Preliminary Analysis of Coupling **SCO_2 Cycle** and **Natural Draft Dry Cooling** Tower for **SMR Application**

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5/13 Zoom-live

2021 KNS Spring Meeting

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Background
Small Modular Reactor (iPWR)

Recent trend in SMR technology development : iPWR | integrated PWR

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SMART & 혁신형 SMR

CAREM

CAREM

NUSCALE
Power for all humankind

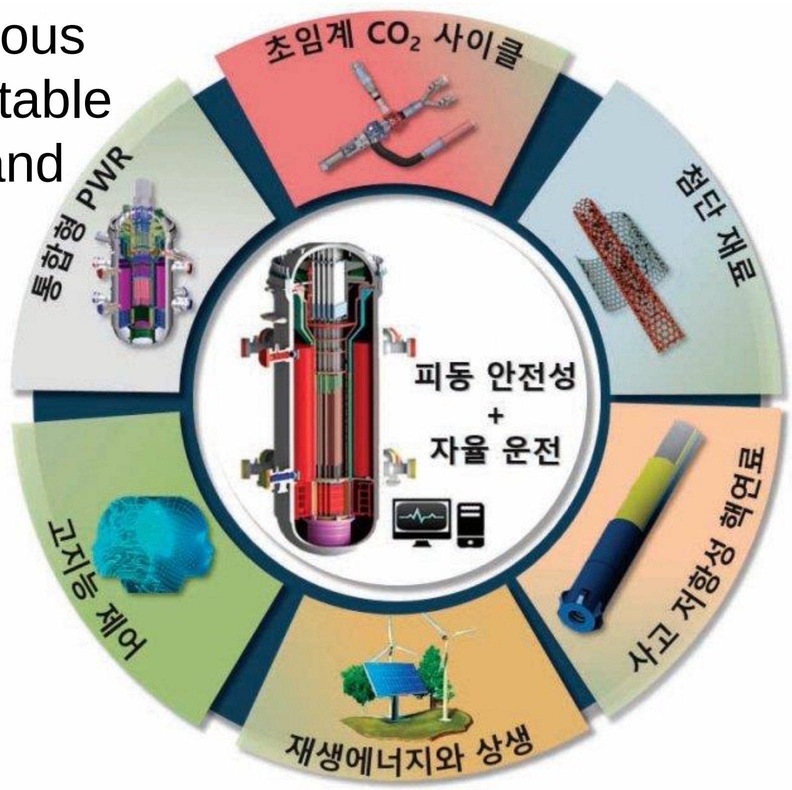
NuScale

B&W BABCOCK & WILCOX

mPower

■
■
■

Autonomous
Transportable
On-demand
Module



ATOM 시스템 설계 개념

Background

Conversion System of iPWRs

Enhanced siting flexibility from advanced power conversion system

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SMART & 혁신형 SMR

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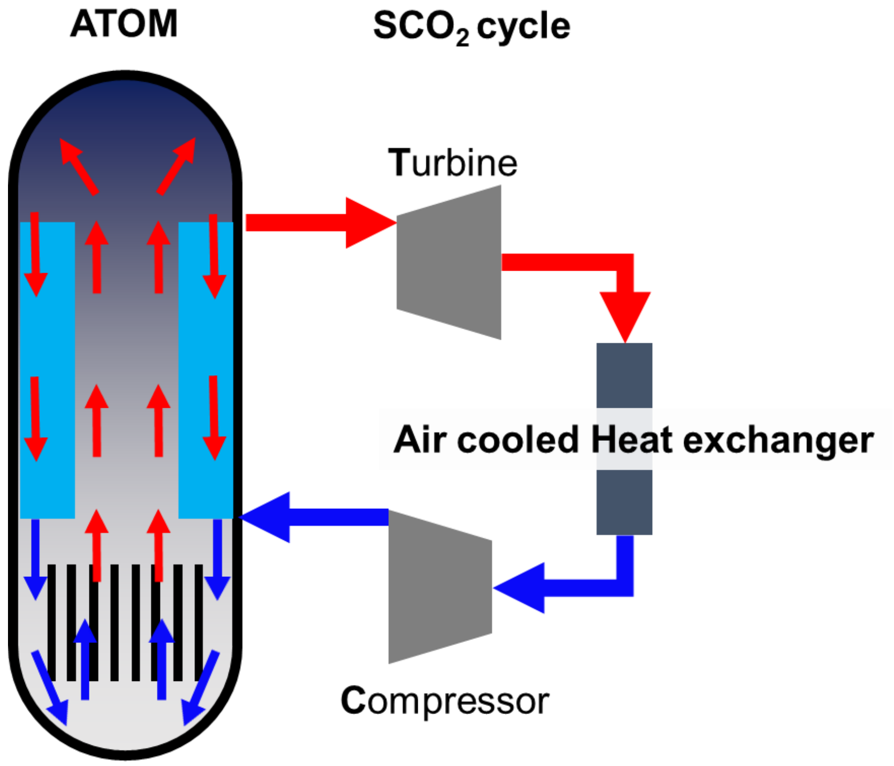
Steam Rankine cycle

- ✓ Multi-stage of the turbines
- ✓ Large scale condenser
- ✓ <u>**Evaporative loss of water for air-cooling system**</u>

SCO_2 Brayton cycle

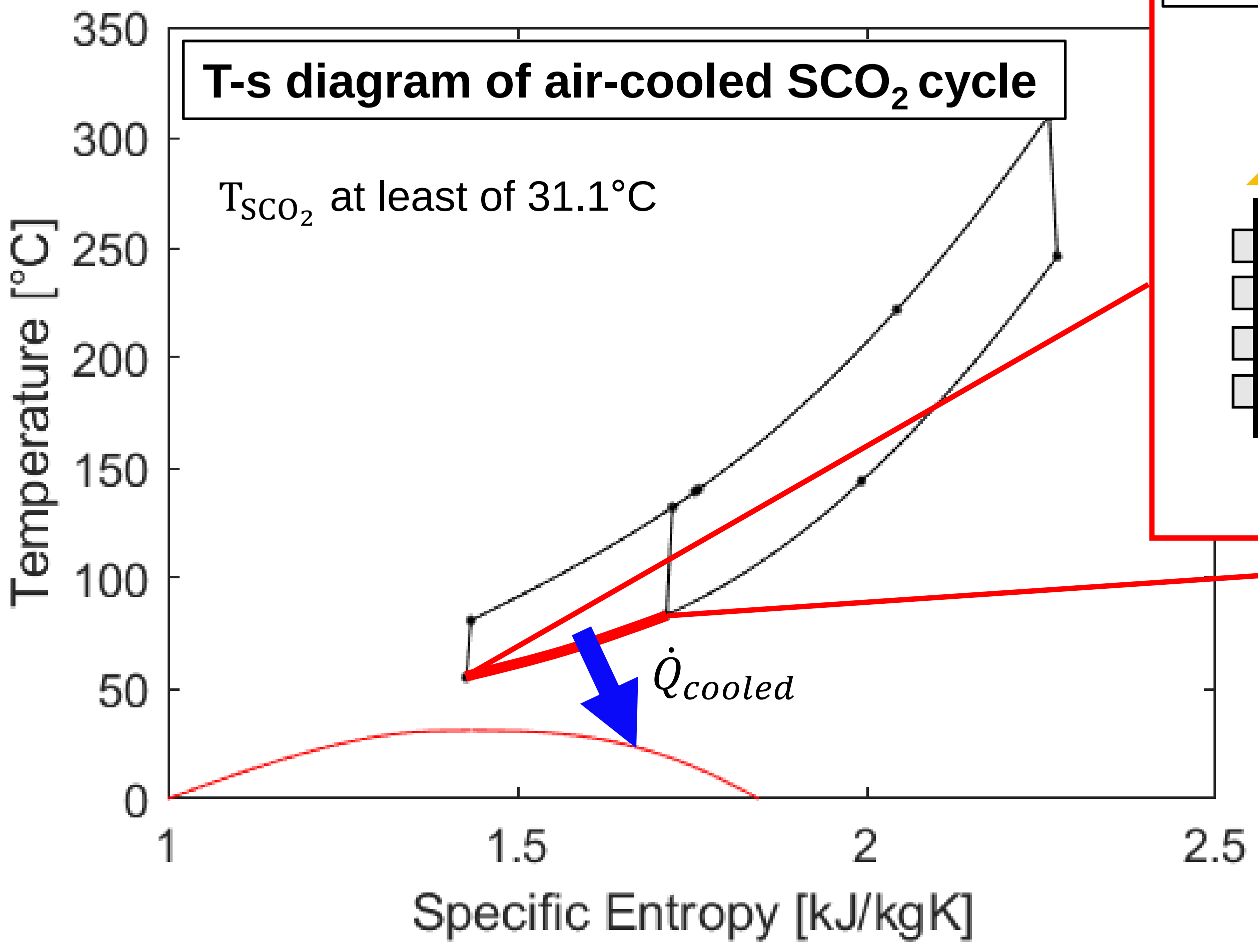
- ✓ High operation pressure
- ✓ Compact size of turbomachinery
- ✓ Simple configuration

