Thermodynamic Study of Compressed CO_2 Energy Storage System Integrated to a Conventional PWR

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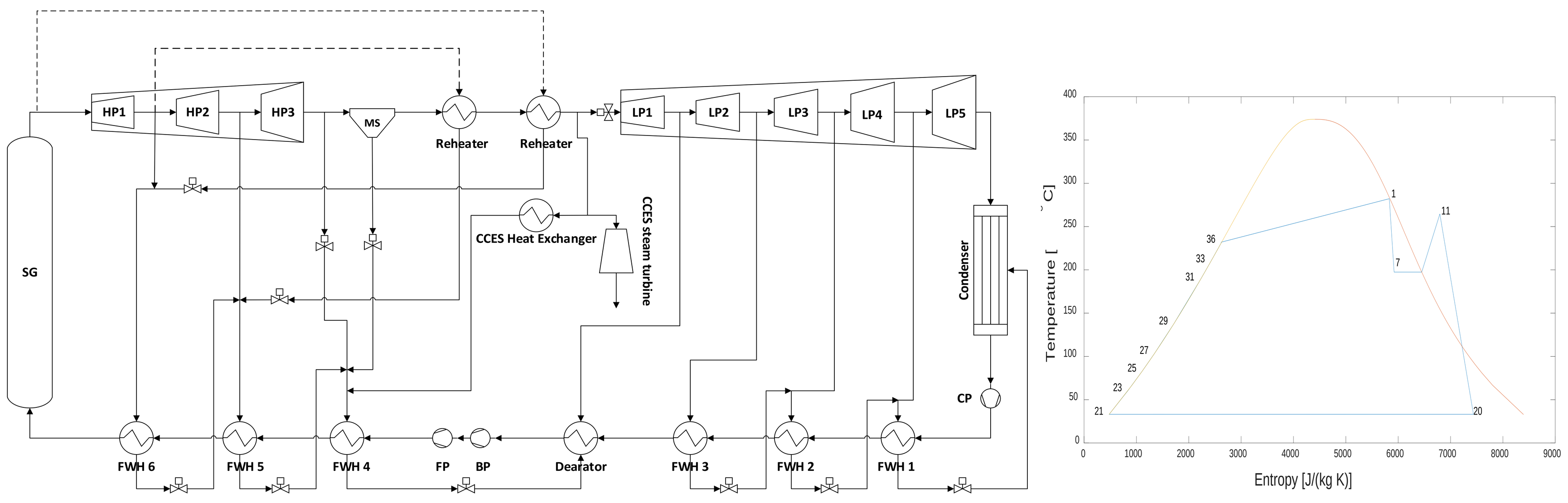
Introduction

- ✓ Recently, the ratio of renewable energy in the grid has increased as changes in energy policy globally to prevent climate change, but renewable energy has unexpectable intermittency during power generation. This issue can be alleviated by load-following operation of a nuclear power plant (NPP).
- ✓ it is not economical to control power output of the reactor in an NPP and can have a problem in nuclear fuel integrity. Energy Storage System (ESS) attached to the power cycle can solve this issue.
- ✓ Supercritical-CAES (SC-CAES) has quite high round-trip efficiency, but the critical point of air cannot be reached easily. If air is substituted with CO_2 , its critical point can be easily reached with the current technology.
- ✓ A concept of supercritical compressed CO_2 energy storage (CCES) system was developed previously and showed good expected performance. Therefore, it needs to study the feasibility of a NPP integrated with CCES.

