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Proposal and Applicability Assessment of Control Logic for an sCO_2 Recompression Brayton Power Conversion System Considering Partial load Operation

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1. Introduction

Generation IV nuclear reactor concepts are designed to operate at significantly higher temperatures than conventional light-water reactors, thereby offering enhanced thermodynamic potential for high-efficiency power conversion. Realizing these thermal advantages requires power conversion technologies capable of maintaining high efficiency beyond the practical limits of conventional steam Rankine cycles. Among the available advanced power conversion technologies, the supercritical carbon dioxide (sCO_2) Brayton cycle has been considered a promising alternative to conventional steam Rankine cycles for next-generation nuclear energy systems. Previous research reported that the sCO_2 Brayton cycle offers higher efficiency, a simpler system configuration, and a more compact system size than conventional steam cycles [1]. Its thermodynamic efficiency advantage becomes more pronounced for heat-source temperatures in the range of approximately 350-550 °C.

Traditionally, nuclear power plants have been operated primarily as baseload power sources, and their power conversion systems have therefore been designed to maximize efficiency and reliability at rated operating conditions. However, advanced nuclear energy systems are increasingly expected to provide not only electricity but also hydrogen production, industrial process heat, desalination, district heating, and other cogeneration services. Because the thermal and electrical demands associated with these applications can vary over time, future nuclear power conversion systems must provide greater operational flexibility while maintaining stable and efficient performance under off-design and partial load conditions.

Partial load operation of an sCO_2 Brayton cycle simultaneously affects the mass flow rate, pressure distribution, temperature level, heat-exchanger conditions, and turbomachinery operating points. Accordingly, appropriate control logic is required not only to regulate the system load but also to maintain the principal system variables within their allowable ranges.

The objective of this study is to propose control logic for an sCO_2 power conversion system considering partial load operation and to assess its system-level applicability by applying it to Start-up, Normal operation, and Stop conditions. The principal control targets, control variables, and manipulated variables are defined to establish an operating concept capable of responding to changes in heat demand.

2. sCO_2 Recompression Brayton Cycle system

The sCO_2 Brayton Cycle has been considered as a candidate power conversion system that can be coupled to nuclear heat sources. The high density of CO_2 and the resulting low volumetric flow rate are advantageous for reducing the size of turbomachinery, while compact heat exchangers can reduce the installation footprint of the overall power conversion system. Because of these characteristics, the sCO_2 Brayton Cycle has been investigated as a power conversion option for integration with various nuclear systems [1,2].

Among the various sCO_2 Brayton Cycle configurations, the Recompression Cycle has been widely studied as a representative configuration for improving regenerative heat recovery and cycle efficiency. In a simple recuperated cycle, the strong variation of the CO_2 specific heat with temperature and pressure causes an imbalance in the heat-capacity rates on the two sides of the recuperator and can produce an internal Pinch-point. The Recompression Cycle diverts a portion of the Total mass flow rate through the Recompressor path and thereby adjusts the flow rate on the LTR cold side. This mitigates the imbalance between the two heat-capacity rates and the Pinch-point problem, improves regenerative heat recovery, and can provide higher cycle efficiency than a simple recuperated cycle [1,2].

Accordingly, the system selected for this study is an sCO_2 Recompression Brayton power conversion system that can be coupled to a nuclear heat source and has a rated IHX thermal duty of 300 MWth. The sCO_2 Recompression Brayton Cycle is a closed-loop power conversion system comprising a Main Compressor (MC), Recompressor (RC), Turbine, Recuperators (LTR and HTR), Cooler, and Intermediate Heat Exchanger (IHX). The IHX is set as the heat-transfer boundary. The study assesses system-level control applicability under Start-up, Normal operation, and

Stop conditions; detailed component design and validation are outside the scope, and turbomachinery and heat-exchanger performance are applied as assumed model conditions.

Various load-control approaches have been considered for partial load operation of sCO_2 power conversion systems, including Inventory control, Temperature control, Compressor speed control, Turbine throttle control-valve control, and Turbine bypass control. These methods have mainly been evaluated in terms of Cycle thermal efficiency, response characteristics, and maintenance of major operating conditions during load changes. Combined control strategies using multiple control methods have also been studied to compensate for the limitations of a single control method [2,3].

Based on the characteristics of the sCO_2 Recompression Brayton Cycle reviewed above, this study defines the IHX thermal duty as the load and configures the system to track the target thermal duty by adjusting the Total mass flow rate.