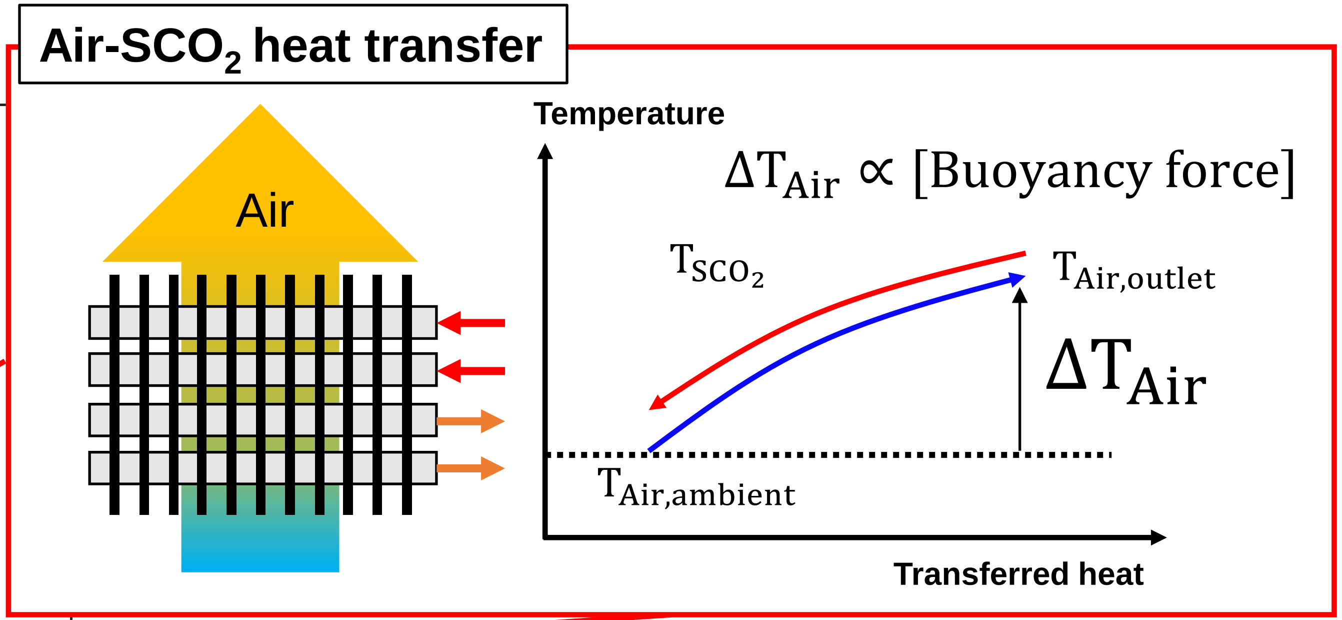
SCO_2 Brayton cycle



Background

Feasibility of dry air-cooled SCO_2 cycle





High feasibility of natural draft dry cooling system

- ✓ No evaporative loss of water
- ✓ No power loss of cooling fan

➢ **"Flexibility of siting"**

Background

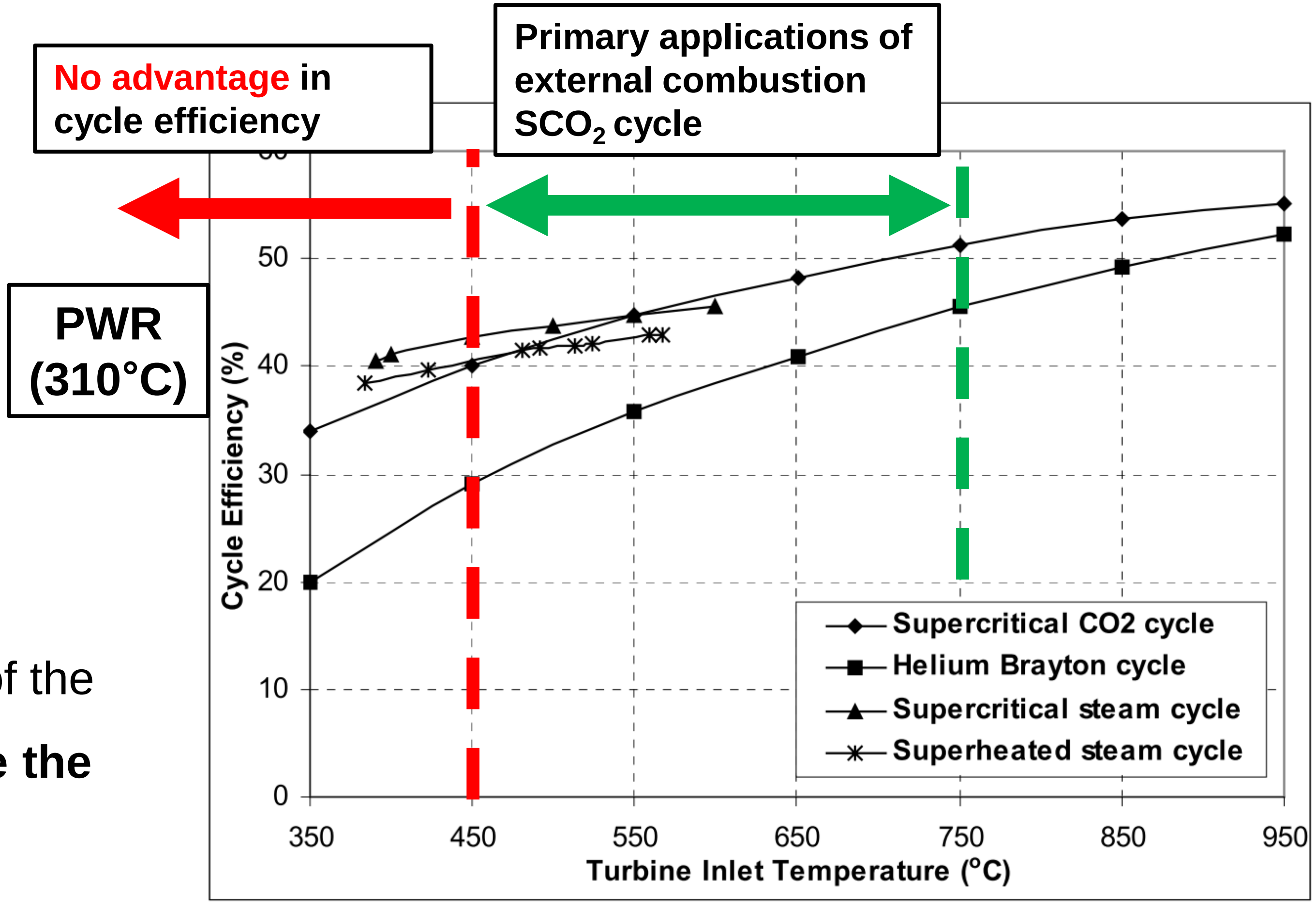
Disadvantages of the SCO_2 cycle for iPWR

