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

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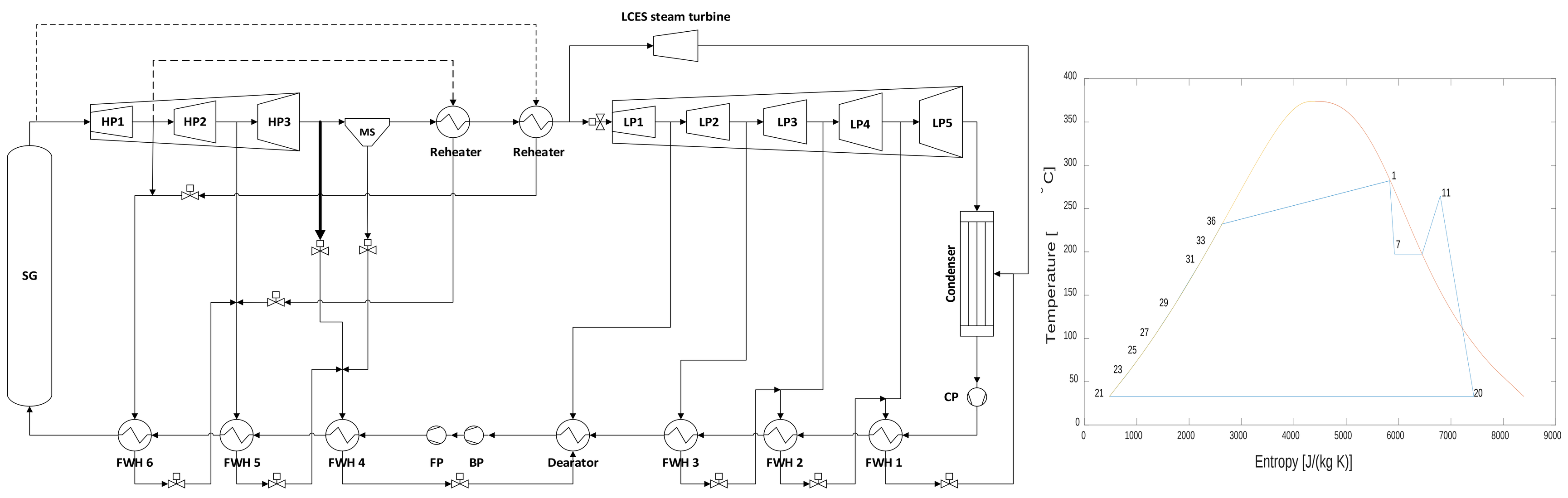
Introduction

- ✓ Recently, the energy production from renewable energy (RE) sources is increasing globally and domestically to reduce greenhouse gas (GHG) emission and 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.
- ✓ Among the various ESSs, compressed CO2 energy storage (CCES) is promising ESS due to high round-trip efficiency (RTE) and simple layout.
- ✓ CCES integrated to a conventional PWR was studied and analyzed thermodynamically previously. From this reference, its maximum RTE was estimated to be around 52%. However, it had quite low energy density, 3.2kWh/m³