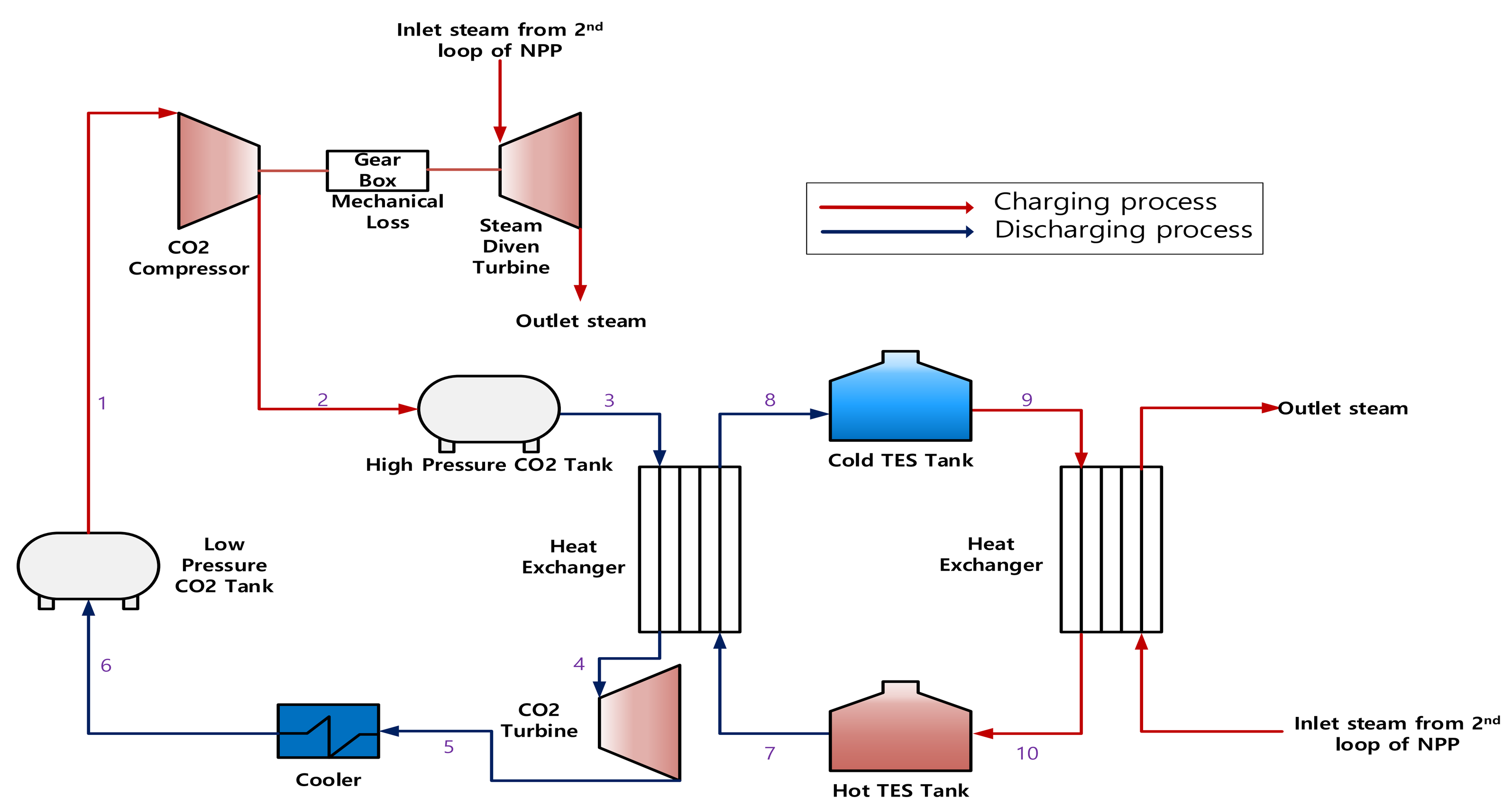


- Layout (Left) and T-s diagram (Right) of Steam Cycle integrated with CCES

- ✓ In the previous study, thermodynamic study Secondary side (steam cycle) of the NPP integrated with CCES was studied and then it was shown how much work of the steam turbine was changed. Using these results, the performance of CCES with NPP can be obtained.
- ✓ Thus, in this paper, **a thermodynamic analysis of CCES integrated to a conventional PWR are studied.**

Thermodynamic modeling

✓ Thermodynamic modeling of CCES integrated with a PWR



- Layout of simple CCES integrated to PWR steam cycle

(1) CCES has two storage methods. - thermal energy storage (TES) and mechanical storage using a steam driven CO_2 compressor (STDC).