In addition, multiple control logics are configured to manage the Compressor inlet condition, high-side pressure, Turbine inlet temperature, and LTR heat-recovery condition as the Total mass flow rate changes. Maintenance of the major operating conditions and system efficiency during partial load operation is then assessed.

3. Proposed Control Logic for Partial load Operation

3.1 Configuration and Overview of the Control Logic

This section proposes control logic for partial load operation of an sCO_2 Recompression Brayton power conversion system with a rated IHX thermal duty of 300 MWth. The proposed control logic comprises a load-adjustment function that responds to changes in IHX thermal duty and functions that regulate the principal pressure, temperature, and heat-recovery conditions during partial load operation.

The basic concept of the proposed control logic is to vary the IHX thermal duty by adjusting the Total mass flow rate. The Thermal duty transferred from the IHX to the sCO_2 power conversion system is expressed by Eq. (1).

$$Q_{IHX} = \dot{m}_{CO_2}(h_{IHX,out} - h_{IHX,in}) \qquad (1)$$

Here, Q_{IHX} is the IHX thermal duty, $\dot{m}_{CO_2}$ is the sCO_2 Total mass flow rate, and $h_{IHX,out}$ and $h_{IHX,in}$ are the specific enthalpies of sCO_2 at the IHX outlet and inlet, respectively.

When the principal pressure and temperature conditions and the turbomachinery performance characteristics are maintained so that the change in the specific-enthalpy difference between the IHX inlet and outlet is limited, the IHX thermal duty can be varied by adjusting the sCO_2 Total mass flow rate.

Based on the relationship between IHX thermal duty and Total mass flow rate, control logic for stable partial load operation is configured in this study.

Fig. 1 presents the configuration concept of the control logic proposed for partial load operation. Each control logic uses a principal operating variable of the power conversion system as its control variable and uses valve opening or turbomachinery Speed as its manipulated variable.

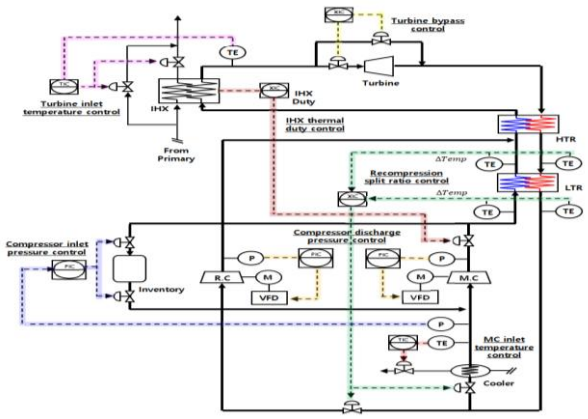


figure 1. Conceptual configuration of the sCO_2 Recompression power conversion system control logic for partial load operation.

3.2 Functions, Objectives, Control Variables, and Manipulated Variables

Table I summarizes the function and objective of each proposed control logic, the process variable (PV), the manipulated variable (MV), and the principal set point (SP).

Table I. Functions, Objectives, Control Variables, and Manipulated Variables of the Proposed Control Logic

Control function	Control logic	Process variable (PV)	Manipulated variable (MV)	Main set point (SP)
IHX thermal duty adjustment	IHX thermal duty control	IHX thermal duty	Total mass flow rate valve opening (Total mass flow rate)	300-100 MWth
Maintain Compressor inlet condition	Compressor inlet pressure control	Compressor inlet pressure	Inventory valve opening (Cycle inventory)	8 MPag
Maintain Compressor inlet condition	Main Compressor inlet temperature control	Main Compressor inlet temperature	Cooling valve opening (Cooling duty)	35 °C
Maintain Turbine inlet condition	Compressor discharge pressure control	Each Compressor discharge pressure	Compressor speed (VFD)	25 MPag

Control function	Control logic	Process variable (PV)	Manipulated variable (MV)	Main set point (SP)
Maintain Turbine inlet condition	Turbine inlet temperature control	Turbine inlet temperature	IHX bypass valve opening (IHX thermal duty)	600 °C
Maintain LTR heat-recovery condition	Recompression split ratio control	Deviation between LTR hot- and cold-end temperature differences	Recompression split-ratio valve opening	$e_{LTR} = 0$
Transfer flow path during Start-up and Stop	Turbine bypass control	Turbine flow / Bypass flow	Turbine bypass valve opening	Sequence criterion

3.2.1 IHX Thermal Duty Control

IHX thermal duty control is the control logic responsible for load adjustment in this study. Because the load is defined as the IHX thermal duty rather than the generator electrical output, the sCO_2 Cycle Total mass flow rate is adjusted in response to the IHX thermal duty. The rated load and minimum partial load conditions are set to 300 MWth and 100 MWth, respectively, corresponding to a turndown ratio of 3:1.