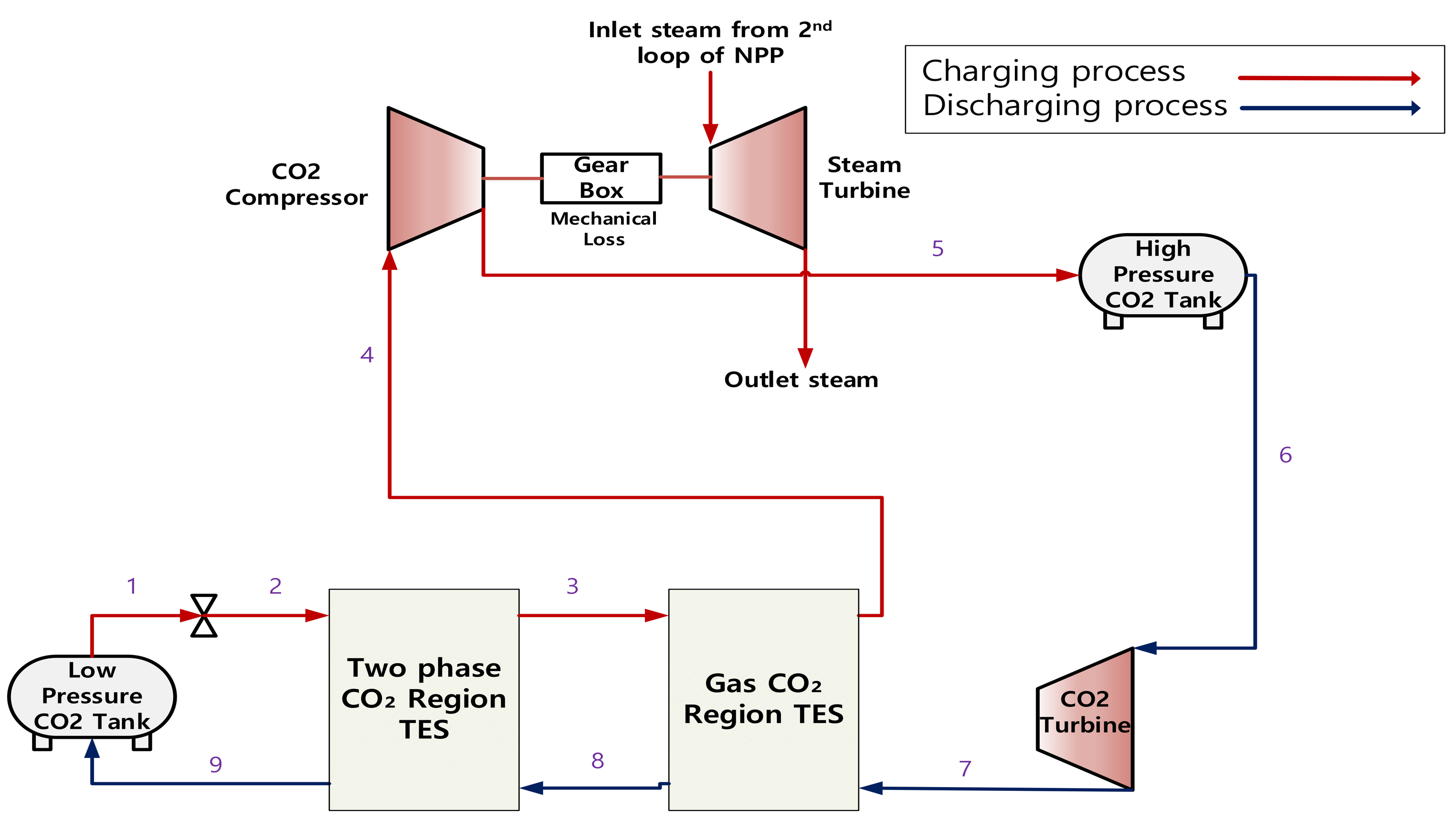


- Layout (Left) and T-s diagram (Right) of Steam Cycle integrated with LCES

- ✓ Liquid air energy storage (LAES) has high energy density due to small mass flow rate and high density of working fluid from liquefaction of air. In order to make CCES more economical, CCES needs to further increase the energy density. This paper proposes to use the liquefaction process for this purpose
- ✓ Thus, in this paper, **a thermodynamic modeling and analysis of a liquid CO_2 energy storage (LCES) integrated to a conventional PWR are studied.**