Low efficiency compared to superheated steam cycle

$$Q_{out} = Q_{in}(1 - \eta)$$

- ✓ the low efficiency increases **the heat rejection duty.**
- ✓ **Lack of information & interest** in applications where ***<u>no advantage in cycle efficiency.</u>***

  - ➢ **<u>It is not clear</u>** whether the advantages of the SCO2 cycle in air cooling can **overcome the decreased efficiency.**

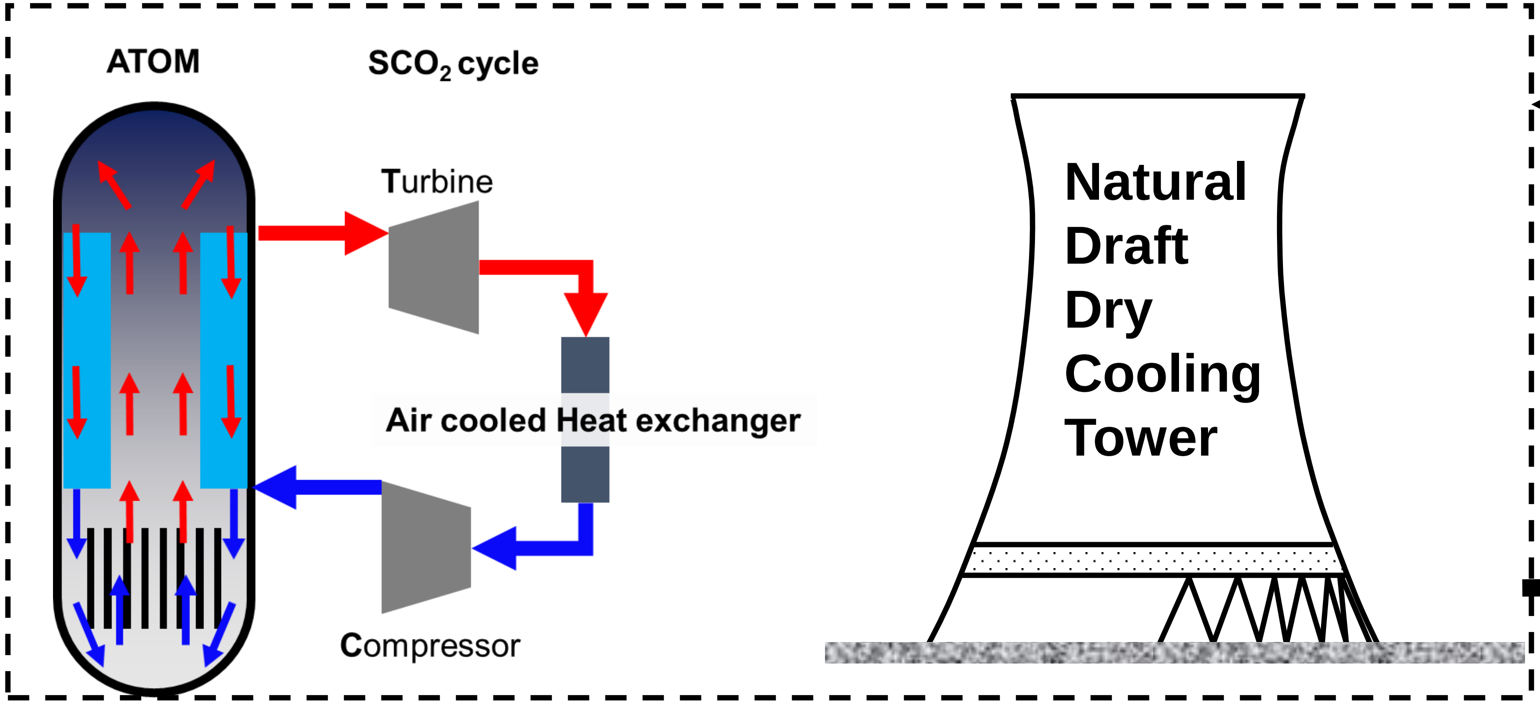


Overview

1st Stage of designing dry air-cooling SCO_2 system for iPWR

Main objective of this study:
To investigate effect of design parameters of SCO_2 cycle on the dry air-cooling system for iPWR type SMR

Main contents of this study : Sensitivity analysis



- Compressor inlet temperature
- Cycle maximum Pressure
- Cycle layout

- **Cycle efficiency**
- **Tower height**

NDDCT solver : Air side approximation

- **Elevation effect of atmosphere**

✓ Pressure gradient in gravity field

$$dP/dz = -\rho_a g$$

➢ Isentropic expansion according to the z-direction

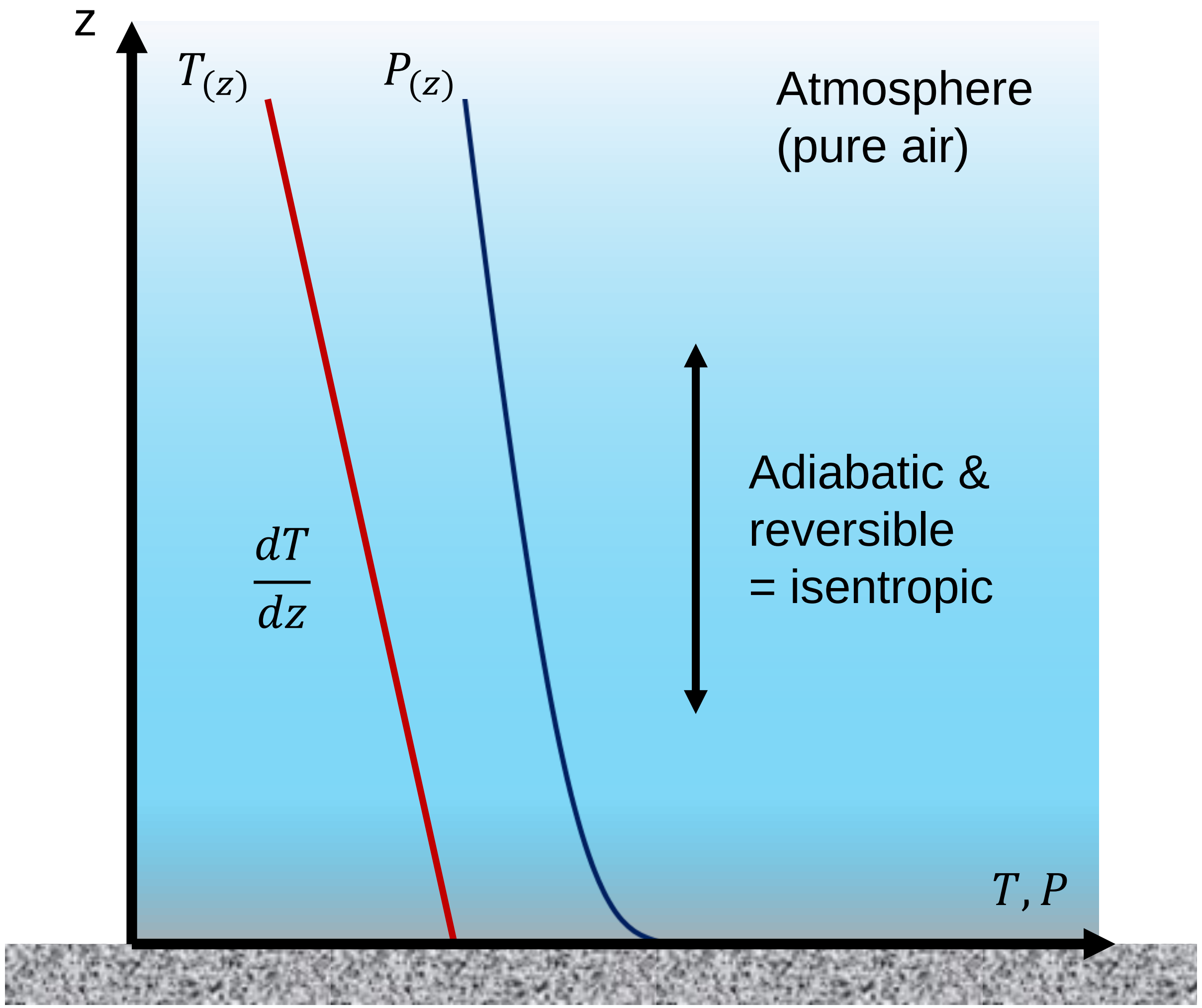
$$\frac{d}{dz}\left(\frac{P}{\rho^k}\right) = 0$$