For this purpose, the opening of the Total mass flow rate control valve in the Cycle is varied to adjust the sCO_2 Total mass flow rate. In the Simulation model, the Total mass flow rate control valve is located downstream of the Main Compressor; its detailed location in an actual system may vary depending on the piping configuration and pressure-loss conditions. The focus of this study is not selection of the detailed valve location but assessment of the applicability of IHX thermal duty control through adjustment of the Total mass flow rate.

3.2.2 Compressor Inlet Pressure Control

The critical pressure of CO_2 is approximately 7.38 MPa(a). Compressor inlet pressure control is configured to maintain the Compressor inlet pressure above the critical pressure. The opening of the Inventory control valve is adjusted to vary the CO_2 inventory in the Cycle, and the Compressor inlet pressure is set to remain at approximately 8 MPag.

3.2.3 Main Compressor Inlet Temperature Control

The critical temperature of CO_2 is approximately 31.1 ℃. Main Compressor inlet temperature control is configured to maintain the Compressor inlet temperature above the critical temperature. The Cooling valve opening is adjusted to vary the Cooling duty, and the Main Compressor inlet temperature is set to remain at approximately 35 °C or higher.

3.2.4 Compressor Discharge Pressure Control

Compressor discharge pressure control is used to establish and maintain the high-side pressure required for Turbine admission. With reference to representative operating conditions reported in previous studies, the discharge-pressure SP of the Main Compressor and Recompressor are set to approximately 25 MPag [1], and the VFD speed of each Compressor is used as the manipulated variable.

3.2.5 Turbine Inlet Temperature Control

Turbine inlet temperature control is used to maintain a constant Turbine inlet temperature. With reference to the 450-600 °C Turbine inlet temperature range in which previous studies reported high sCO_2 Cycle efficiency [1], the Turbine inlet temperature SP is set to 600 °C, and IHX heat input or the IHX bypass control valve is applied as the manipulated variable.

3.2.6 Recompression Split Ratio Control

Recompression split ratio control is used to maintain the LTR heat-exchange condition by minimizing the deviation between the hot-end and cold-end temperature differences of the LTR as the IHX thermal duty changes. When the Recompression split ratio (β) increases, the LTR cold-side flow rate decreases; the cold-side heat-capacity rate therefore decreases, changing the balance of the two LTR heat-capacity rates and the terminal temperature differences. The Recompression split ratio (β) must therefore be adjusted to maintain the LTR heat-exchange condition while the IHX thermal duty changes.

For this control function, the LTR hot-end temperature difference ($\Delta T_{LTR,H}$), cold-end temperature difference ($\Delta T_{LTR,L}$), and deviation between the two terminal temperature differences are defined by Eqs. (2)-(4).

$$\Delta T_{LTR,H} = T_{hot,in} - T_{cold,out} \quad (2)$$

$$\Delta T_{LTR,L} = T_{hot,out} - T_{cold,in} \quad (3)$$

$$e_{LTR} = \Delta T_{LTR,H} - \Delta T_{LTR,L} \quad (4)$$

In this study, an e_{LTR} value close to zero is considered to indicate a balanced temperature distribution on the two sides of the LTR. Accordingly, the opening of the Recompression split-ratio control valve is adjusted so that e_{LTR} approaches zero, thereby mitigating imbalance in the LTR temperature distribution, reducing the potential for an internal Pinch-point, and suppressing deterioration of LTR heat-recovery performance during load changes.

To estimate a reference value of the Recompression split ratio at the rated condition, the heat-capacity rates on the two sides of the LTR are assumed to be similar. Under this assumption, the Recompression split ratio (β) can be calculated as shown in Eqs. (5)-(9).

$$C_{LTR,h} = \dot{m}_{total}\overline{c_p}_{,h} \quad (5)$$

$$C_{LTR,c} = (1-\beta)\dot{m}_{total}\overline{c_p}_{,c} \quad (6)$$

$$C_{LTR,h} \approx C_{LTR,c} \quad (7)$$

$$\dot{m}_{total}\overline{c_p}_{,h} \approx (1-\beta)\dot{m}_{total}\overline{c_p}_{,c} \quad (8)$$

$$\beta \approx \frac{\overline{c_p}_{,h}}{\overline{c_p}_{,c}} \quad (9)$$

Assuming balanced heat exchange at the rated condition, the expected LTR operating conditions and average specific heats at the rated condition are applied to the calculation summarized in Table II.

