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Thermodynamic Modeling and Optimal Design of High-Temperature Gas-Cooled Reactor Waste Heat Utilization Systems

With the advancement of nuclear energy technologies, high-temperature gas-cooled reactors (HTGRs) have emerged as a promising next-generation nuclear system due to their high safety, high-temperature output, and potential for high thermal efficiency. During electricity generation, HTGRs produce a substantial amount of low- and medium-to-high-grade waste heat. If not effectively utilized, this heat results in energy loss and reduces overall system efficiency. Waste heat utilization systems (WHUS) can recover reactor heat for district heating, process steam, or thermochemical hydrogen production, significantly enhancing energy efficiency and reducing environmental impact.

The thermodynamic performance of the waste heat utilization system directly affects the overall economy and energy efficiency of HTGRs. Therefore, establishing a scientifically sound thermodynamic model is fundamental for system design and optimization. The model should account for reactor outlet temperature, heat exchanger performance, working fluid characteristics, and heat load fluctuations to accurately predict energy conversion efficiency and heat loss distribution. Optimization design aims to determine the best combination of system parameters, heat exchanger dimensions, and operational strategies under safety and operational constraints to maximize energy recovery and economic benefits.

In practice, multi-objective optimization methods are often applied to resolve trade-offs between efficiency and investment cost, or between heat recovery rate and equipment load. By combining numerical simulation with optimization algorithms, different design schemes can be evaluated, and optimal configurations can be identified. This approach enhances the scientific and practical feasibility of system design and provides guidance for engineering applications of HTGR waste heat utilization.

This study aims to conduct thermodynamic modeling and optimal design of HTGR waste heat utilization systems, including system modeling, energy flow analysis, heat exchanger optimization, and multi-objective performance optimization. The results are expected to provide theoretical support and design guidance for efficient waste heat recovery in HTGRs, contributing to improved system efficiency and sustainable development of nuclear energy.