(2) Two-tank TES and HITEC molten slat are used as TES type and heat transfer fluid (HTF), respectively.

(3)As shown in the layout, 1-3, 10-12 and 15-16 are the energy storage process (Charing operation) and the rest of processes are the energy recovery process (Discharging operation).

✓ Limitation condition of component

(1) Heat exchanger (HX)

- If it has too small pinch, the length and volume of a HX would be too big.
- Minimum pinch should be considered due to realistic size of HX.

(2) Pipe sizing

- From preliminary study of CCES integrated to NPP, it may have large mass flow rate CO_2
- It should check whether the pipe diameter is over acceptable maximum diameter (ASME standard, about 2m)
- Pipe diameter can be evaluate from an empirical formula suggested by Ronald W. Capps

$$D = 2\sqrt{\frac{\dot{m}}{\pi f_{pv}\rho^{0.7}}}$$

✓ Cycle condition and Parameters

Parameters	Value	Unit
Temperature of low-pressure reservoir	308.15	K
Temperature of HITEC cold tank	423.15	K
Mass flow rate of HITEC	9000	kg/sec
Isentropic efficiency of turbines	0.9	
Isentropic efficiency of compressor	0.85	
Effectiveness of heat exchangers	0.9	
Ratio of charging time to discharging time	1	
Pressure drop in HX	1	%
Total steam bypass fraction	20	%
Minimum pinch in HX	5	K
Mechanical loss of gear box	5	%

Variables	Range of Variation	Unit
Steam bypass fraction to TES of CCES	10-90	%
Pressure of low-pressure reservoir	7.8-8.3	MPa
Pressure of high-pressure reservoir	20-25	MPa

✓ Criteria of cycle performance

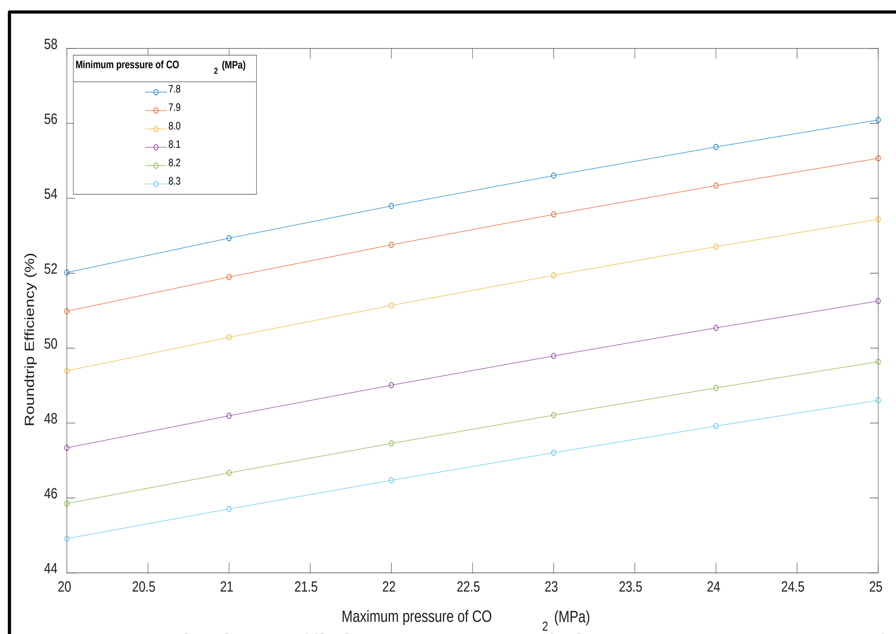
(1) Round-trip efficiency (RTE)

$$\eta_{RT} = \frac{E_{charging}}{E_{discharging}} = \frac{W_{turb,CCES}}{W_{NPP,loss}}$$

