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HIGH TEMPERATURE NUCLEAR COGENERATION UTILIZING SUPERCRITICAL CO_2 FOR ENHANCED THERMAL EFFICIENCY

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ABSTRACT

This research addresses the challenges of clean energy production for industrial applications and highlights the role of nuclear power in achieving economic, safety and environmental sustainability goals. A thermodynamic analysis of a high-temperature nuclear reactor integrating sCO_2 Brayton cycle and reboiler was carried out. System performance was evaluated by varying turbine inlet temperature and compressor pressure ratio. The results show that higher reboiler CO_2 inlet temperature significantly improves the power cycle efficiency up to the optimal threshold of 740°C, beyond which the efficiency improvements diminish. However, increasing turbine efficiency can significantly increase thermal efficiency, raising it from around 25% to 45%. The effect of compressor efficiency is less pronounced, with thermal efficiency increasing from 21% to 25%. The net power output increases with the turbine inlet temperature and compressor pressure ratio, with the peak temperature of 725°C and pressure ratio of 4.0, with the maximum power output of approximately 3.35MW. These insights are critical to optimize the design and operation of nuclear-driven thermal power systems to maximize efficiency and net power output.

INTRODUCTION

Fossil fuel supplies are running low, global energy demand is rising quickly, and concerns about climate change are gaining traction. Fossil fuel combustion releases greenhouse gases, which are the primary driver of global climate change and are severely detrimental to the environment [1]. To meet these global energy and environmental concerns, we must improve our industry's energy efficiency [2]. As a result, finding alternative energy sources is critical in addressing this urgent global crisis. Researchers are looking into numerous feasible energy generation methods, including solar power [3], nuclear power [4], geothermal energy, flue gas from biogas combustion, and waste heat [5]. Using clean energy, lowering pollutant emissions, and improving energy conversion efficiency are critical measures for dealing with the rising demand for fossil fuels and serious environmental pollution [6]. The supercritical carbon dioxide (sCO_2) offers an environmentally benign, non-toxic, cost-effective inert working fluid [7]. This cycle is more efficient than typical power cycles, especially when combined with medium- to high-temperature heat sources such as waste heat, solar energy, and nuclear energy. Nuclear energy has grown quickly in recent years, owing to its environmental friendliness, cost-effectiveness, and reliability. With the development of IV generation nuclear reactors, the future of nuclear electricity appears bright [8].

Europe is prioritizing the production of clean energy, which is becoming more and more acknowledged as a worldwide imperative. Due to its comparatively easy solution, electricity generation has received the most efforts to date. Electricity, however, only makes up 18% of the total energy used. Nearly all other industries, including transportation and heating, depend on fossil fuels like coal, oil, and natural gas, which are significant contributors to high emissions [9]. Residence and industrial sectors in Europe utilize 50% of their energy to heat and cool, with electricity making up 24% of this total. The majority of the heat produced in this industry is produced via combustion. Therefore, despite the public's frequent disregard, this issue must be given top priority in any effective European energy policy. Such a policy is projected to have huge socio-economic and political benefits [10]. The goal of the GEMINI+ project, carried out by the European Nuclear Cogeneration Industry Initiative, is to further the industrial demonstration of high-temperature gas-cooled reactor (HTGR) power units for cogeneration [11].

A simpler, compact, and more effective substitute for the superheated steam cycle is the sCO_2 recompression cycle. In comparison to helium Brayton cycle, it is substantially simpler. The sCO_2 recompression cycle's thermal efficiency reaches 46% at 550°C, which is equivalent to the helium Brayton cycle's efficiency, which is only possible at 800°C [12]. Energy conversion systems that maintain their core power and temperature are essential for meeting power demands. Dynamic power cycle systems are popular because of their high thermal efficiency and power output requirements. The Rankine cycle's

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inefficiency and lack of compactness make it unsuitable for core exit temperatures as high as 700°C, thus the Brayton cycle system was selected as a result. The sCO_2 Brayton cycle is promising due to its high thermal efficiency, compact design with turbine inlet temperatures of 500°C to 700°C, and reduced water consumption [13].

Fossil fuels are primarily used to meet the 26% of industrial heat demand in the EU that requires temperatures above 400°C [14] With over 50% of industrial process heat being consumed, the steel, mining, and food and drink sectors in the UK are the most energy-intensive [15]. In the UK, 14% of CO_2 emissions come from industrial heating applications. Although the use of nuclear energy to process heat is presently limited internationally, the high-temperature heat generated by nuclear power plants has the potential to eradicate these emissions [16]. The energy and material resources needed for industrial operations are currently a major concern in Europe. Considering incorporating small modular reactors (SMRs), [17] into regions with factories in light of their benefits and advancements. Direct or indirect nuclear reactors with core exit temperatures higher than 500°C are ideally suited for the sCO_2 recompression cycle. In addition, compared to helium Brayton cycles or Rankine steam cycle, it may have lower capital costs [18].