Thermodynamic modeling

✓ Thermodynamic modeling of LCES integrated with a PWR

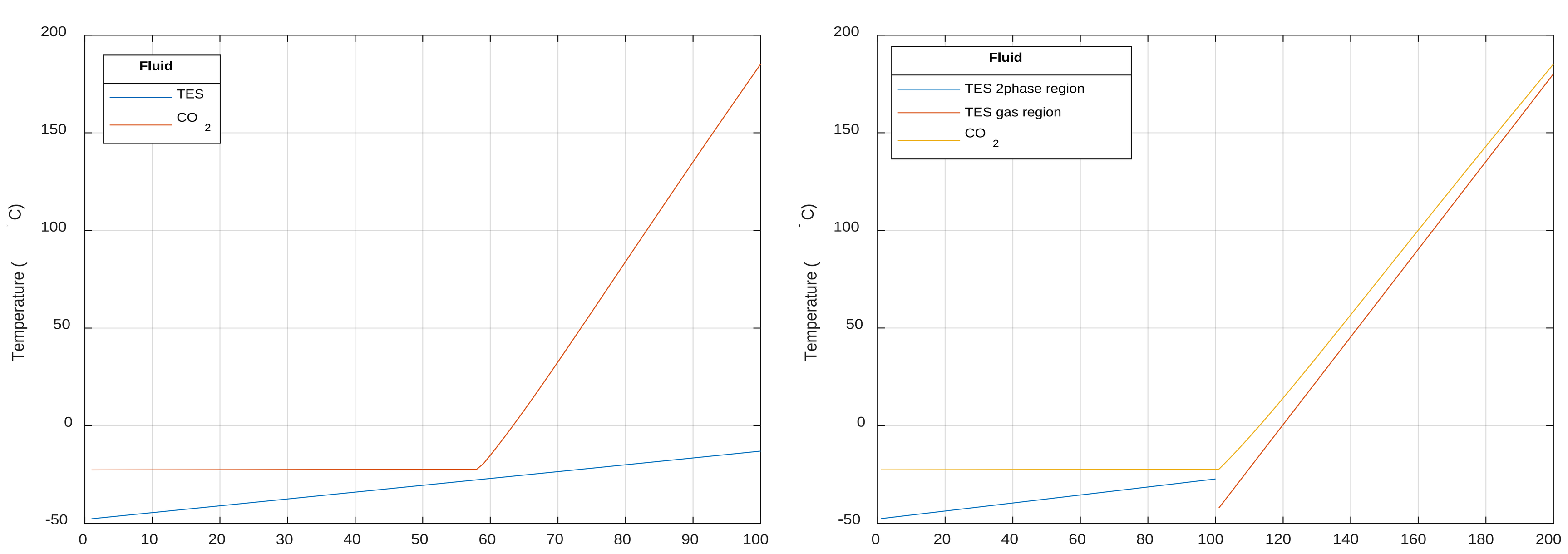


- Layout of LCES integrated to PWR steam cycle

(1) As shown in the above layout, processes 1-5 are the energy storage process (Charing operation) and the rest of processes are the energy recovery process (Discharging operation).

(2) In order to achieve high energy density, a liquefaction process is introduced before entering the low-pressure tank. TES for the liquefaction process and a throttling valve for better heat exchange are added.

✓ Limitation of liquefaction process



- Temperature profile in one TES (Left) and two TESs (Right) of LCES

(1) If it uses only one TES for liquefaction of CO_2, the maximum temperature loss of CO_2 is quite high due to pinch problem in the heat exchanger.

(2) When it uses two TESs, the maximum temperature loss problem can be avoided.

- Gas region CO_2 TES : -20~180℃
- Two-phase region CO_2 TES : -50~20℃

✓ Cycle condition and Parameters

Parameters	Value	Unit
Total steam bypass fraction to LCES	20	%
Ratio of charging time to discharging time	1	
Inlet temperature of CO_2 compressor	308.15	K
Isentropic efficiency of turbines	0.9	
Isentropic efficiency of compressor	0.85	
Effectiveness of heat exchangers	0.9	
ΔT between two tanks in 2-phase region TES	20	K
Pressure drop in HX	1	%
Minimum pinch in HX	5	K
Mechanical loss of gear box	5	%

Variables	Range of Variation	Unit
Pressure of low-pressure reservoir	0.6-3.4	MPa
Pressure of high-pressure reservoir	20-30	MPa