➢ Ideal gas assumption

$$\rho = P/RT \qquad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$\frac{(1-k)}{kP}\frac{dP}{dz} + \frac{1}{T}\frac{dT}{dz} = 0$$

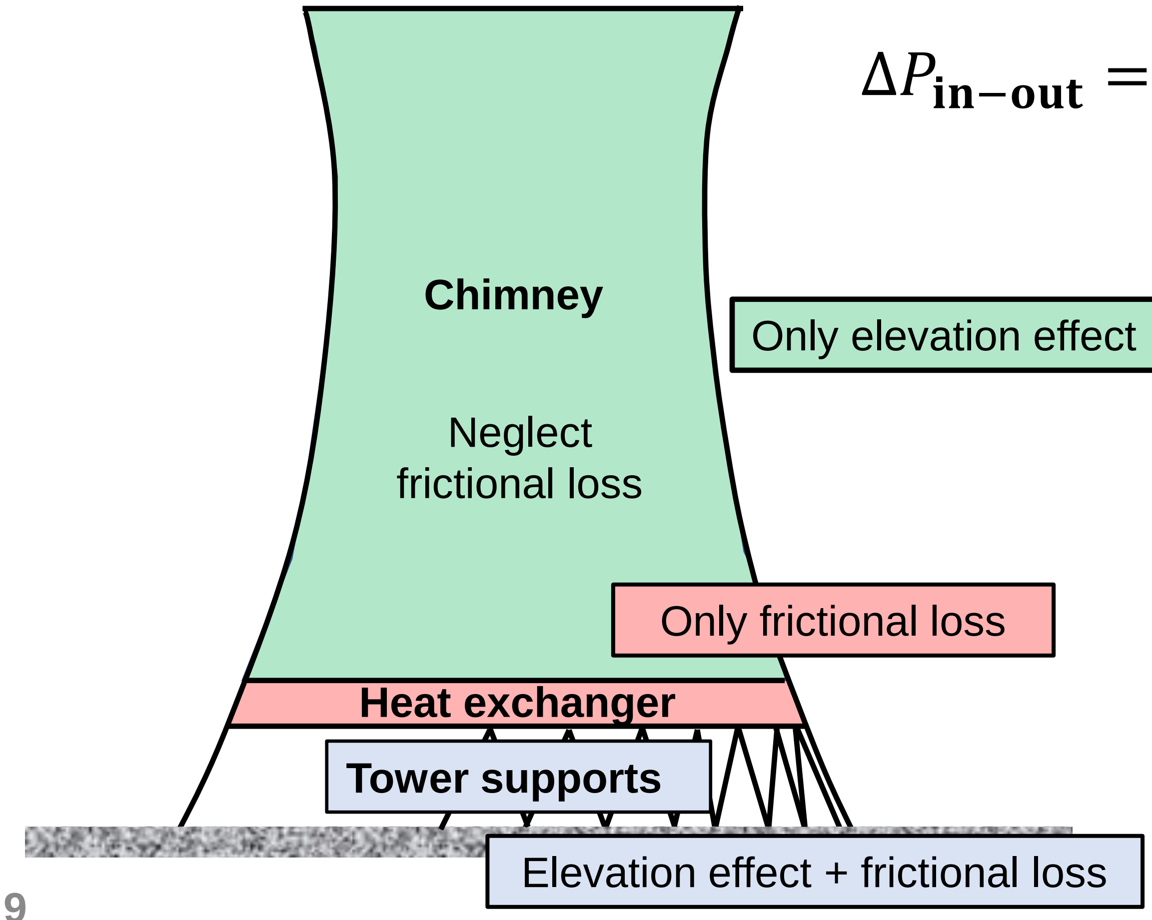
$$\therefore \frac{dT}{dz} = -\frac{g(k-1)}{kR} \qquad \therefore P = P_1\left(1 + \frac{z}{T_1}\frac{dT}{dz}\right)^{\frac{k}{k-1}}$$



Method

NDDCT solver : Tower side approximation

- **Pressure balance of NDDCT**



$$\Delta P_{\mathbf{in-out}} = \Delta\rho g H_c - \left[\text{Elevation to chimney outlet} + \text{Heat exchanger loss} + \text{Elevation to chimney inlet} + \text{Tower inlet loss} + \text{Tower support loss}\right]$$

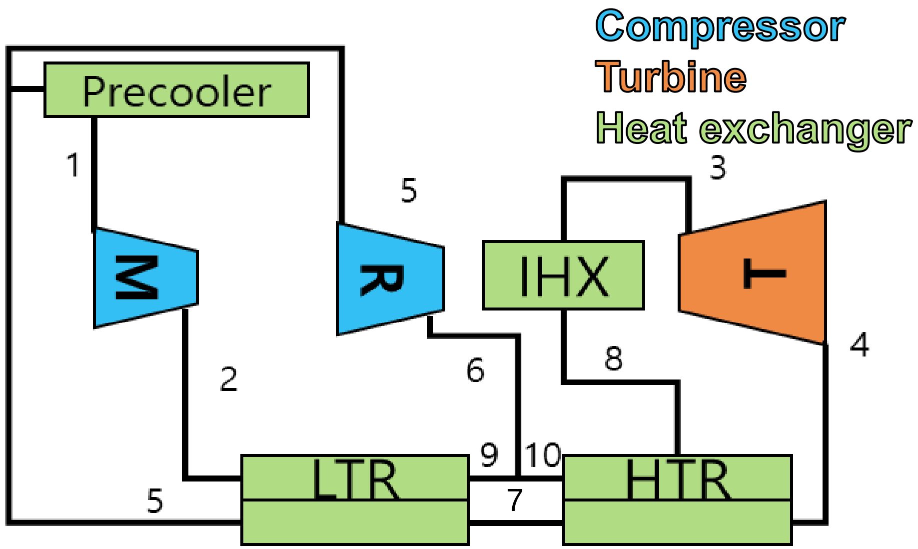
- **Tower geometrics**

Parameters	Value
The aspect ratio (H_5/d_3)	1.4
Tower inlet height (H_3)	10 m
Diameter ratio (d_5/d_3)	0.7
Heat exchanger coverage ratio (A_{fr}/A_3)	0.65
Length & diameters of tower supports	10.5 & 0.5 m