Details of the 27 EU nations' energy consumption in 2005 and 2009 are compiled in the European Commission study [19]. It is anticipated that the industry has utilize 5,349 PJ of heat in 2005 and 4,434 PJ in 2009. Figure 1 presents the projected useful heat demand in the industrial sector. Most requirements can be satisfied by high-temperature gas-cooled reactors. High-temperature gas-cooled reactor technology has reached a high degree of technological preparedness thanks to development programs in the US, UK, and Germany as well as research and development efforts in Europe, China, Japan, South Korea, and other nations [20]. Steam at about 550°C is currently the main source of process heat. Nonetheless, there is a sizable and growing market for bulk hydrogen, with much room for expansion. This article focuses on the GEMINI+ study, which has drawn interest from several developed nations, that examines the use of process heat from the nuclear combined heat and power sCO_2 Brayton cycle in a variety of industrial applications.

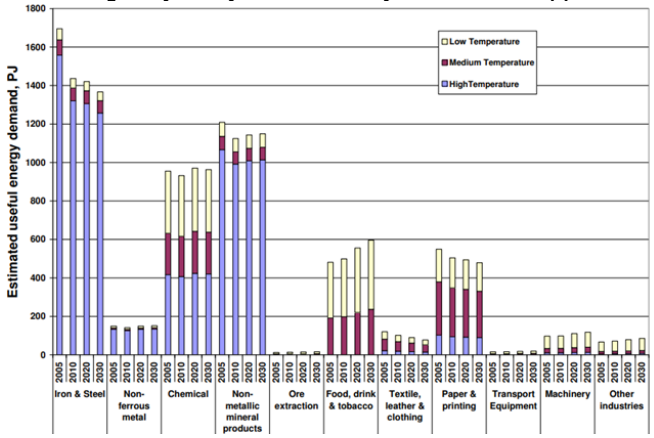

Figure 1: Estimated useful heat demand in the European Industry.

SCO₂ AS WORKING FLUID

Compared to existing steam-based power cycles, supercritical carbon dioxide (sCO_2) power cycle offers lower capital costs and greater thermal efficiency. Due to its unique properties, there is a lot of interest in using sCO_2 for power generation [21]. At the critical point, carbon dioxide achieves its critical temperature of 304.12 K and its critical pressure of 7.3773 MPa as shown in Figure 2. It is inexpensive with abundant availability, non-toxic, non-corrosive, non-flammable, and non-explosive, it only costs 1/10 of helium. Recycling is therefore not required, additionally it is compatible with standard materials and poses no environmental harm.

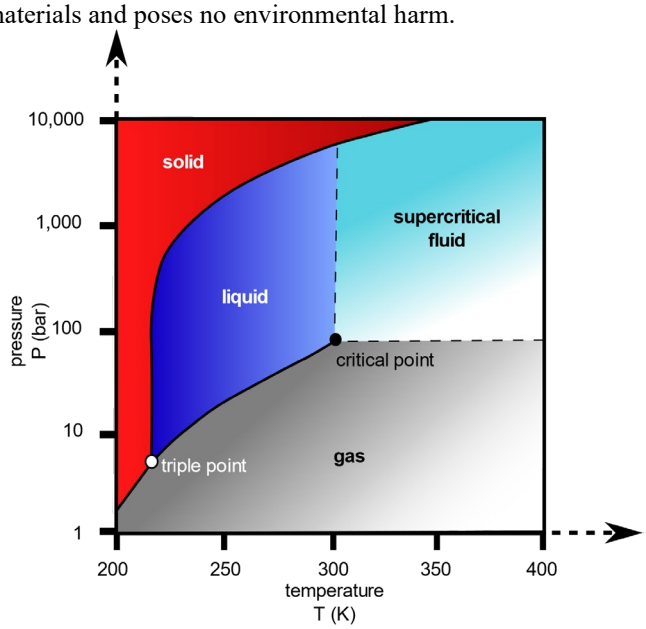

Figure 2: Carbon dioxide pressure-temperature phase diagram.

Carbon dioxide offers the advantages of a low critical point and a high critical density when compared to other working fluids utilized in the supercritical Brayton cycle. The physical properties of CO_2 are detailed in Table 1.

Table 1: Properties of selected working fluids for the supercritical Brayton cycle.

Fluids	CO_2	H_2O	He	Air
Molecular weight	44.01	18.015	4.0026	28.965
Critical density/kg.m−3	467.6	322	72.567	342.68
Critical temperature/K	304.13	647.1	5.1953	132.53
Critical pressure/MPa	7.3773	22.064	0.2276	3.786

SYSTEM DESCRIPTION

A nuclear cogeneration system combined with the sCO_2 Brayton cycle to produce power and heat efficiently is shown schematically in Figure 3. The system consists of several key components and processes.