Table II. Expected sCO_2 Specific Heat and Recompression Split-Ratio Calculation by LTR Flow Path at the Rated Condition

Item	LTR hot side	LTR cold side	Note
Pressure	8 MPag	25 MPag	
Temperature range	244 → 114 °C	103 → 234 °C	
Average specific heat ($\bar{c_p}$)	1.21 kJ/kg-K	1.78 kJ/kg-K	
Heat-capacity rate	$\dot{m}_{total}\bar{c_p}_{,h}$	$(1-\beta)\dot{m}_{total}\bar{c_p}_{,c}$	$C_{LTR,h} \approx C_{LTR,c}$
Flow-rate ratio	1.00	$(1-\beta)$	$\beta = 0.32$

Applying the average specific heats in Table II gives β ≈ 0.32 at the rated condition. This means that the heat-capacity rates on the two sides of the LTR can become similar when approximately 32% of the Total mass flow rate is diverted to the Recompressor. This value is used as a reference at the rated condition, and the Recompression split ratio during partial load operation is evaluated from the control results.

3.2.7 Turbine Bypass Control

Turbine bypass control is the control logic used to transfer the Turbine flow path under Start-up and Stop conditions. During Start-up and Stop, the Bypass path is used to manage the Turbine flow in stages.

Accordingly, Turbine bypass control is configured not as a load-adjustment method during Normal operation but as control logic for managing the Turbine flow path in the Start-up and Stop Sequences.

4. Applicability Assessment of the Proposed Control

In this section, the control logic proposed in Section 3 is implemented in a dynamic model of the sCO_2 Recompression Brayton power conversion system developed in Aspen HYSYS V14 Dynamics. The NIST REFPROP property package is used for fluid-property calculations, and the operating response and applicability of the control logic are assessed. Expected operating Sequences are assumed for the Start-up, Normal operation, and Stop conditions, and the changes in the principal system variables during each process are analyzed. The assessment confirms whether the power conversion system operates according to the intended Sequence and evaluates the pressure, temperature, flow rate, and IHX thermal duty changes during transitions between operating states.

4.1 Overview of the Applicability Assessment

Applicability of the proposed control logic is assessed separately under Start-up, Normal operation, and Stop conditions. These conditions are configured as one continuous operating procedure. Under the Start-up condition, the response from initial charging to entry into Normal operation is assessed. Under the Normal operation condition, the response to changes in IHX thermal duty over 300-100 MWth is assessed. Under the Stop condition, the response from termination of Normal operation to the stopped state is assessed using a conceptual reverse of the Start-up process.

To implement these operating conditions continuously, the control logic proposed in Section 3 is applied to the Aspen HYSYS V14 Dynamics model shown in Fig. 2. The model is configured to continuously assess operation of the control logic and the resulting system response during Start-up, Normal operation, and Stop.

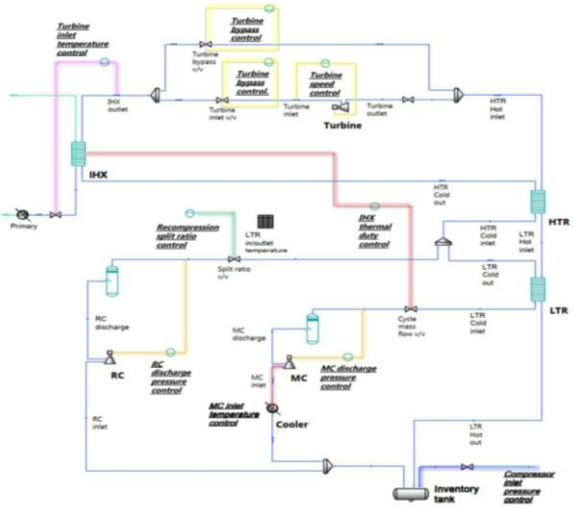


figure 2 Configuration of the Aspen HYSYS Dynamics simulation model with the proposed control logic.