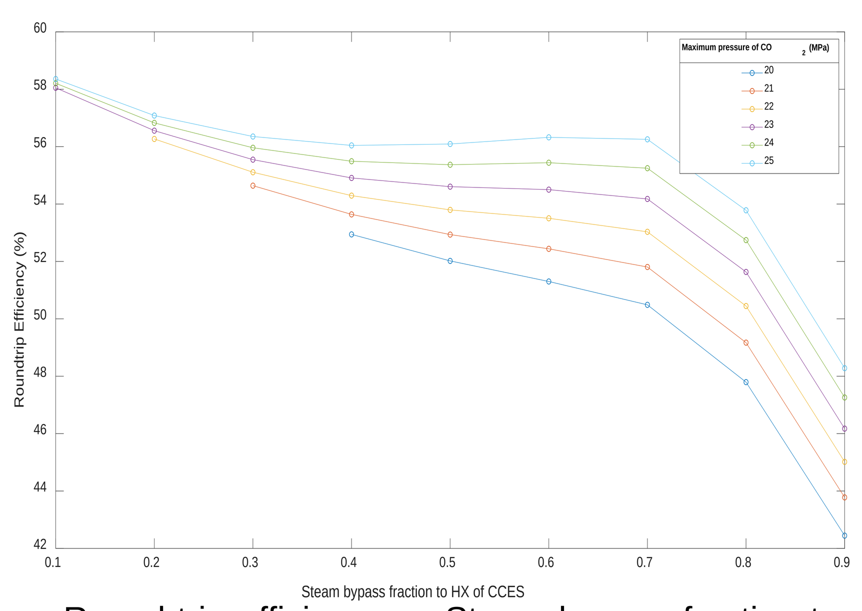
(2) Energy density

$$\rho_{energy} = \frac{W_{turb}}{\dot{m}_{charg}/\rho_{LPT} + \dot{m}_{discharg}/\rho_{HPT}}$$