The nuclear reactor operates at a thermal power output of 180 MWth and employs helium (He) as its primary coolant. Before leaving the reactor, the coolant is heated to 750°C at the pressure of 6 MPa. It then transfers heat via a heat exchanger to

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a supercritical carbon dioxide working fluid, which is then cooled to 325°C. After heat exchange, the pump returns the cooled helium gas to the reactor for reheating.

The sCO_2 Brayton cycle begins with sCO_2 being compressed to boost the pressure for the heat exchange process. The working fluid is first compressed in the compressor at state 1 and preheated in a recuperator (state 2) by absorbing residual heat from the turbine exhaust (state 5), enhancing the cycle efficiency. The preheated sCO_2 is further heated in the heat exchanger (state 3) before expanding through a turbine (state 4), where it drives a generator to produce electricity, dedicated to meeting the internal electricity needs for the nuclear plant. After expansion, the sCO_2 exhaust (state 5) undergoes heat recovery in the recuperator, transferring residual thermal energy to the incoming fluid, before being cooled in a cooler (state 6) to complete the cycle. Furthermore, the waste heat from the sCO_2 cycle generates process steam at 540°C in the reboiler, with a mass flow rate of 64 kg/s and a pressure of 13.8 MPa. This steam is sent to end-user facilities for usage in a variety of industrial applications. Condensed steam at 200°C is returned from the end user site to the reboiler and reheated.

The entire system is designed to maximize the reactor's heat use, with the sCO_2 Brayton cycle serving as the primary source of power generation and heat recovery. The reboiler efficiently converts excess heat energy into industrial steam, boosting the overall energy efficiency of the system. In summary, this integrated system includes the reactor, the sCO_2 Brayton cycle, and the reboiler to ensure optimal energy conversion and usage, hence increasing the overall system efficiency.

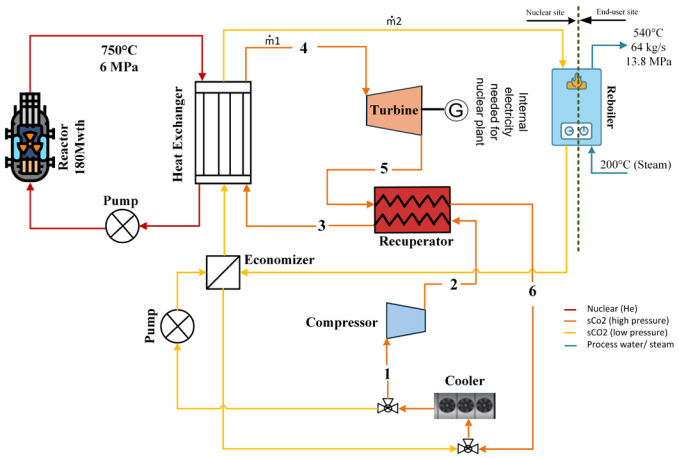

Figure 3: Schematic layout of nuclear cogeneration with sCO_2 Brayton cycle.

The temperature-entropy relationship is shown in the T-S diagram in Figure 4. State points and saturation domes are used to graphically depict phase boundaries. Understanding the cycle's thermodynamic behavior and identifying efficiency enhancements.

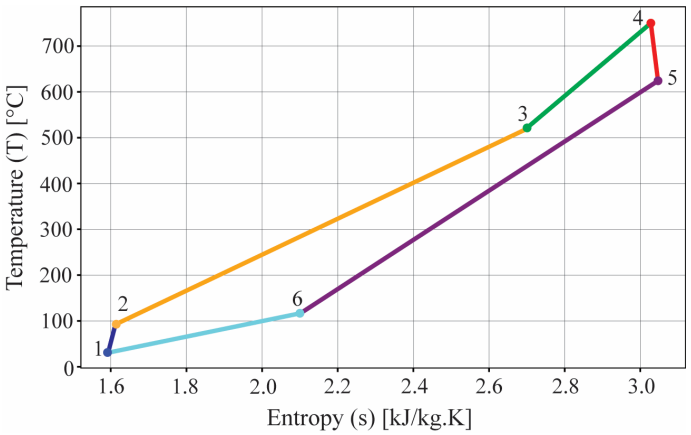

Figure 4: Temperature-entropy diagram cascading nuclear cogeneration with sCO_2 cycle.

THERMODYNAMIC MODELLING

The thermodynamic cycle used in this study has several components, including a reactor, compressor, turbine, reboiler, heat exchanger, economizer, and recuperator. Modeling entails estimating the enthalpy, temperature, and entropy at various points during the cycle. Calculations employ the CoolProp library to determine the thermodynamic parameters of the working fluids (CO_2 and He). A full description of each loop component's mathematical modeling is provided below and input parameters for cycle are presented in Table2.