Applicability under each operating condition is evaluated from changes in pressure, temperature, flow rate, IHX thermal duty, and the principal manipulated variables. The result plots present the variables directly related to the objective of each operating-condition assessment; these variables are used to analyze the operating characteristics of the control logic and transitions between system operating states.

4.2 Results Under the Start-up Condition

Under the Start-up condition, pressure establishment by the Compressors, system heating, and formation of Turbine flow after initial charging are assessed. Table III summarizes the expected operating Sequence and the principal variables evaluated under the Start-up condition.

Table III. Expected Operating Sequence Under the Start-up Condition

Step	Main action	Principal variable assessed
S1	Loop initial filling	Loop pressure
S2	Main Compressor start-up	Main Compressor discharge pressure
S3	IHX heat input	Turbine inlet temperature
S4	Recompressor start-up and flow-distribution establishment	Recompressor discharge pressure, Recompression split ratio
S5	Turbine minimum-flow establishment and Turbine start-up	Turbine bypass, Turbine speed
S6	IHX thermal duty control (Normal operation)	IHX thermal duty, Total mass flow rate control valve

The Start-up response is summarized in Fig. 4. After initial charging, the Compressor inlet pressure is established near 8 MPag, and the Main Compressor and Recompressor discharge pressures increase sequentially to approximately 25 MPag. The Main Compressor inlet temperature is maintained near 35 ℃ while the Turbine inlet temperature increases to approximately 600 °C. The Bypass path is used initially; after the Turbine minimum flow is secured at approximately 5% inlet-valve opening, the flow path transfers gradually to the Turbine. These trends confirm sequential establishment of the required pressure, temperature, and flow-path conditions. The assumed 5% criterion may be revised according to the actual turbine and valve design.

4.3 Results Under Normal Operation and Partial load Operation

Under Normal operation, partial load operation is assessed by varying the IHX thermal duty from 300 to 100 MWth. Table IV summarizes the expected operating Sequence and the principal variables evaluated under Normal operation.

Table IV: Expected Operating Sequence Under Normal Operation

Step	Main action	Principal variable assessed
N1	Change IHX thermal duty	IHX thermal duty and Total mass flow rate control valve
N2	Maintain major operating conditions	Compressor inlet pressure, Compressor discharge pressure, Main Compressor inlet temperature, Turbine inlet temperature, Recompression split ratio

As summarized in Fig. 3, the Total mass flow rate decreases and increases with the IHX thermal duty, demonstrating load regulation through the Total mass flow rate control valve. During these transitions, the Compressor inlet pressure remains near 8 MPag, the Main Compressor and Recompressor discharge pressures remain near 25 MPag, the Main Compressor inlet temperature remains near 35 ℃, and the Turbine inlet temperature remains near 600 °C. Thus, the proposed control logic maintains the principal pressure and temperature conditions while the load varies between 300 and 100 MWth.