✓ Criteria of cycle performance

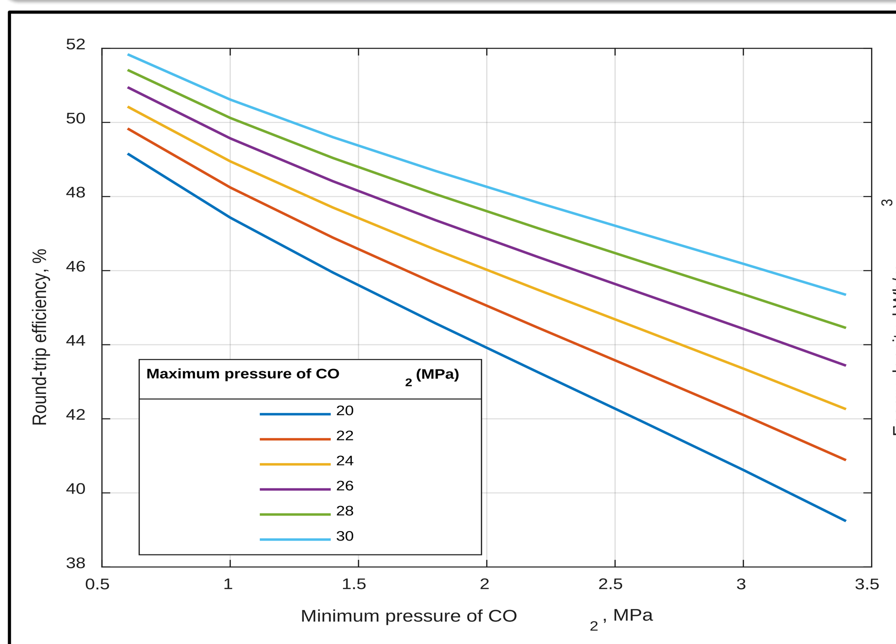
(1) Round-trip efficiency (RTE)