Table 2: Input parameters for cycle.

Compressor efficiency	80%
Pump efficiency	80%
Reboiler efficiency	95%
Heater efficiency	90%
Temp. difference between steam and CO_2	25°C
Temp. difference between He and CO_2	10°C
Pressure ratio	2.5
Heat exchanger inlet temp. (hot)	750°C
Heat exchanger outlet temp. (hot)	325°C

Reactor

The reactor generates thermal power for the cycle. The enthalpy change across the reactor is expressed as:

$$Q_{Re} = m_{Re} * \left(h_{i,Re} - h_{o,Re}\right) \quad (1)$$

The mass flow rate of helium in the reactor is computed using the provided thermal power and enthalpy change:

$$m_{Re} = \frac{Q_{Re}}{h_{i,Re} - h_{o,Re}} \quad (2)$$

Compressor

The compressor raises the pressure of the CO_2. The actual enthalpy at the outlet is calculated using the compressor's isentropic efficiency:

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$$h_{o,Comp} = h_{i,Comp} + \frac{h_{o,Comp,is} - h_{i,Comp}}{\eta_{Comp}} \quad (3)$$

The isentropic outlet enthalpy of a compressor is calculated using the inlet entropy and outlet pressure:

$$h_{o,Comp,is} = f\left(T_{o,Comp,is}, s_{i,Comp}, P_{o,Comp}\right) \quad (4)$$

The actual output temperature and entropy are then computed as follows:

$$T_{o,Comp} = f\left(h_{o,Comp}, P_{o,Comp}\right) \quad (5)$$

$$s_{o,Comp} = f\left(T_{o,Comp}, P_{o,Comp}\right) \quad (6)$$

Turbine

The turbine operates similarly to the compressor but in the opposite direction, where it expands the working fluid:

$$h_{o,Tur} = h_{i,Tur} + \frac{h_{o,Tur,is} - h_{i,Tur}}{\eta_{Tur}} \quad (7)$$

The isentropic outlet enthalpy of turbine is determined using the inlet entropy and the outlet pressure of turbine:

$$h_{o,Tur} = f\left(T_{o,Tur}, s_{i,Tur}, P_{oTur}\right) \quad (8)$$

The actual outlet temperature and entropy are then calculated using:

$$T_{o,Tur} = f\left(h_{o,Tur}, P_{o,Tur}\right) \quad (9)$$

$$s_{o,Tur} = f\left(T_{o,Tur}, P_{o,Tur}\right) \quad (10)$$

Reboiler

The reboiler heats the working fluid by condensing steam. The thermal power supplied by the reboiler is:

$$Q_{Reb} = m_{Reb} * \left(h_{o,Reb} - h_{i,Reb}\right) \quad (11)$$

Heat Exchanger

The heat exchanger transfers thermal energy from the reactor to the working fluid. The enthalpy change across the heater is given by:

$$h_{o,Heater} = h_{i,heater} + \frac{Q_{Heater}}{m_{CO_2,Heater}} \quad (12)$$

The outlet temperature and entropy are then calculated using:

$$T_{o,Heater} = f\left(h_{o,Heater}, P_{o,Heater}\right) \quad (13)$$

$$s_{o,Heater} = f\left(T_{o,Heater}, P_{o,Heater}\right) \quad (14)$$

Economizer

The economizer preheats the working fluid using heat from the turbine exhaust. The enthalpy change across the economizer is given by:

$$h_{o,Eco} = h_{i,Eco} + \frac{Q_{Eco}}{m_{CO_2,Eco}} \quad (15)$$

The outlet temperature and entropy are then calculated using:

$$T_{o,Eco} = f\left(h_{o,Eco}, P_{o,Eco}\right) \quad (16)$$

$$s_{o,Eco} = f\left(T_{o,Eco}, P_{o,Eco}\right) \quad (17)$$

Recuperator

Recuperative heat exchangers increase cycle efficiency by collecting waste heat from turbine exhaust and using it to pre-heat the working fluid before it reaches the heat exchanger. The heat exchanger's enthalpy change can be calculated as:

$$h_{o,Rec,hot} = h_{i,Rec,hot} - \eta_{Rec} * \left(h_{i,Rec,hot} - h_{o,Rec,is}\right) \quad (18)$$

$$h_{o,Rec,cold} = h_{i,Rec,cold} + \eta_{Rec} * \left(h_{i,Rec,hot} - h_{o,Rec,is}\right) \quad (19)$$

The overall cycle efficiency and net power output are calculated as:

$$\eta_{cycle} = \frac{W_{net}}{Q_{Reactor}} \quad (20)$$

$$W_{net} = W_{Tur} - W_{Comp} \quad (21)$$

Calculate the thermodynamic properties of the loop's various state points using the CoolProp package. The properties are enthalpy (h), temperature (T), and entropy (s). These attributes are calculated using library functions depending on state variables (pressure, temperature, or enthalpy and pressure).