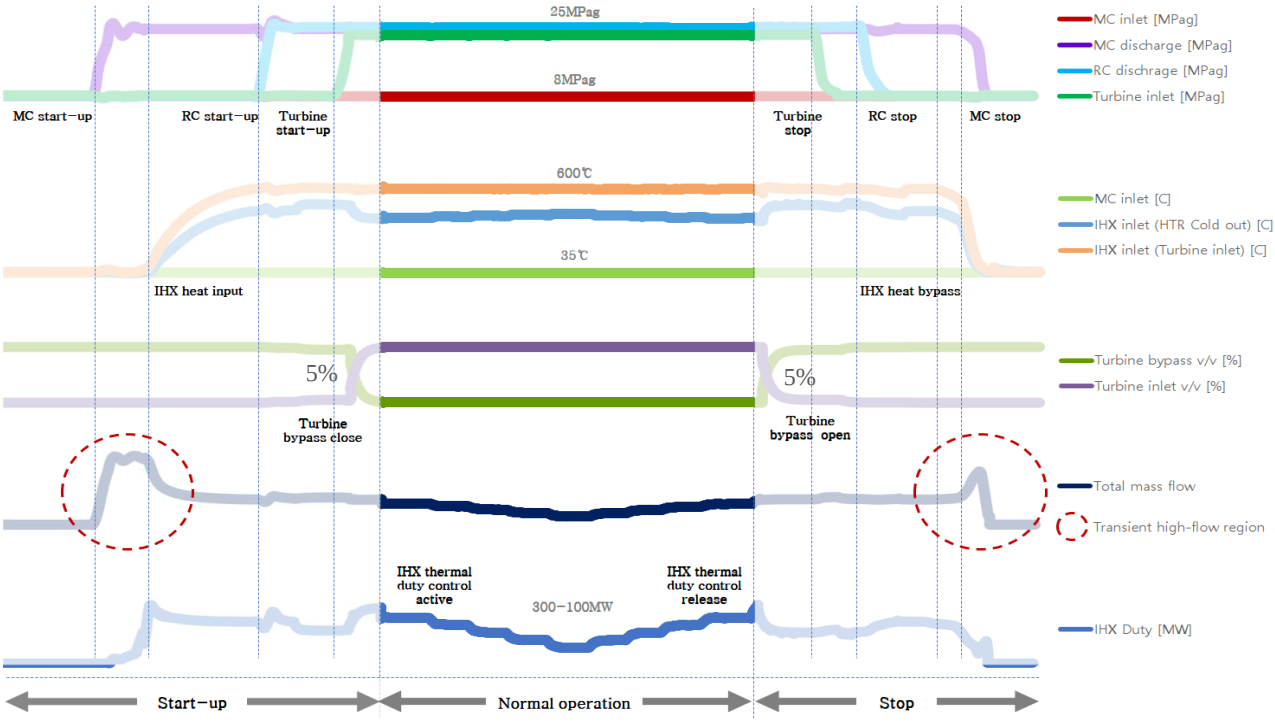


figure 3. Principal operating variables and Turbine bypass control-valve opening from Start-up to Stop.

Fig. 4 shows changes in the deviation between the two LTR terminal temperature differences and the Recompression split ratio during partial load operation. The deviation between the LTR hot-end and cold-end temperature differences increases temporarily during partial load transitions but approaches zero after the load stabilizes. This indicates that adjustment of the Recompression split ratio regulates the LTR cold-side flow rate and maintains similar terminal temperature differences.

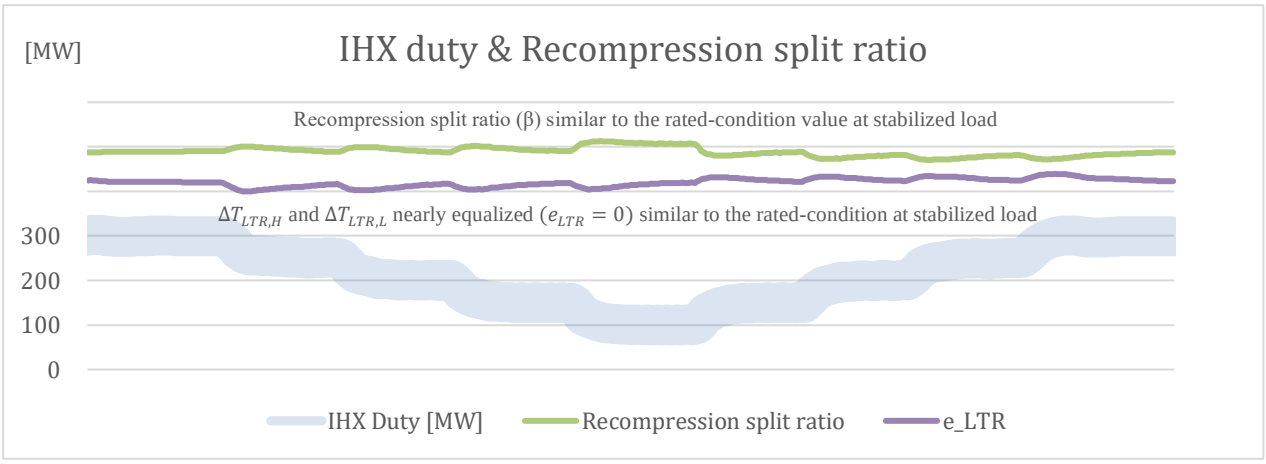


figure 4. Deviation between the LTR terminal temperature differences and Recompression split ratio during partial load operation.

4.4 Results Under the Stop Condition

Under the Stop condition, transfer to the Turbine bypass, reduction of the Turbine inlet temperature, and reduction of the Compressor discharge pressures after Normal operation are assessed. Table V summarizes the expected operating Sequence and the principal variables evaluated under the Stop condition. The Stop Sequence is configured using the conceptual reverse of the Start-up process.