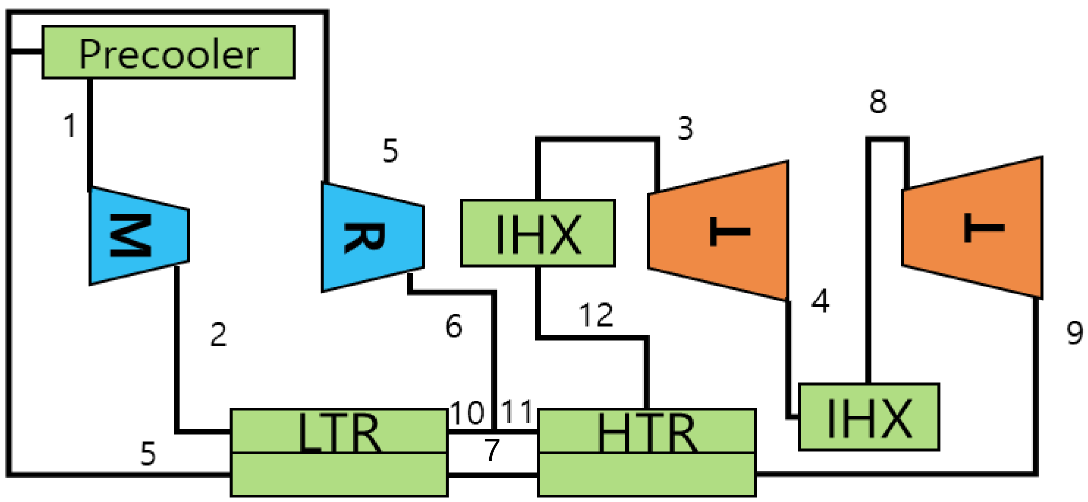
Method

Thermodynamic solver : SCO2 cycle layout

- **Recompression Cycle**



- **Recompression Reheating Cycle**



Turbine & Compressor

✓ Turbomachinaery : isentropic efficiency

$$\Delta h_{comp} = \frac{\Delta h_s}{\eta_{comp}}, \Delta h_{turb} = \Delta h_s * \eta_{turb}$$

Heat exchanger

✓ Heat exchanger : effectiveness method

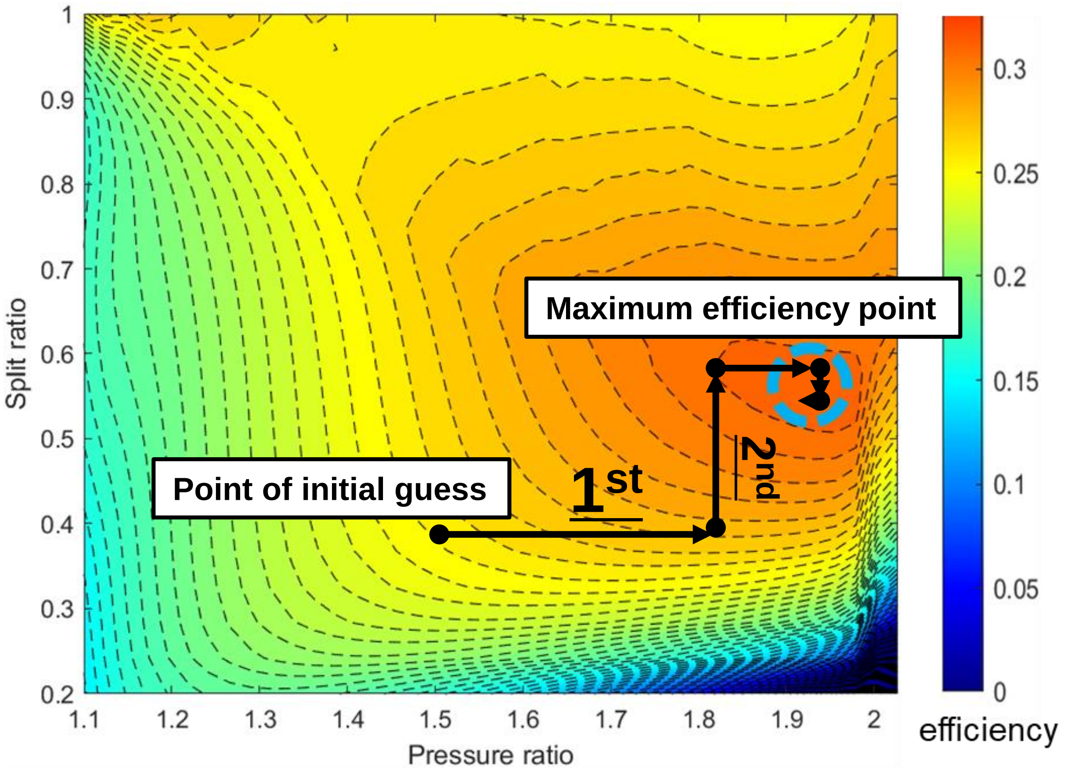
$$q_{req} = \epsilon_{HTR,LTR} * \Delta h_{\max}$$

Method

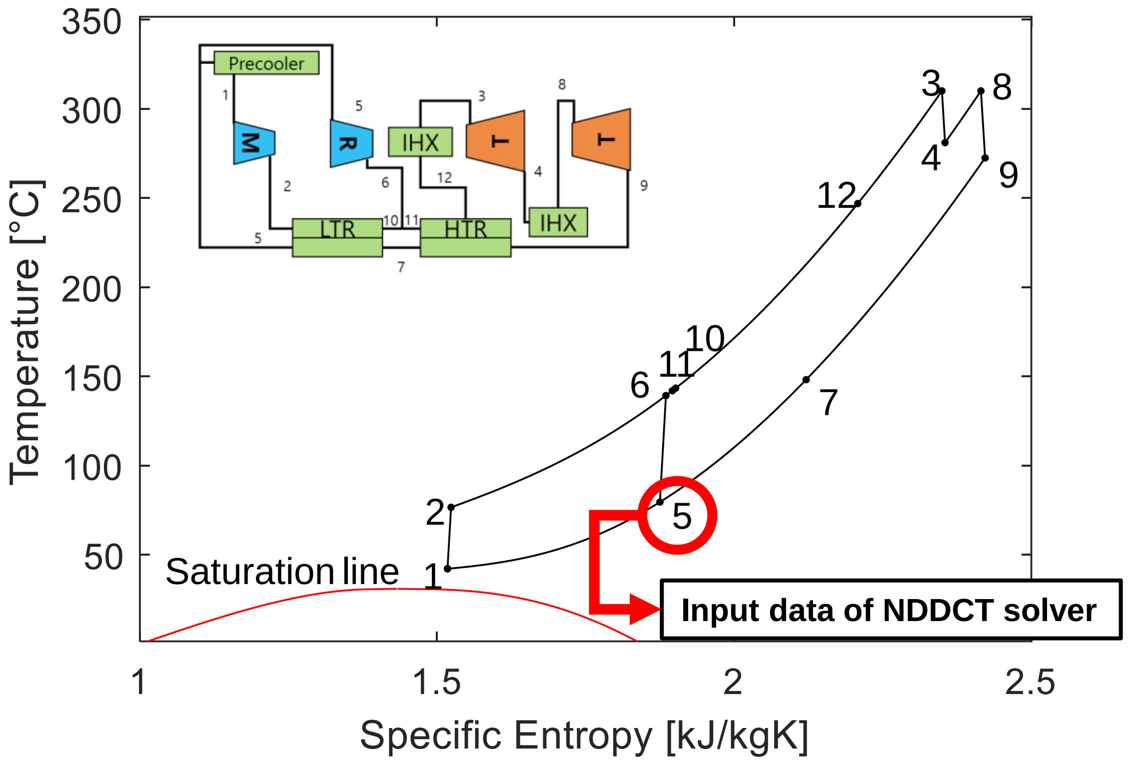
Thermodynamic solver : cycle efficiency & Operating parameters

