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Comparison of Isothermal and Isentropic Thermo-electric energy storage systems with trans-critical CO_2 cycle coupled to nuclear energy

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1. Introduction

For decades, reducing greenhouse gas emissions and ensuring long-term stability in energy supply have been a challenge. Energy storage with zero carbon emissions and low marginal cost can solve this problem. As shown in Figure 1, load-following and picking services are also provided by energy storage plants, consuming electricity during periods of least demand and transmitting it back to the grid during periods of peak demand. In S. Korea, since nuclear electricity is the least expensive energy, it is best to couple an energy storage system with nuclear power.

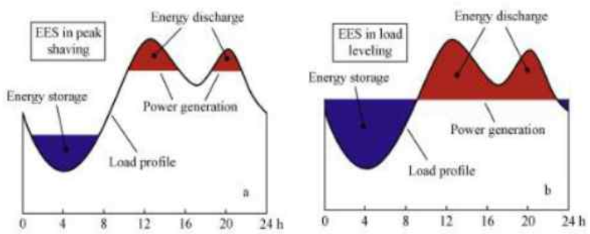

Fig. 1. Load profile of a large-scale electricity storage system. (right) EES in Peak Shaving (left) EES in load levelling [3]

This large system also has the advantage of being able to control intermittent fluctuations in wind and solar energy [1]. Among these ESSs(energy storage system), this study deals with the isothermal TEES(thermo-electro energy system) with trans-critical CO_2 cycle. TEES is consisted of a heat pump cycle and a heat engine cycle, which the ideal machine will be a reversible Carnot cycle.

The high CO_2 density near the critical point results in large power density and consequently enabling components to be compact. TEES has the advantages of competitive energy storage efficiency, good scalability, independent of site location, and minimal environmental impact [2]. In this study, the performance of an isentropic TEES and an isothermal TEES are compared while the temperature of the hot storage is fixed.

2. Methods and Results

As shown in Figure 2, isothermal TEES has the following layout. For isentropic TEES, isentropic processes occur in components where isothermal processes occur. To compare the two systems, most of the design parameters were kept the same as summarized in Table 1. The performance of the two systems was evaluated in terms of round-trip efficiency(RTE) and power density, and the two values were calculated using MATLAB in-house code as discussed in the previous studies[4,5].

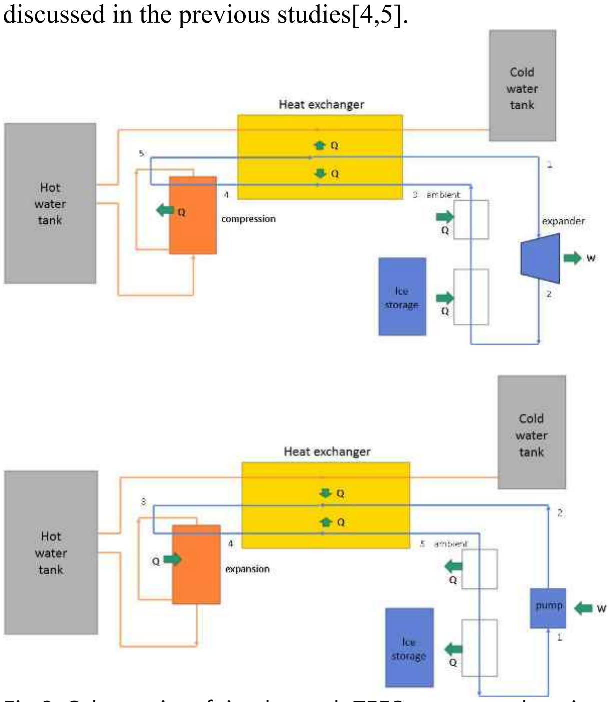

Fig.2 Schematic of isothermal TEES system, charging mode (up) and discharging mode (down)

parameters	Isentropic TEES	Isothermal TEES
Maximum pressure	16 MPa	16 MPa
Isentropic efficiency of Expander	0.9	0.9
Isentropic efficiency of Pump	0.85	0.85
Isothermal efficiency of Expander	None	0.88
Isothermal efficiency of Compressor	None	0.86
Mass flow ratio (co2:tank fluid)	1:2	1:0.3
Hot tank temperature	395 K	395 K
Cold tank temperature	303 K	Variable

Table1. Design parameters for isentropic TEES (left) and isothermal TEES (right) calculation

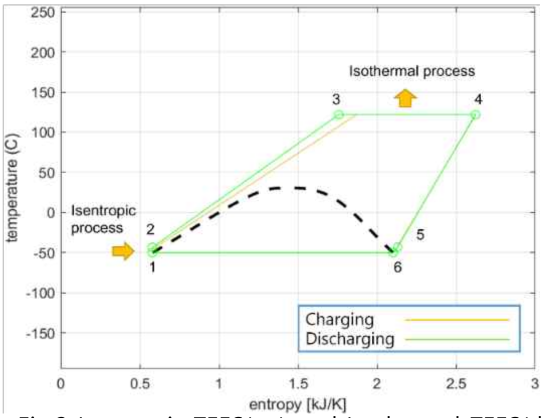

Fig.3 Isentropic TEES(up) and Isothermal TEES(down) charging and discharging cycle model with T-S diagram

The definition of RTE of the isothermal TEES is basically the ratio of the electric output power during discharge mode to the electric input power during charging mode.

$$\mathrm{RTE} = \frac{W_{discharging}}{W_{charging}} = \frac{W_{E2} - W_P}{W_C - W_{E1}} \quad (1)$$

The power density of the isothermal TEES can be defined as the ratio of work during the discharging mode to the hot and cold tanks. Volumes are calculated from the temperature of the fluid.

$$\text{power density} = \frac{W_{discharging}}{V_{hot} + V_{cold}} \quad (2)$$

Table2. Performances of Isentropic TEES(left) and Isothermal TEES(right)

result	Isentropic TEES	Isothermal TEES
Round-trip efficiency	0.5	0.66
Power density(kWh/m^3)	14.47	16.82

As shown in Table 2, the isentropic TEES has RTE of 0.5 and power density of 14.47 kWh/m^3, and the isothermal TEES has RTE of 0.66 and power density of 16.82 kWh/m^3, which is a significant difference. The difference in expansion work can be clearly seen in the T-s diagram. In Fig. 3, the isentropic expansion in discharging mode is less than the amount of isentropic compression in charging mode. Conversely, isothermal compression / expansion process requires large amount of energy in the charging/discharging mode of isothermal TEES. This is because the isothermal TEES has large expansion work in the discharging process due to effective heat transfer from the hot storage tank.

3. Conclusions

Thermo-electric energy storage system using CO_2 has attracted attention for its competitive energy storage efficiency and compact components. Compared to the isentropic system, the isothermal system emphasizes the advantages of TEES more and has an impact on its performance. Therefore, isothermal TEES is better than isentropic TEES. In this study, the performances of the two systems were compared, but future work should consider the practical aspect of the isothermal process. In order to perform isothermal expansion and compression, a special technology is required, which has been described by double-acting liquid piston type of isothermal compressor/expander [4] or isothermal compression using infinitesimal approach [6] in the previous studies. In addition, it will be necessary to pursue changes in the temperature of the water tank and its fluid, such as therminol (heat transfer fluids), that can have better heat transfer.

ACKNOWLEDGEMENT

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