Table V: Expected Operating Sequence Under the Stop Condition

Step	Main action	Principal variable assessed
P1	Release IHX thermal duty control	Total mass flow rate control valve (Full open)
P2	Establish Turbine minimum flow and stop Turbine	Turbine bypass, Turbine speed
P3	Stop Recompressor	Recompressor discharge pressure
P4	Bypass IHX heating	Turbine inlet temperature
P5	Stop Main Compressor	Main Compressor discharge pressure
P6	System stopped state	Loop pressure

The Stop response is also summarized in Fig. 3. The Turbine bypass control valve opens while the Turbine inlet valve closes, transferring the flow from the Turbine to the Bypass path; the Turbine is assumed to stop near 5% inlet-valve opening. The IHX heat input and Turbine inlet temperature then decrease, followed by sequential deceleration of the Recompressor and Main Compressor and a reduction of their discharge pressures from approximately 25 MPag. The Main Compressor inlet temperature remains near 35 °C and the low-side pressure remains near 8 MPag during the transition.

4.5 Applicability Results and Limitations

The complete operating process from Start-up to Stop with the proposed control logic is summarized in Fig. 3. The required pressure and temperature conditions and Turbine flow are established during Start-up, maintained during Normal operation while the Total mass flow rate tracks the IHX thermal duty, and reduced sequentially after transfer to the Bypass path during Stop. The proposed control logic therefore follows the defined operating Sequence throughout the complete process.

In the Start-up and Stop portions of Fig. 4, the Total mass flow rate temporarily exceeds the rated-operation flow rate. During Start-up, the pressure difference between the high and low sides is established by Compressor operation before the system is sufficiently heated, and a Total mass flow rate greater than the rated-operation value appears during this period. During Stop, a similar temporary increase in Total mass flow rate occurs when the IHX heat input decreases first while the pressure difference between the high and low sides remains.

The Total mass flow rate through a valve or flow path is affected by the pressure difference and fluid density. The basic relationships for the upstream-to-downstream pressure difference and Total mass flow rate are given by Eqs. (10) and (11), respectively.

$$\Delta P = P_{upstream} - P_{downstream} \quad (10)$$

$$\dot{m} = C_d A\sqrt{2\rho\Delta P} \quad (11)$$

Here, $P_{upstream}$ and $P_{downstream}$ are the pressures upstream and downstream of the Turbine bypass control valve, ΔP is the pressure difference, C_d is the flow coefficient, A is the effective flow area, ρ is the CO_2 density, and $\dot{m}$ is the Total mass flow rate. Equation (11) shows that the Total mass flow rate is affected by the pressure difference, effective flow area, and fluid density. During Start-up, a pressure difference can be established while the system has not yet been sufficiently heated and the CO_2 density is comparatively higher than under the rated operating condition. During Stop, the density can also increase as the temperature decreases following reduction of the IHX heat input while the pressure difference remains. The increase in Total mass flow rate observed in Fig. 3 can therefore be interpreted as the combined effect of the high-to-low side pressure difference and the change in CO_2 density.

These results show that the system design conditions, operating method, and operating range of each component must be considered comprehensively when Start-up and Stop Sequences are established for an actual project.

During partial load operation, the Total mass flow rate is adjusted as the IHX thermal duty decreases from 300 MWth to 100 MWth, while the Compressor inlet pressure, Compressor discharge pressures, Main Compressor inlet temperature, and Turbine inlet temperature remain at their set conditions. To assess maintenance of system efficiency under these operating conditions, the Cycle thermal efficiency is evaluated.

In this analysis, the Turbine and Compressor efficiencies are applied identically regardless of load, and the Cycle thermal efficiency is defined by Eq. (12).

$$\eta_{cycle} = \frac{W_{turbine} - W_{compressor}}{Q_{IHX}} \quad (12)$$

Here, $W_{turbine}$ is the Turbine work, $W_{compressor}$ is the Compressor work including the compression work of the Main Compressor and Recompressor, and Q_{IHX} is the Thermal duty transferred from the IHX to the sCO_2 power conversion system. Expressing these terms using the Total mass flow rate $\dot{m}_{CO_2}$, the specific works w_t and w_c, and the specific heat input q_{IHX} gives Eqs. (13) and (14).

$$\eta_{cycle} = \frac{\dot{m}_{CO_2}(w_t - w_c)}{\dot{m}_{CO_2} q_{IHX}} \quad (13)$$

$$\eta_{cycle} = \frac{(w_t - w_c)}{q_{IHX}} \quad (14)$$

Fig. 5 shows changes in the IHX thermal duty and Cycle thermal efficiency during partial load operation. Even when the IHX thermal duty decreases from 300 MWth to approximately 100 MWth, the Cycle thermal efficiency remains at a level similar to the rated condition. This occurs because load adjustment in this analysis is achieved by changing the Total mass flow

rate rather than by reducing the Turbine inlet temperature, while the Compressor inlet pressure, Compressor discharge pressures, Main Compressor inlet temperature, and Turbine inlet temperature are maintained at their set conditions.