- **Optimization of operating parameters : Flow split ratio & Pressure ratio**

✓ Optimization process of operating parameter



✓ Calculation results of the thermodynamic solver



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Method

Sensitivity parameters & Fixed parameters

- **Sensitivity parameters**

Parameter	Range
Compressor inlet temperature	32°C – 55 °C
Cycle maximum Pressure	15MPa – 25 MPa
Cycle layout	Simple RC cycle & Single stage reheating

✓ Parameters with high sensitivity to efficiency are selected as sensitivity parameters for this preliminary analysis.

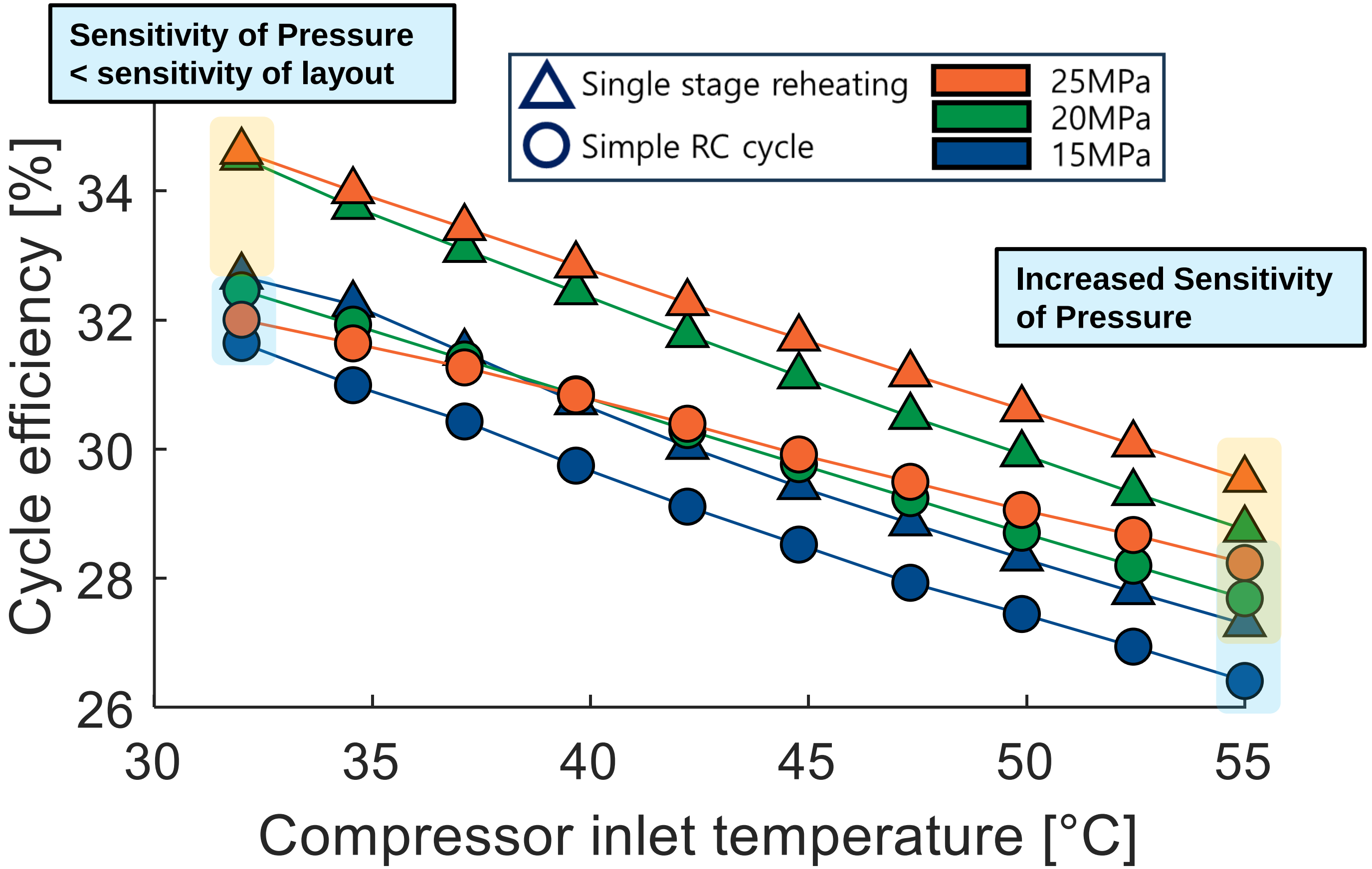
- **Fixed parameters of SCO_2 cycle for 470MWt iPWR**

Parameters	Value (or range)	Consideration
Turbine inlet temperature.	310°C	PWR condition
Compressor efficiency	0.89	Literature reference
Turbine efficiency	0.9	Literature reference
Maximum heat exchanger effectiveness	~0.95	Literature reference
Ambient air temperature	25°C	Assumption
Ambient air pressure	103kPa	Assumption

Results & Discussion

Sensitivity analysis of the cycle

- **Cycle efficiency results**



✓ In **25MPa with reheating case**, it shows the **best efficiency** over the whole cases.

