European Union, the reduction of long-life wastes and transmutation of the minor actinides (MAs) are being experimented under the project of the molten salt reactor technology (MOST)[2]. In Russia, the molten salt advanced reactor transmuter (MOSART) has been developed to burn Pu and MAs[3,4]. In addition, the SIMMER code[5,6], which was originally developed for fast reactor safety analysis by JNC-FZK-CEA, is being extended for neutronics and thermo-hydraulics analysis of the MSR. However, the molten fuel salt in a high temperature MSR is not only coolant, but also nuclear heat source. This is very different from the traditional reactors with solid fuels. Therefore, there are few reactor design theories and safety analysis methods which could be referenced for the MSR.

In this study, a theoretical investigation on the steady thermal hydraulic characteristics of a graphite-moderated channel type MSR is conducted. The DRAGON code is adopted to compute the axial and radial power factor firstly. Based on the calculation, the flow distribution in the core, and the temperature profiles of the fuel salt and inner/outer wall in the nine representative elements are simulated by numerical method.

2 System descriptions

A schematic diagram of the MSR is shown in Fig.1[7]. The ternary system of LiF-NaF-BeF_2,

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functioning as the reactor fuel solvent, coolant and moderator, has fissile and fertile fission products in the primary loop, which works at 873.15 K at the inlet and at 1073.15 K at the core exit. The high temperature fuel salt transfers nuclear heat to the secondary salt $NaBF_4$-NaF of the primary heat exchanger. Then, the secondary salt transfers the heat to helium for electricity generation or hydrogen production.

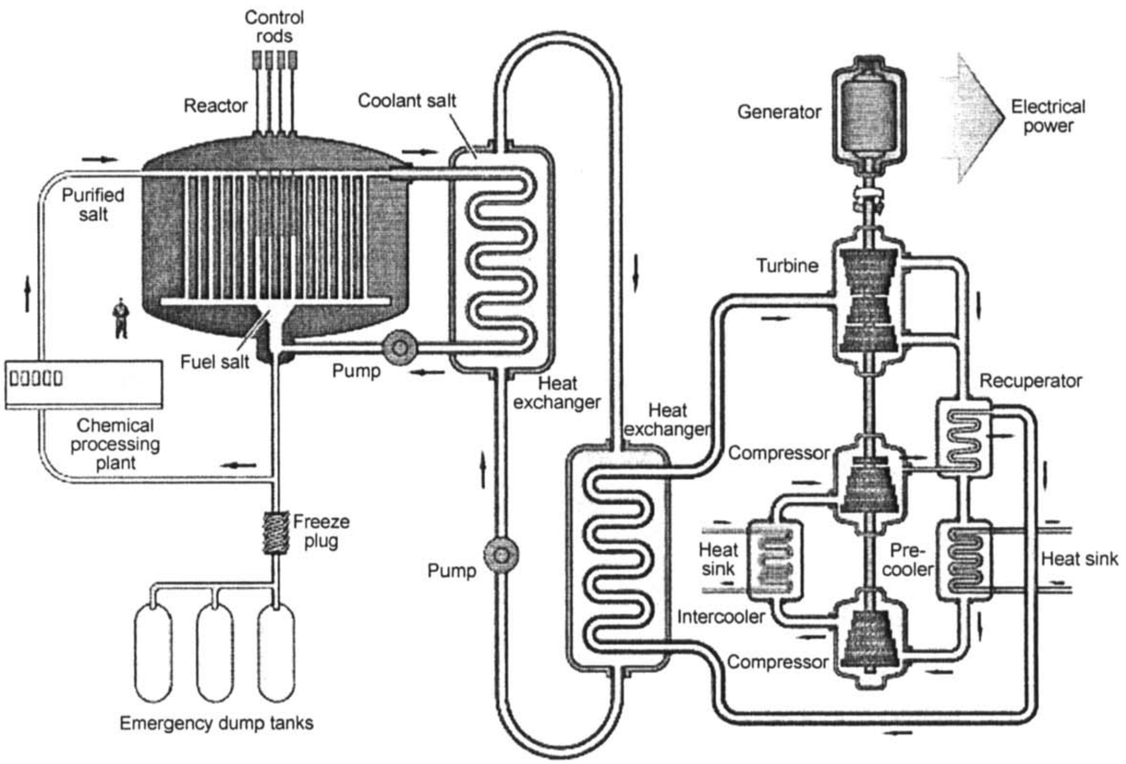

Fig.1 Schematic diagram of the Molten Salt Reactor system.

The designed MSR core consists of 199 one-dimensional parallel coolant channels in a form of hexagonal graphite blocks, each with a central fuel channel (Fig. 2). The active core height is 6.5 m, and the radius is 3.6 m. Fig. 3 shows the schematic diagram of a single graphite element, in which the channel diameter is 0.2 m and the distance between the opposite sides of the hexagonal graphite is 0.4 m.

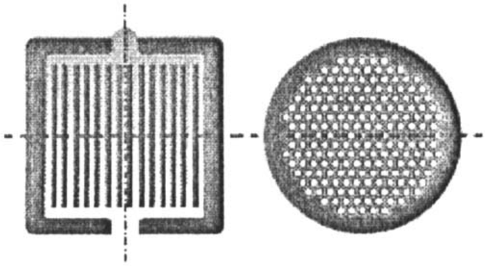

Fig.2 The axial and radial cut of the MSR core represented by 199 hexagonal graphite channels.

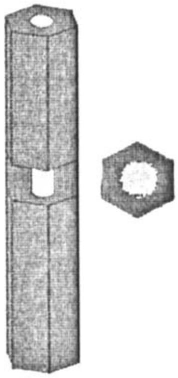

Fig.3 Schematic diagram of a graphite element.

3 Theoretical model

3.1 Calculation of power factor

The 199 graphite elements are divided into 9 groups (Table 1) according to the distance between the element and the core center, and every element is parted to 13 same control volumes in axial direction.