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基于 Newton-Krylov 方法联立求解核能供热的碘硫循环制氢系统

摘要

高温气冷堆（HTR）是先进的第四代核电堆型之一，利用高温堆产生的高温氦气，通过热化学循环来生产氢气，被认为是能充分发挥高温气冷堆特性优势的下一步研究方向，其中碘硫（IS）循环被认为是能实现工业大规模制氢的先进工艺之一。传统方法或者程序在求解高温堆制氢耦合系统时，往往采用 Picard 迭代，将各个子系统甚至子物理场解耦并分别求解，再传递边界条件进行耦合，该方法只有线性收敛率并且稳定性较差。采用 Newton-Krylov（NK）方法直接联立求解这样的非线性耦合系统具有计算效率和稳定性的优势。本研究运用 NK 方法求解了基于清华大学 INET 制氢流程的简化 IS 循环制氢回路系统，分别求得了稳态下系统内部的物质组成分布，和堆芯出口氦气参数变化引起的制氢回路的动态响应过程，及其对堆芯的温度影响，相关计算结果对于进一步研究高温气冷堆氢电热联供系统的全耦合联立求解具有借鉴意义。

关键词

高温气冷堆；碘硫循环；核能制氢；Newton-Krylov 方法

Abstract

High-temperature gas-cooled reactor (HTR) is one of the advanced fourth-generation nuclear power reactor types. Using the high-temperature helium generated from HTR to produce hydrogen through thermochemical cycles is considered to be the next research direction that can fully utilize the advantages of the characteristics of high-temperature gas-cooled reactors. The iodine-sulfur (IS) cycle is considered to be one of the advanced processes that can realize industrial large-scale hydrogen production. The traditional method or program for solving the high-temperature reactor hydrogen production coupled system often adopts Picard iteration, decoupling each subsystem or sub-physical field and solving them separately, and then transferring the boundary conditions for coupling, which has only linear convergence rate and poor stability. Using the Newton-Krylov (NK) method to directly solve such nonlinear coupled systems has the advantages of computational efficiency and stability. In this study, a simplified IS cycle hydrogen loop system based on the INET hydrogen production process at Tsinghua University is solved by the NK method. The composition distribution of the system in the steady state and the dynamic response of the hydrogen loop due to the change of the helium parameter at the core outlet are obtained, as well as its effect on the temperature of the core. The numerical results of the calculations are of great significance for the further study of the fully coupled solution of the hydrogen-electricity-heat supply system of high-temperature gas-cooled reactor.

Keywords

High-temperature gas-cooled reactors; Iodine-sulfur cycle; Nuclear energy for Hydrogen production; Newton-Krylov method

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