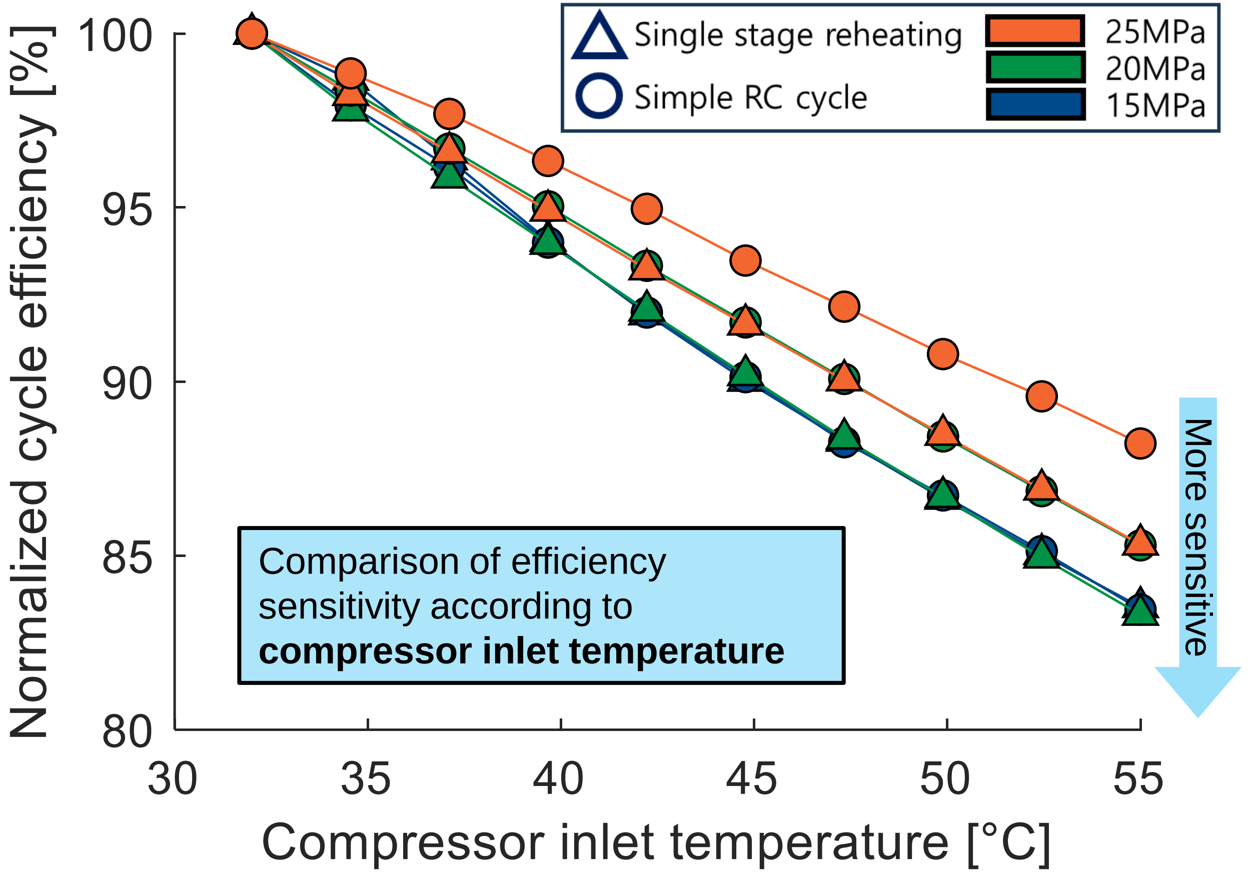
✓ In **reheating cases**, the **effect of cycle maximum pressure is greater** than that of simple RC cases.

✓ In the **case of 25 MPa**, the **sensitivity according to temperature** was the smallest.

Results & Discussion

Sensitivity analysis of the cycle

- **Normalized cycle efficiency :** $\eta/\eta_{@T=32°C}$



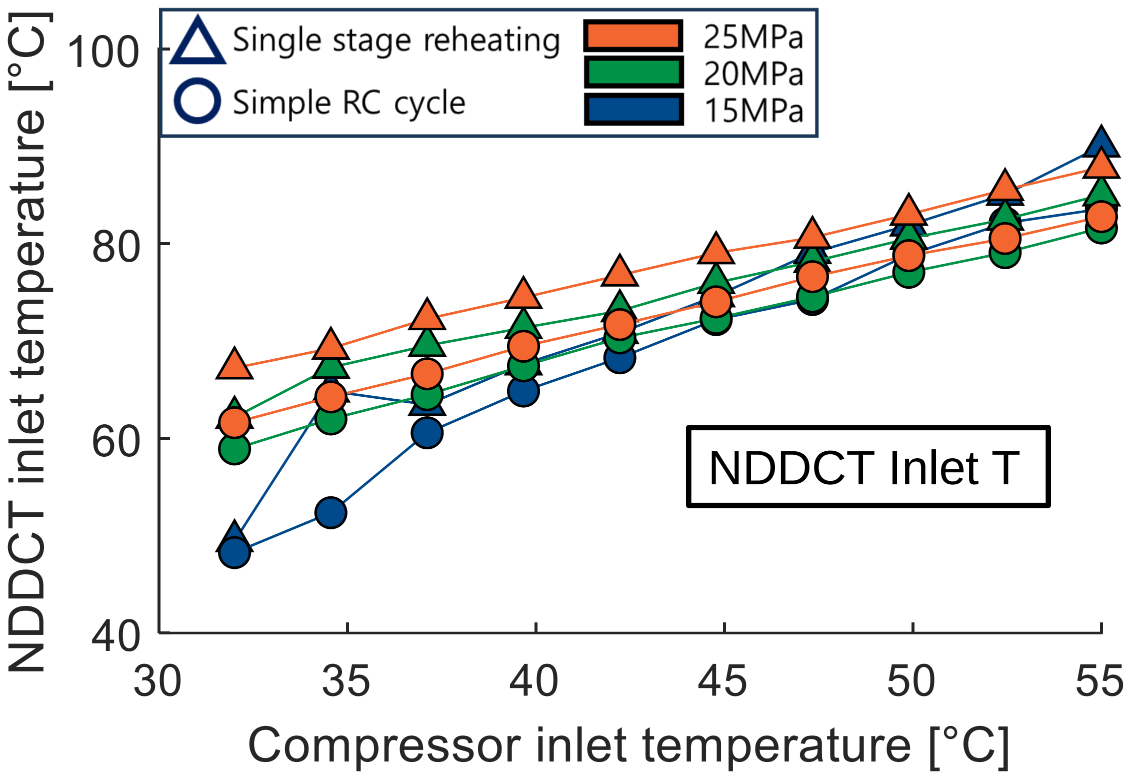
✓ In the case of 20 MPa and 25 MPa, it was found that the **temperature sensitivity of the system increased as reheating system** was applied.

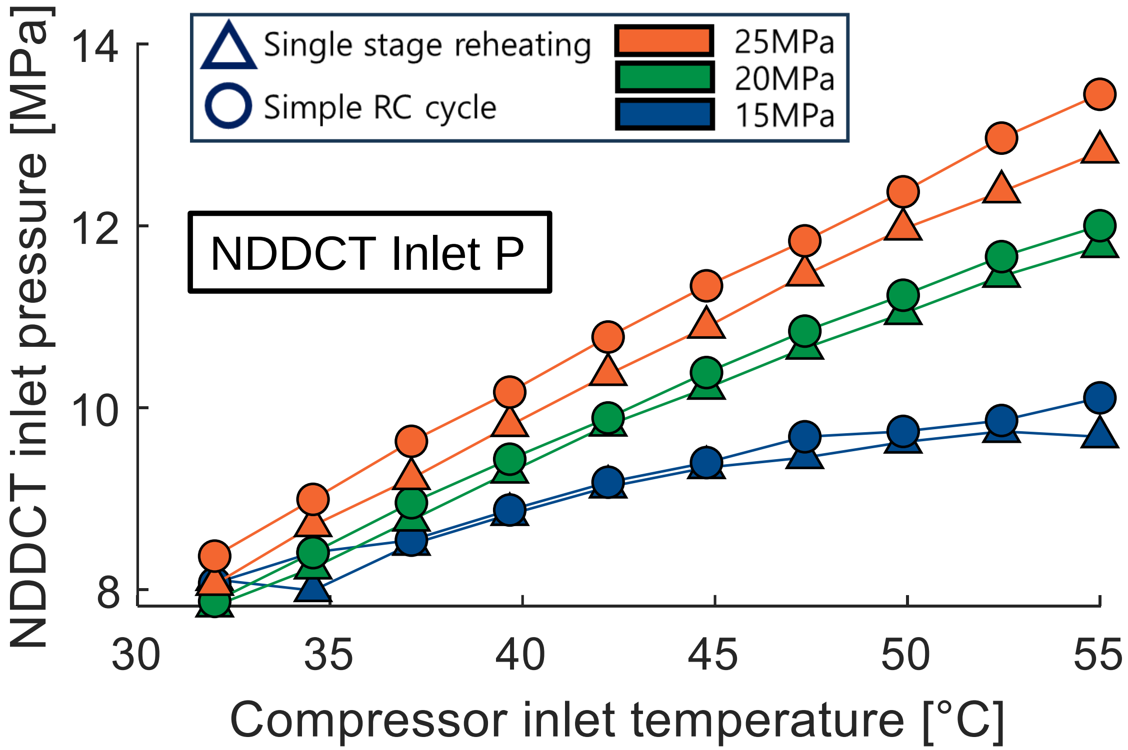
✓ At 15 MPa case, the sensitivity due to the difference of layout was not observed.

