Abstract

This study addresses the challenge of clean energy production for industrial applications, emphasizing the role of nuclear power in meeting economic, security, and environmental sustainability goals. A thermodynamic analysis was conducted on a high-temperature nuclear reactor integrated with an *s*CO2 Brayton cycle and a reboiler. The system performance was assessed by varying turbine inlet temperature and compressor pressure ratio. Results indicate that higher reboiler CO2 inlet temperatures significantly enhance power cycle efficiency, with an optimal threshold at approximately 740°C. Beyond this threshold, efficiency improvements diminish. Enhancing turbine efficiency substantially improves thermal efficiency, with the thermal efficiency increasing from approximately 25% to 45% as turbine efficiency improves from 50% to 100%. Conversely, compressor efficiency has a less pronounced impact, with thermal efficiency increasing from 21% to 25% as compressor efficiency improves from 70% to 100%. Net power output increases with higher turbine inlet temperatures and compressor pressure ratios, peaking at 725°C and a pressure ratio of 4.0, resulting in a maximum power output of approximately 3.35 MW. These insights are vital for optimizing the design and operation of nuclear-driven thermal power systems to maximize efficiency and net power output.

Conclusion:

The integration of a reboiler into a nuclear-driven *s*CO2 Brayton cycle has significantly enhanced power cycle efficiency and met the heat demand for industrial processes. Through extensive thermodynamic analysis, this study explored the effects of turbine and compressor efficiencies on the thermal performance of the cycle, focusing on variations in reboiler CO2 inlet temperature, turbine power, power cycle efficiency, and net power with respect to turbine inlet temperature and compressor pressure ratio.

The main findings indicate that optimal power cycle efficiency is achieved at higher reboiler CO2 inlet temperatures, with substantial efficiency gains observed up to approximately 740°C, beyond which improvements diminish. The balance between reboiler CO2 inlet temperature, turbine inlet temperature, and compressor pressure ratio is critical for optimizing the system's performance. Turbine efficiency improvements from 50% to 100% resulted in thermal efficiency increases from 25% to 45%, while compressor efficiency improvements from 70% to 100% showed a smaller increase in thermal efficiency from 21% to 25%. Net power output peaked at 3.35 MW with a turbine inlet temperature of 725°C and a compressor pressure ratio of 4.0.

Future research should focus on incorporating these findings into dynamic models for real-time optimization and control of power generation systems. Further investigation into the combined optimization of turbine and compressor efficiencies, particularly potential non-linearities and interactions, could provide deeper insights. Understanding the mechanisms influencing these efficiencies will lead to more effective strategies for enhancing overall thermal efficiency in nuclear-driven *s*CO2 Brayton cycles.

This research provides a valuable framework for designing more efficient thermal power systems, with practical applications in optimizing the design and operation of nuclear-driven thermal power plants. It aligns with the goals of projects like "NC2I-R" and "Gemini+" for practical deployment in industrial applications, potentially contributing to cleaner and more efficient energy production.