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

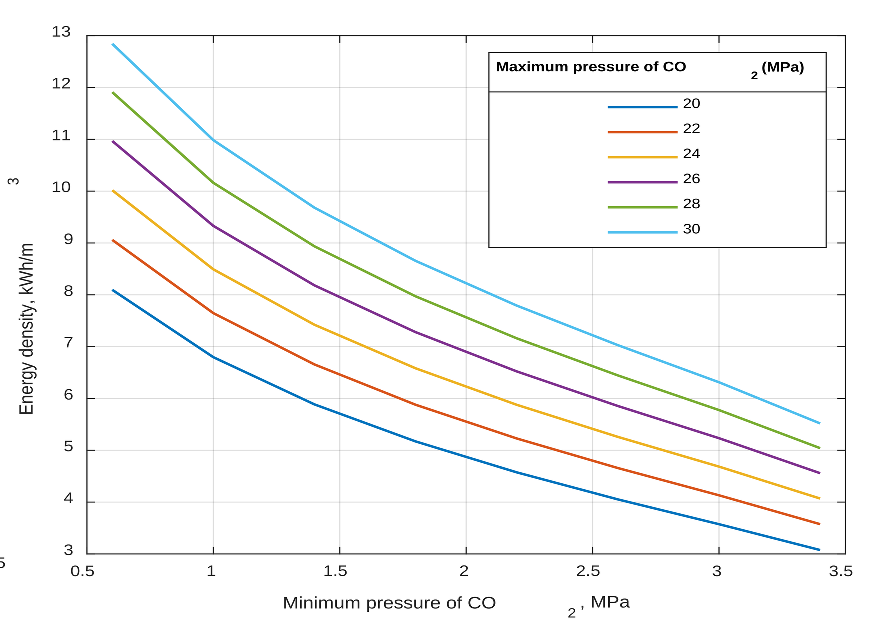
(2) Energy density

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

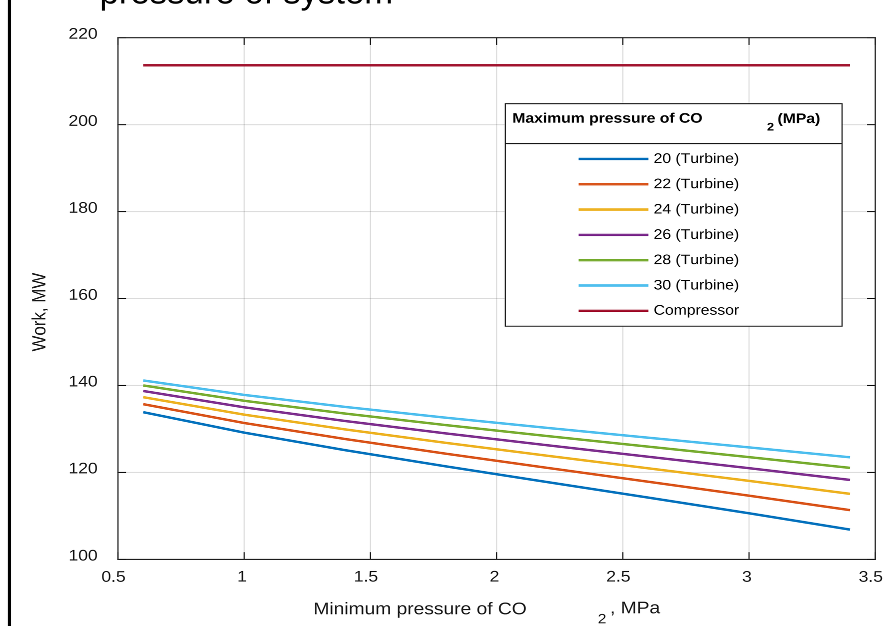
3. Results



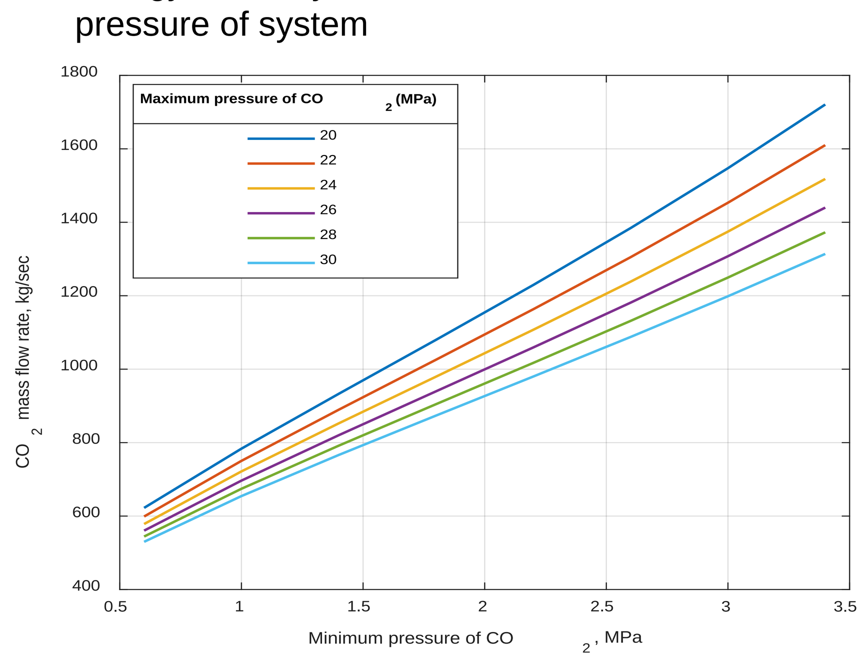
- Round-trip efficiency vs Minimum and maximum pressure of system



- Energy density vs Minimum and maximum pressure of system



- Work of turbine and compressor vs Minimum and maximum pressure of system



- CO_2 mass flow rate vs Minimum and maximum pressure of system

Optimization point	Range of Variation	Unit
Pressure of low-pressure reservoir	0.6	MPa
Pressure of high-pressure reservoir	30	MPa

Optimization result	Value	Unit
Round-trip efficiency	51.8	%
Energy density	12.8	kWh/m³
CO_2 turbine work	141.16	MW
CO_2 mass flow rate	529.9	kg/sec
Density of CO_2 in LP tank	1043.7	kg/m³
Density of CO_2 in HP tank	253.1	kg/m³

Summary and Future works

- ✓ As the **maximum CO_2 pressure increases** and **the minimum CO_2 pressure decreases**, the **energy density** and **RTE increase**. In other words, the pressure ratio is the largest, it can be seen that it has the highest RTE and energy density
- ✓ The **maximum and minimum pressures** of CO_2 at the optimum point are **30 MPa** and **0.6 MPa**, respectively. The **maximum energy density and RTE are 12.8 kWh/m³ and 51.8%**, respectively.
- ✓ Compared with previous **CCES**, **LCES** has almost the **same RTE** while having more than **3 times** the **energy density**.
- ✓ Further investigation will commence soon regarding **optimization of LCES round-trip efficiency and energy density by adding various liquefaction processes** as well.