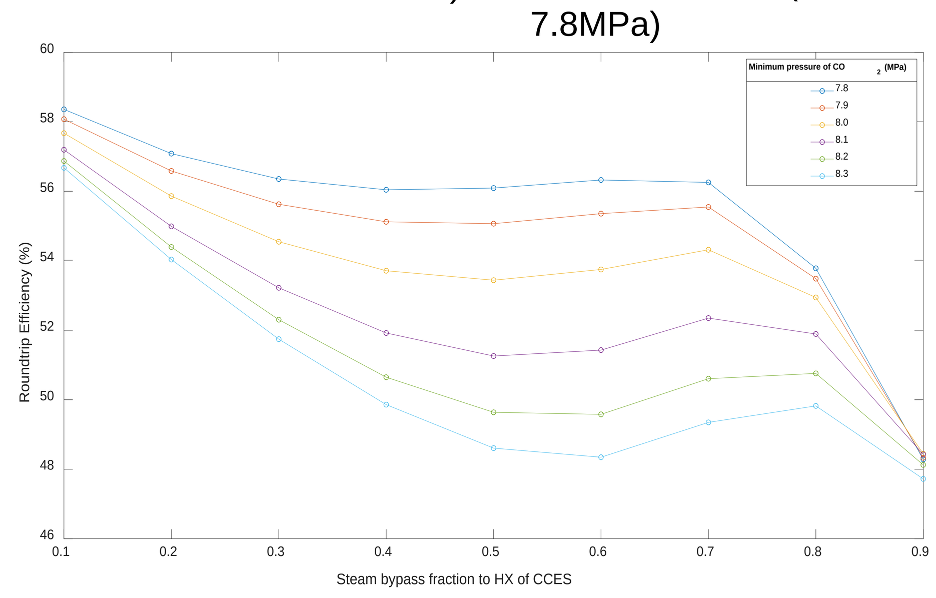
3. Results



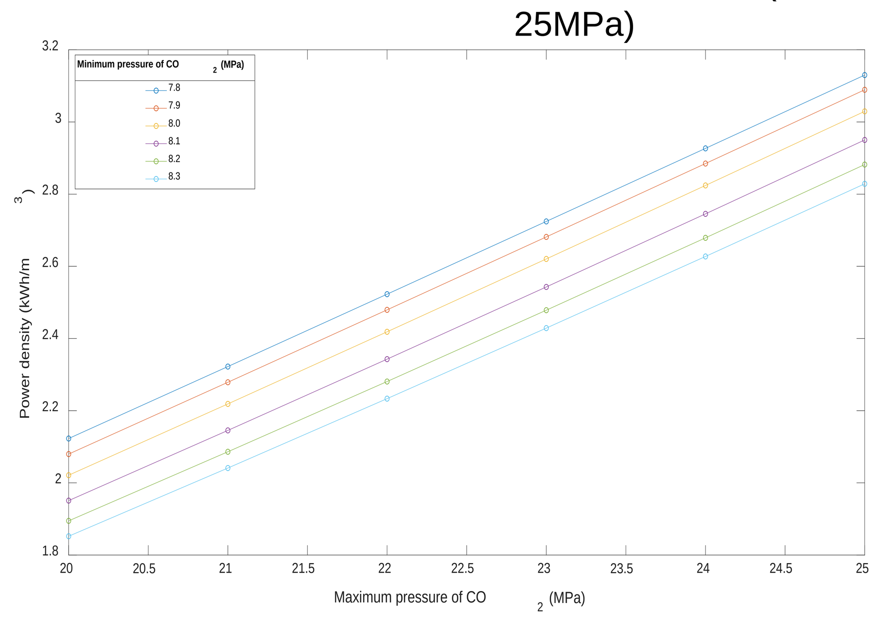
- Round-trip efficiency vs Minimum pressure of system (Steam bypass fraction to HX of CCES: 0.5)



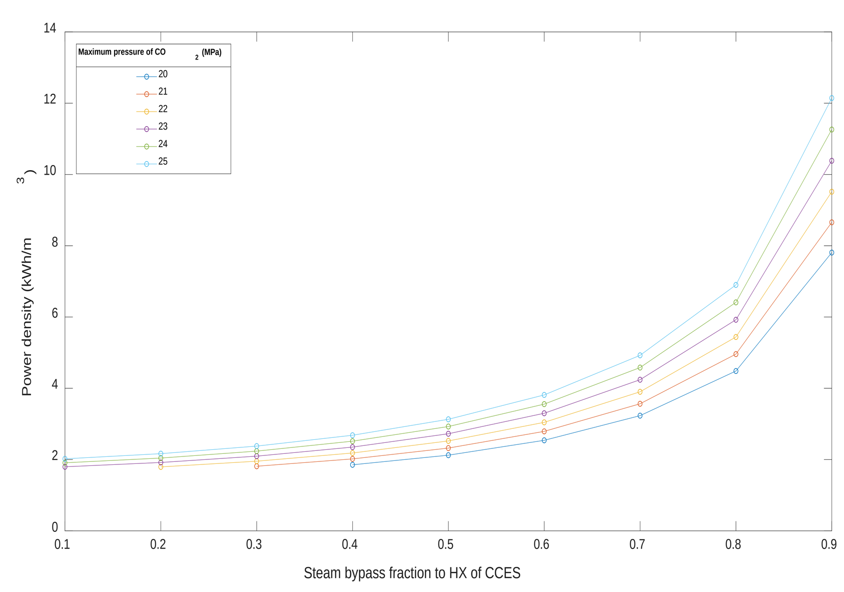
- Round-trip efficiency vs Steam bypass fraction to HX of CCES (Minimum pressure of system: 7.8MPa)



- Round-trip efficiency vs Steam bypass fraction to HX of CCES (Maximum pressure of system: 25MPa)



- Power density vs Minimum pressure of system (Steam bypass fraction to HX of CCES: 0.5)



- Power density vs Steam bypass fraction to HX of CCES (Minimum pressure of system: 7.8MPa)

Summary and Future works

- ✓ As **the maximum pressure and the steam bypass fraction to steam turbine** to drive CO_2 compressor **increase** and **the minimum pressure decreases,** the **round-trip efficiency increases** while **power density decreases**.
- ✓ **The maximum RTE** is about **52%** and **maximum power density** is about **12kWh/m³**.
- ✓ Among them, **the bypass fraction of steam to HX of CCES** is the **most effective parameter**.
- ✓ Further investigation will commence soon regarding **optimization** of CCES round-trip efficiency and power density by adding **off-design model** as well.