RESULTS AND DISCUSSION

This study evaluates the performance of a nuclear cogeneration system connected with the sCO_2 Brayton cycle and the attached reboiler to supply useable heat/process steam for industrial purposes. The system runs on the heat of a nuclear reactor and employs two different working fluids: helium in the nuclear cycle and sCO_2 in the secondary cycle.

The impact of several parameters, such as turbine and compressor efficiency, on the thermal efficiency of the cycle was assessed. Furthermore, turbine power, power cycle efficiency, and net power were calculated using turbine inlet temperature and compressor pressure ratio.

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Effect of turbine efficiency and compressor efficiency on thermal efficiency of the cycle

Figure 5(a) shows the link between turbine efficiency and cycle thermal efficiency. As demonstrated, there is a direct link between turbine efficiency and cycle thermal efficiency. Specifically, increasing turbine efficiency from 0.50 to 1.0 leads to a large increase in cycle thermal efficiency from around 0.25 to 0.45. This demonstrates how boosting turbine efficiency can dramatically increase the total thermal performance of the cycle.

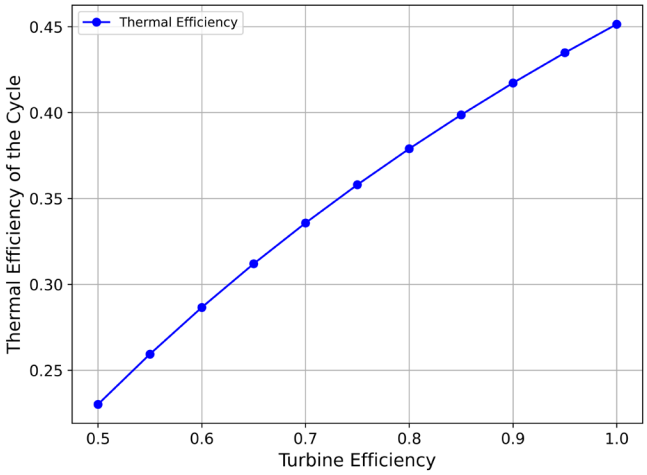
The data point follows almost linear tread that demonstrates the sensitivity of the cycle thermal efficiency to variations in turbine efficiency. This highlights how crucial it is to enhance cycle thermal efficiency by optimizing turbine efficiency.

The impact of compressor efficiency on the cycle thermal efficiency is depicted in Figure 5(b). Compressor efficiency and thermal efficiency are positively correlated, similar to turbine efficiency. According to the plot, the cycle's thermal efficiency rises from around 0.21 to 0.25 as the compressor efficiency rises from 0.70 to 1.00.

The trend is positive and noteworthy even though the rise in compressor efficiency leads to a lower improvement in thermal efficiency than turbine efficiency. This demonstrates that although compressor efficiency optimization contributes to thermal efficiency, its influence is marginally smaller than that of turbine efficiency.

The findings in the figure demonstrate that the cycle's thermal efficiency is mostly determined by the compressor and turbine's efficiency. Any increase in turbine performance might result in a corresponding increase in cycle thermal efficiency, according to the linear relationship between turbine efficiency and thermal efficiency that has been observed. However, even while compressor efficiency still has a favorable impact, it appears to be less significant in comparison.

These results emphasize the significance of increasing turbine efficiency as the main objective to raise the cycle's total thermal efficiency. However, improvements in compressor efficiency should not be neglected as they also contribute to the overall performance enhancement.



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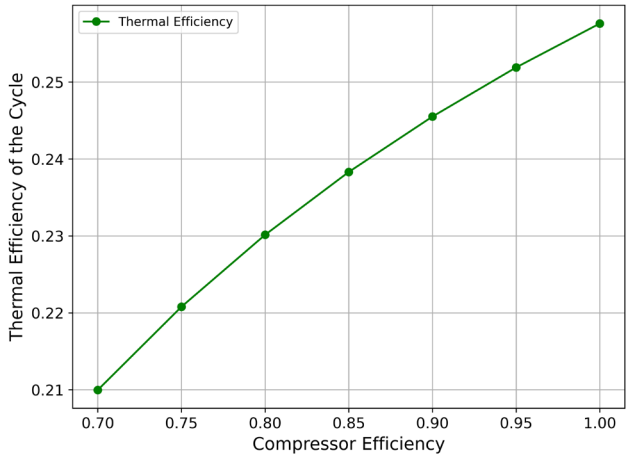

(b)

Figure 5: Effect of turbine and compressor efficiency on thermal efficiency of the cycle.