Results & Discussion

NDDCT Input data from thermodynamic solver

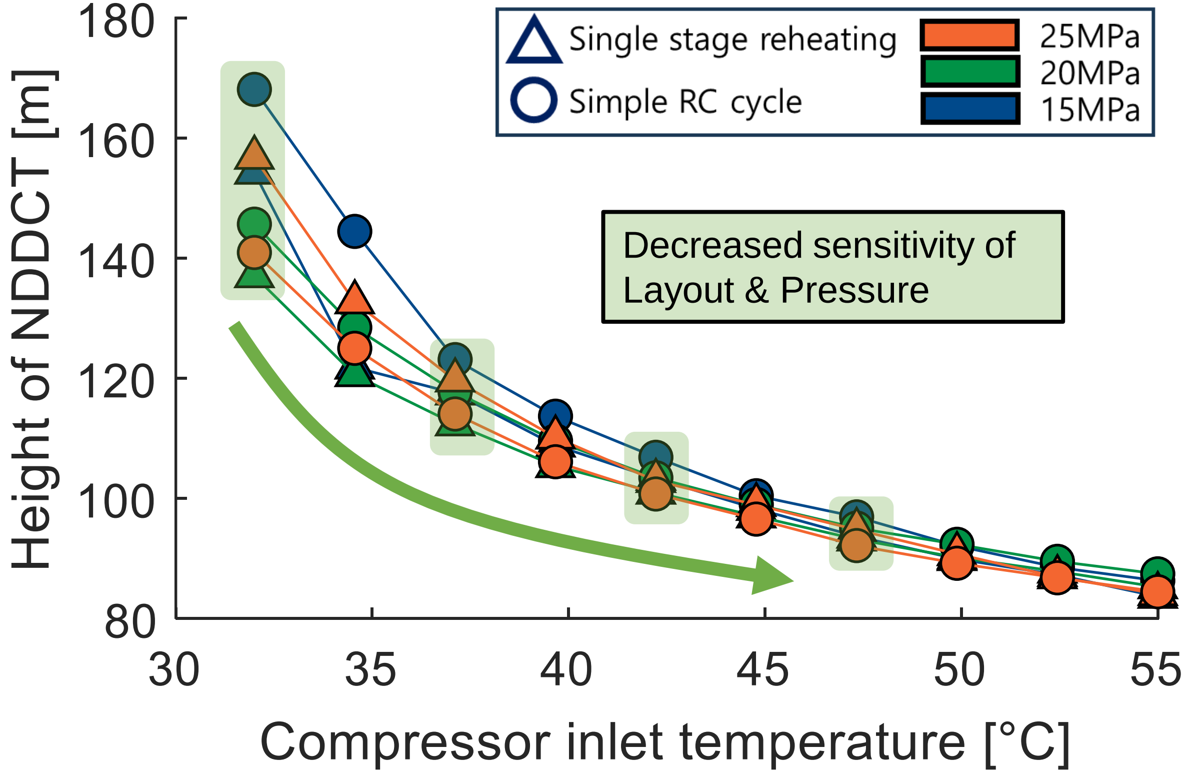
- **NDDCT Input data from thermodynamic solver**





Sensitivity analysis of the cycle

- **Evaluated height of NDDCT**



✓ In the case of compressor inlet temperature of 32°C, **20MPa reheating case** was found to be **the most advantageous for air-cooling.**

✓ Sensitivity of **all design parameters decreases** with increasing system minimum temperature.

Conclusion

Sensitivity analysis of the cycle

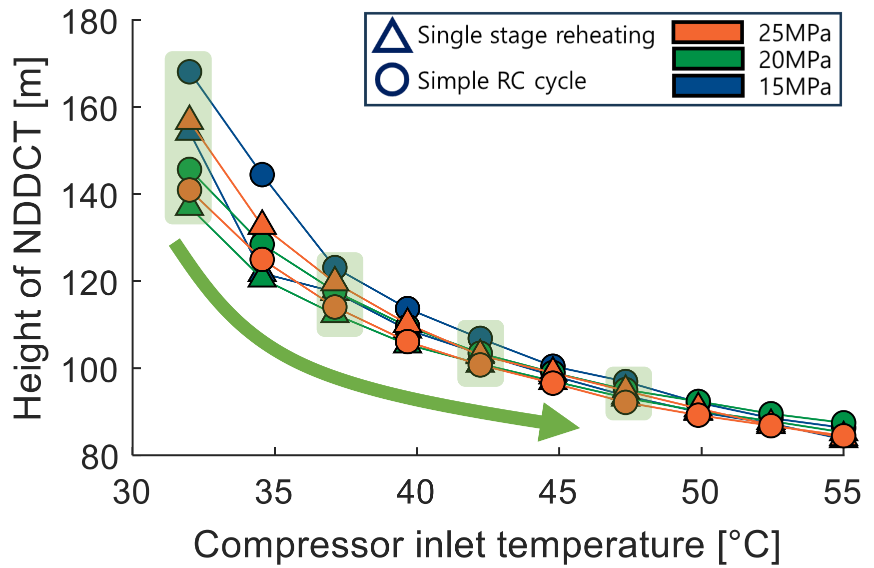
- **Key finding :**

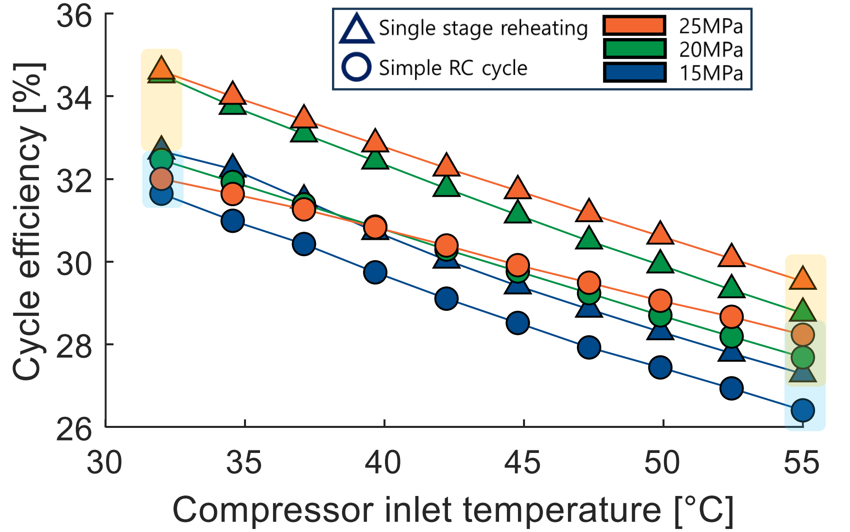
1. In dry air-cooling conditions, although efficiency determines the amount of heat rejection duty, it did not have a significant effect on the height of NDDCT.
2. Optimization of **the compressor inlet temperature** is essential.

✓ In the dry air-cooled SCO_2 cycle for iPWR-type SMR, it was found that **the compressor inlet temperature is the most important variable** through sensitivity analysis.

✓ Finding a reference variable for optimizing compressor inlet temperature will be a key task of designing NDDCT.

✓ It is necessary to find out the cause of the nonlinear sensitivity to the system maximum pressure.





Thank you for your attention

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