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Development of Dynamic Model of Supercritical Carbon Dioxide Power Cycle with Thermal Energy Storage System

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Introduction

· As the proportion of the new renewable energy increases, the intermittency and volatility of power generation increases. In order to flexibly respond to such fluctuations, the necessity for the large-capacity energy storage capability of storing and supplying power are increasing.

· The thermal energy storage systems are considered a promising alternative due to their strength such as relatively few installation restrictions, eco-friendly, long-them energy storage, long life, and economical efficiency.

· The target ramp rate performance of the thermal energy storage system is 5%/min. In order to design control systems for such a load following operation, a dynamic model that can analyze the dynamic characteristics of thermal energy storage and power conversion system is required.

· In this study, a dynamic model for the selected partial heating cycle with thermal energy storage system was developed. The accuracy of the dynamic model was confirmed by performing steady state calculation and comparing with the heat balance.

Heat Balance of Partial Heating Cycle

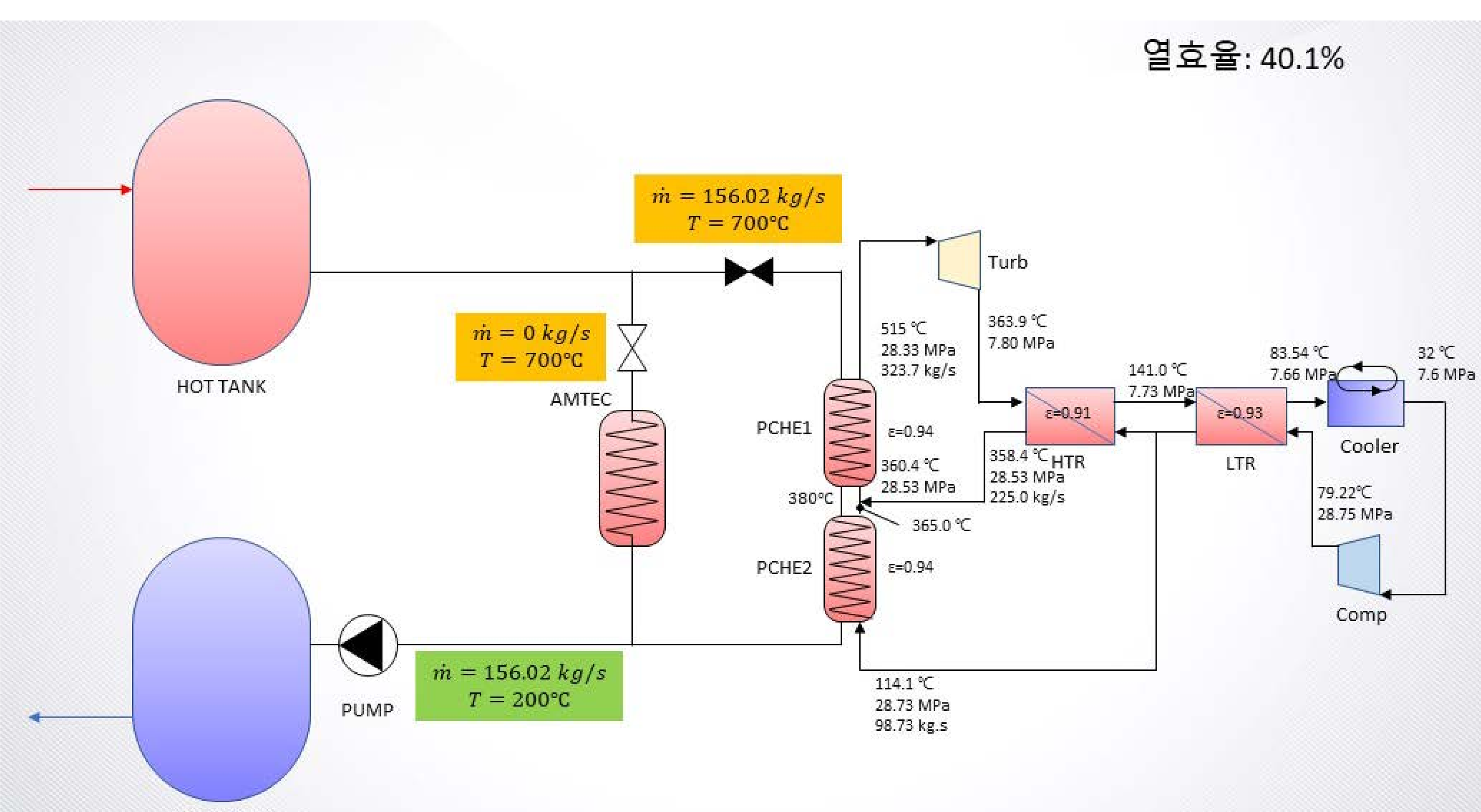

Fig. 1. Heat balance of partial heating cycle with thermal energy storage system

- The partial heating sCO_2 brayton cycle with thermal energy storage system consists of one compressor and turbine, two recuperators, and two heating heat exchangers

- The heat storage capacity of the thermal energy storage system is 1 GWht and the rated output is 100 MWth, and the capacity is set to supply energy for 10 hours during rated power operation

- Compressor and turbine efficiencies were assumed to be 88% and 92%, respectively, as typical efficiencies of commercial products

- In the heat balance, the effect of pressure change in other equipment other than the turbine and compressor was neglected