Variation in reboiler CO_2 inlet temperature and turbine power with respect to turbine inlet temperature and compressor pressure ratio

The results investigate the relationship between compressor pressure ratio, turbine inlet temperature, reboiler CO_2 inlet temperature and turbine power output. Significant patterns in turbine power generation can be found by examining these findings.

The relationship between turbine inlet temperature and reboiler CO_2 inlet temperature and turbine power are shown in Figure 6(a). At all investigated reboiler CO_2 inlet temperatures, raising the turbine inlet temperature from 550°C to 725°C increases turbine power output and, consequently, thermal efficiency. Reboiler CO_2 inlet temperature also increases the turbine power, and the effect is more obvious when the turbine inlet temperature is higher. The highest turbine inlet temperature of about 725°C and the reboiler CO_2 inlet temperature of about 740°C yields the maximum turbine power output of about 2.85 MW, while the lowest turbine inlet temperature yields the minimum power output of about 1.41 MW at 550°C and the reboiler CO_2 inlet temperature is 580°C.

The turbine power variation with compressor pressure ratio and reboiler CO_2 inlet temperature is shown in Figure 6(b). There is a positive correlation between turbine power output and the compressor pressure ratio, which rises from 2.0 to 4.0. Pressure ratios below 2.0 typically result in lower turbine power output due to insufficient expansion of the working fluid, thus limiting energy conversion efficiency. Conversely, pressure ratios above 4.0 may result in excessive compression work, thereby reducing net power output and creating challenges related to mechanical stress and material limitations. Similarly, due to increased thermal efficiency, raising the reboiler CO_2 inlet temperature from 580°C to 740°C considerably boosts turbine power output. The sum of these factors indicates that the maximum turbine power output of approximately 3.35 MW is attained at a reboiler

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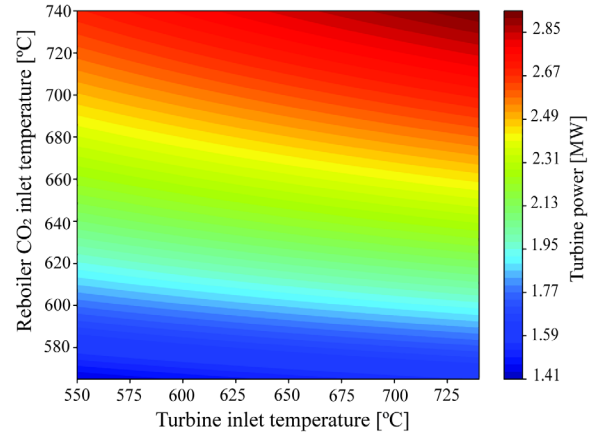
CO_2 inlet temperature of around 740°C and an upper limit of compressor pressure ratio of approximately 4.0. Conversely, the lowest power output, approximately 1.35 MW, was recorded at the lowest compressor pressure ratio of 2.0 and reboiler CO_2 inlet temperature of 580°C.

According to analysis, the compressor pressure ratio and turbine input temperature are important factors that affect turbine power output. The reboiler CO_2 inlet temperature rises with increasing values of these parameters, resulting in optimal performance. With the goal of increasing efficiency and power generation capacity, these findings offer important insights into the construction and functioning of thermal power plants.



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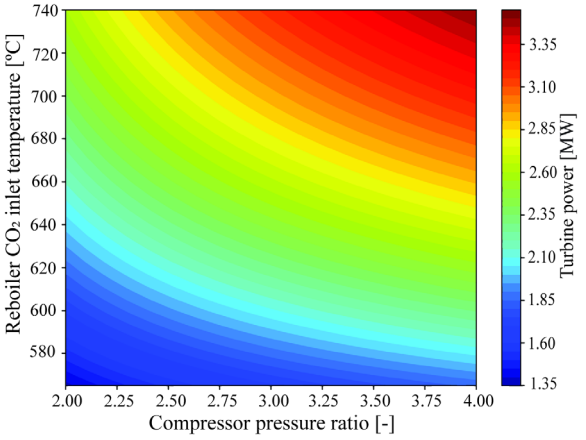


(b)

Figure 6: Variation in reboiler CO_2 inlet temperature and turbine power with respect to turbine inlet temperature and compressor pressure ratio.

Variation in reboiler CO_2 inlet temperature and power cycle efficiency with respect to turbine inlet temperature and compressor pressure ratio

With an emphasis on variations in turbine inlet temperature and compressor pressure ratio, the following findings examine how reboiler CO_2 inlet temperature affects power cycle efficiency. We aim to provide insight concerning how to improve the thermodynamic cycle's performance by examining two contour plots.