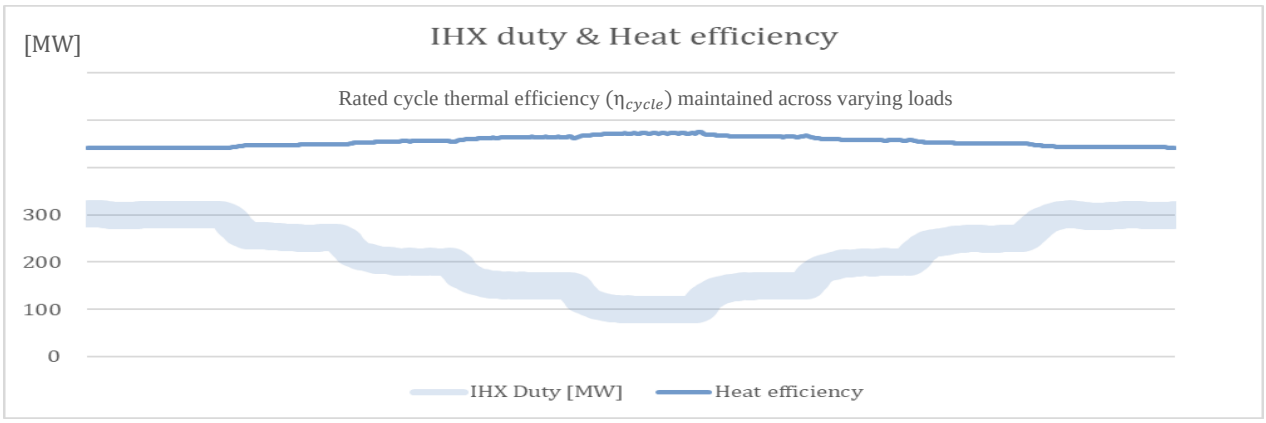


figure 5. IHX thermal duty and Cycle thermal efficiency during partial load operation.

The results in Figs. 4 and 5 show that the proposed control logic performs its intended functions throughout the complete operating process and can maintain the principal operating conditions and Cycle thermal efficiency during partial load operation. Because the IHX is the analysis boundary and component performance is assumed, the results demonstrate system-level applicability under the specified conditions. An actual design must additionally incorporate component performance, operating limits, and coupling with the reactor heat source.

5. Conclusions

This study configured partial load operating control logic centered on adjustment of the Total mass flow rate for an sCO_2 Recompression Brayton power conversion system with a rated IHX thermal duty of 300 MWth. The proposed control logic was applied to an Aspen HYSYS V14 Dynamics model to assess operating characteristics and applicability under Start-up, Normal operation, and Stop conditions. The analysis results confirmed that the proposed control logic establishes and maintains the principal operating conditions throughout the complete operating process and enables partial load operation over 300-100 MWth using the defined control methods.

During partial load operation, the principal pressure and temperature conditions and Cycle thermal efficiency remained at levels similar to the rated condition. Under the analysis conditions of this study, this result shows that operational flexibility can be secured through partial load operation while maintaining Cycle thermal efficiency near its rated level. Therefore, even if operational flexibility for responding to load changes is required in a future nuclear system, the present analysis indicates that partial load operation does not constitute a principal technical constraint on coupling a nuclear heat source with an sCO_2 power conversion system.

This study also confirmed that the operating condition of an actual system is not limited to the rated steady state and that pressure, temperature, and flow rate can enter ranges different from Normal operation during transitions including Start-up and Stop. Consequently, when the design and operating Sequence of an actual system are established, both the steady-state operating conditions and the ranges and characteristics that appear during transitions must be considered. By applying the proposed partial load control approach from Start-up to Stop, this study extends the design-assessment range of an sCO_2 power conversion system from a steady-state-centered perspective to the complete operating range.

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