Dynamic Model

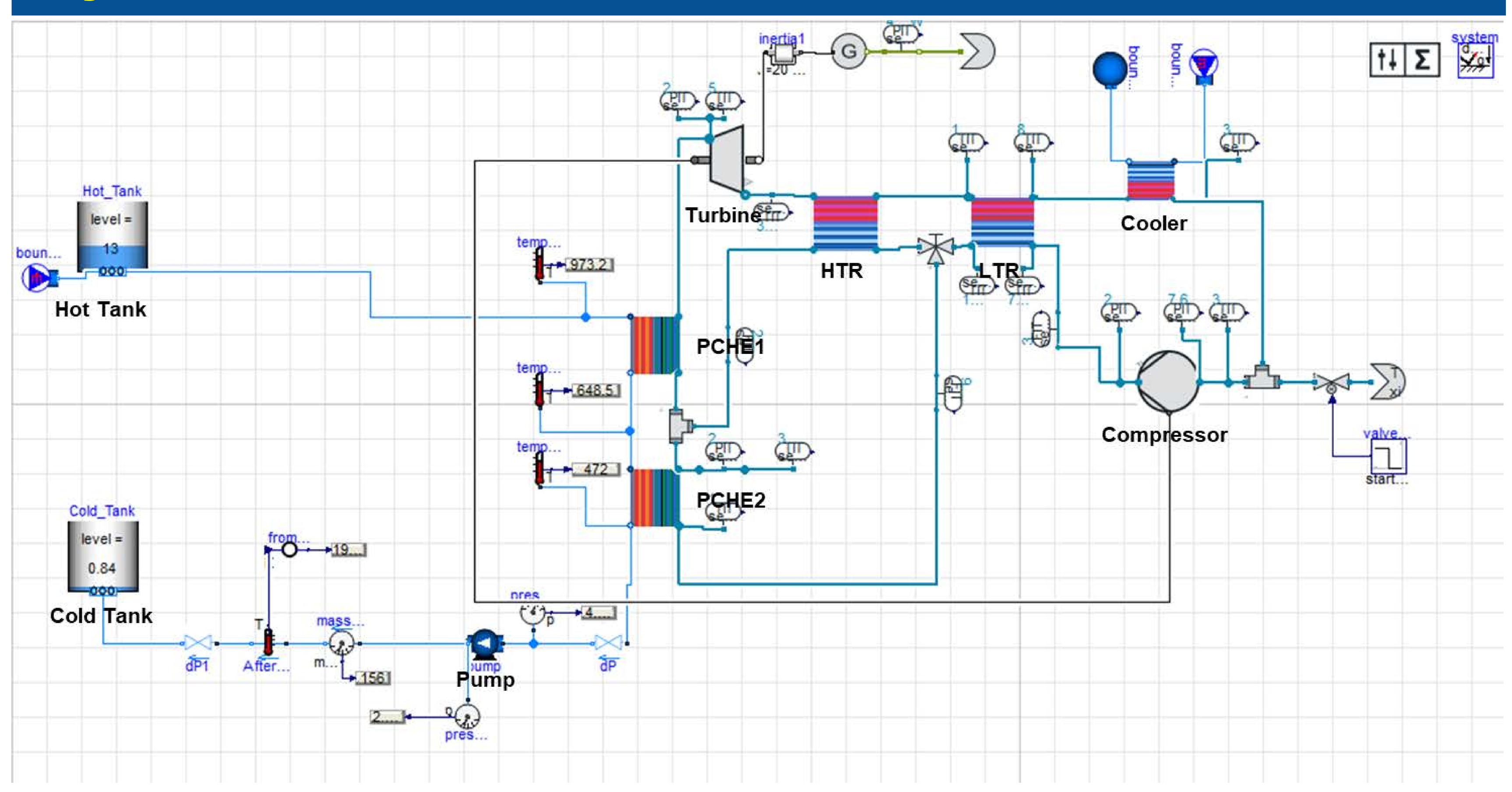

Fig. 2. Dynamic model of the thermal energy storage system and partial heating sCO2 brayton cycle

- Using Dymola software, a dynamic model of the thermal energy storage and utilization system was built.

- For carbon dioxide properties and turbo machinery, the model provided by ClaRaPlus Library v1.3.0 was used

- For sodium properties, the properties provided by SolarTherm Library v0.2, which are basically provided by Modelica, were used

- The heat exchangers of PCHE, recuperator, and cooler were manually modeled by connecting pipes and heat transfer walls

- The main process variables between the calculation results and the heat balance were compared at the inlet point of each device in Table 1

- It was confirmed that the maximum error of temperature and pressure coincided very well with the heat balance within 4°C and 1.55 MPa, respectively

- The heat transfer rate of PCHE1 and PCHE2 was good agreement with the heat balance in the error of 1%. The heat transfer rate of PCHE1 and PCHE2 was 63.88 MW and 36.2 MW

Table I: Comparison of the heat balance and the calculation results from the integrated analysis model of the thermal energy storage and utilization system