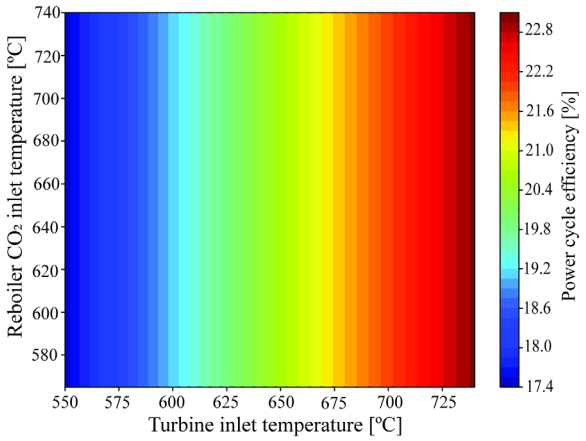
The impact of changing the turbine inlet temperature between 550°C and 740°C on the power cycle efficiency is examined in Figure 7(a), along with changing the reboiler CO_2 inlet temperature. Lower power cycle efficiency is linked to turbine inlet temperatures between 550°C and 600°C. When the turbine input temperature reaches about 675°C, efficiency greatly increases; after that, improvements are marginal.

At varied turbine inlet temperatures, there is a constant relationship between increased efficiency and a higher reboiler CO_2 inlet temperature. The relative efficiency gain, however, declines as the reboiler CO_2 inlet temperature and turbine inlet temperature rise, indicating the existence of saturation effects at high temperatures.

The relation between compressor pressure ratio (2.0 to 4.0), reboiler CO_2 inlet temperature (580°C to 740°C), and power cycle efficiency is shown in Figure 7(b). Efficiency rises dramatically when the reboiler CO_2 inlet temperature rises at lower compressor pressure ratios (2.0 to 2.25). But when the compressor pressure ratio rises above 2.5, efficiency approaches a plateau, and there is minimal variation between pressure ratios of 3.5 and 4.0. This implies that there is a threshold at which efficiency gains become less significant as the compressor pressure ratio is raised.

Additionally, the data indicates that efficiency significantly improves with increasing reboiler CO_2 inlet temperature, notably between 580°C and 700°C. Above 700°C, the efficiency gain tapers off, indicating the ideal temperature range for efficiency maximization.

These results show how these parameters interact in thermodynamic cycles and offer a framework for creating more effective systems.



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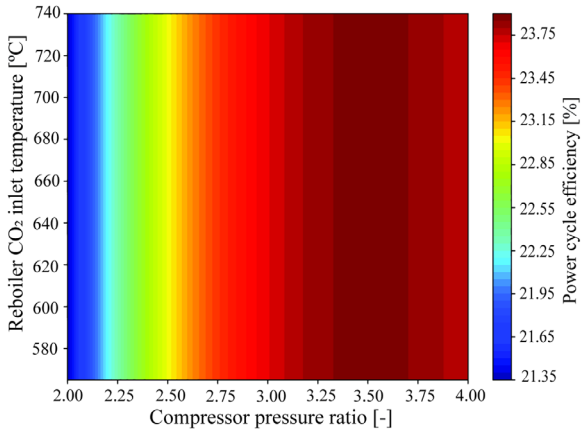

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Figure 7: Variation in reboiler CO_2 inlet temperature and power cycle efficiency with respect to turbine inlet temperature and compressor pressure ratio.

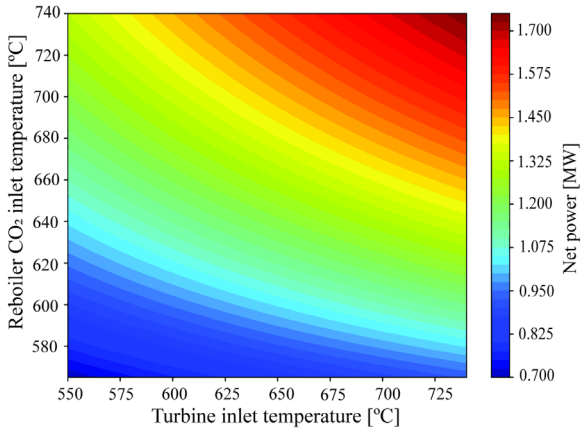
Variation in reboiler CO_2 inlet temperature and net power with respect to turbine inlet temperature and compressor pressure ratio

The impact of the reboiler CO_2 inlet temperature on the power generation system's net power output is demonstrated by the following findings. The analysis focuses on how two important parameters, the compressor pressure ratio and turbine inlet temperature affect variations in net power.

The change in net power with turbine and reboiler CO_2 inlet temperatures is shown in Figure 8(a). The net power output rises nearly linearly as the turbine inlet temperature rises from 550°C to 725°C, demonstrating the significant impact of turbine inlet temperature on total power generating efficiency. Net power increases slightly when the reboiler CO_2 inlet temperature rises at lower turbine inlet temperatures. However, the net power increases to higher values at higher turbine inlet temperatures, suggesting that the net power production is greatly increased by high turbine inlet temperatures. The best performance was found to be between 700°C and 740°C for the high turbine inlet temperature and between 680°C and 740°C for the reboiler CO_2 inlet temperature, where the net power output peaks.