Measured point	Heat balance	Steady Calculation	Error
Comp. inlet	32℃	32.626℃	0.626℃
	7.6 MPa	7.647 MPa	0.047MPa
LTR lower temp. inlet	79.22℃	76.2℃	3.02℃
	28.75MPa	27.2MPa	1.55MPa
HTR lower temp. inlet	114.1℃	115.8℃	1.7℃
	28.73MPa	-	-
PCHE2 lower temp. inlet	114.1℃	115.8℃	1.7℃
	28.73MPa	28.51MPa	0.22MPa
PCHE1 lower temp. inlet	360.4℃	-	-
	28.53MPa	-	-
Turb. inlet	515℃	512.7℃	2.3℃
	28.33MPa	28.4MPa	0.07MPa
LTR higher temp. inlet	363.9℃	362.5℃	1.4℃
	7.8MPa	7.83MPa	0.03MPa
HTR higher temp. inlet	141℃	145℃	4℃
	7.73MPa	-	-
Cooler inlet	83.54℃	83℃	0.54℃
	7.66MPa	-	-
PCHE1 higher temp. outlet	380℃	374.75℃	5.25℃
PCHE2 higher temp. outlet	200℃	198.35℃	1.65℃
Comp. flowrate	323.7 kg/s	325.1 kg/s	1.4 kg/s

Conclusions

· The dynamic model of the thermal energy storage and utilization system was developed using the Dymola, ClaRaPlus, and SolarTherm libraries

· The developed model confirmed its accuracy by comparing with the heat balance, and it was confirmed that the maximum error of temperature and pressure of the thermal energy utilization system was well matched within 4℃ and 1.55 MPa, respectively.

· The heat transfer from the thermal energy storage system was also well matched with a maximum error of 1%.