The net power output is plotted against the compressor pressure ratio and the reboiler CO_2 inlet temperature in Figure 8(b). The net power exhibits a high degree of sensitivity to variations in the compressor pressure ratio at lower reboiler CO_2 inlet temperatures, between 580°C and 620°C. Net power output rises significantly when the pressure ratio is raised from 2.0 to 4.0. The sensitivity of net power to compressor pressure ratio, however, reduces when the reboiler CO_2inlet temperature rises from 620°C to 740°C. The net power curve flattens, showing diminishing returns as the pressure ratio increases. Higher pressure ratios, especially those between 3.0 and 4.0, maximize net power at the majority of reboiler CO_2 inlet temperatures.

According to analysis, the cycle's net power generation is significantly affected by the compressor pressure ratio and turbine inlet temperature. While the turbine inlet temperature keeps raising net power output, the compressor pressure ratio's impact on net power diminishes as the reboiler CO_2 inlet temperature rises. Maintaining high turbine inlet temperatures and choosing suitable compressor pressure ratios are crucial for optimizing net power, as demonstrated by these insights, which are vital to thermal system optimization.



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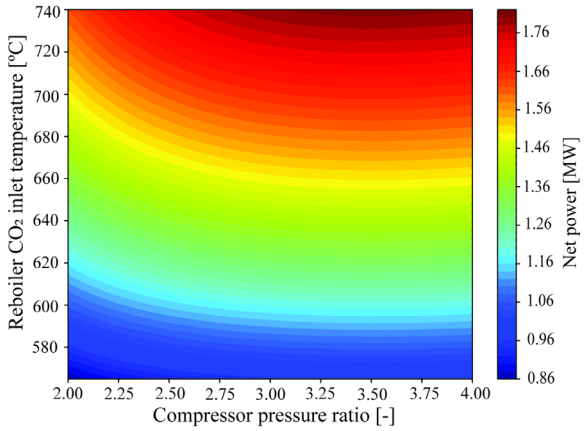

(b)

Figure 8: Variation in reboiler CO_2 inlet temperature and net power with respect to turbine inlet temperature and compressor pressure ratio.

CONCLUSION

Incorporating a reboiler into a nuclear-driven sCO_2 Brayton cycle has been demonstrated to meet the heat requirements of industrial operations and significantly boost power cycle efficiency. Examining reboiler CO_2 inlet temperature, turbine power, power cycle efficiency, and net power in relation to turbine inlet temperature and compressor pressure, this study uses a thorough thermodynamic analysis to investigate how

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turbine and compressor efficiency affect cycle thermal performance.

The results show that higher reboiler CO_2 inlet temperatures yield the best power cycle efficiency, with notable efficiency benefits up to about 740°C. Efficiency gains decrease at this point. In order to maximize system performance, the compressor pressure ratio, turbine inlet temperature, and reboiler CO_2 inlet temperature must all be balanced. Thermal efficiency rises from 25% to 45% as key parameters are optimized, while turbine efficiency improves from 50% to approximately 90% reflecting practical operational limits. Conversely, a lesser gain in thermal efficiency from 21% to 25% occurs when compressor efficiency is raised from 70% to 100%. With a compressor pressure ratio of 4.0 and a turbine inlet temperature of 725°C, the net power production reached its maximum at 3.35 MW.

By determining the ideal operating parameters that optimize net power output, this research also aids in the effective design and operation of thermal power plants. In order to facilitate real-time optimization and control of power generation systems, future research endeavors ought to focus on integrating these discoveries into dynamic models.

Future studies should also examine possible nonlinearities and interactions in greater detail when optimizing turbine and compressor efficiencies together. Additionally, by comprehending the mechanisms influencing these efficiencies, more efficient methods to raise the overall thermal efficiency of core-driven sCO_2 Brayton cycles may be developed. This research has useful applications in optimizing the design and operation of nuclear-driven thermal power plants and offers a useful framework for creating more efficient thermal power systems. Real implementation in industrial applications could lead to cleaner and more efficient energy generation, which is in line with the objectives of initiatives like "NC2I-R" and "Gemini+."

NOMENCLATURE

Abbreviations

CO_2	Cabon dioxide
h	enthalpy
He	Helium
HTGR	High temperature Gas-cooled reactor
m	mass flow rate
P	Pressure
Q	Thermal Power
s	entropy
sCO_2	supercritical carbon dioxide
SMR	Small modular reactor
T	Temperature
W	Work done

Subscripts

$comp$	compressor
Eco	Economizer
i	inlet
is	isentropic
o	outlet
Re	Reactor
Reb	Reboiler
Rec	Recuperator
Tur	Turbine

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