Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Off-design performance of Supercritical CO_2 Power System for Waste Heat Recovery Application

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1. Introduction

As the global climate change becomes substantial, desire to attain efficient power system increases gradually. Power generation from the waste heat of conventional power system is another increasing market. Supercritical CO_2 cycle is gaining interests with several benefits: (1) high efficiency in the mild turbine inlet temperature range (450-650℃), (2) simple layout configuration and (3) small foot print incorporated with compact heat exchangers and turbomachineries. On and off-design performance of supercritical CO_2 power system based on the component design variables is discussed in this paper.

2. Supercritical CO_2 Cycle and Performance Assessment

2.1 System and Component Design

Table I. Supercritical CO_2 cycle design condition

sCO_2 Assumption	Value
Turbine isentropic efficiency	85%
Compressor isentropic efficiency	80%
Compressor inlet pressure	7.739 MPa
Compressor inlet temperature	34.1℃
Recuperator effectiveness	90%
Waste heat exchanger effectiveness	90%
Recuperator pressure loss	0.5% (cold side) 1.5% (hot side)
Waste heat exchanger pressure loss	4%
Precooler pressure loss	3%
Pipe pressure loss	0.5% (each)
Primary gas turbine (LM-2500)	Value
Exhaust gas flow rate	70.5kg/s
Exhaust gas temperature	566℃
Gas turbine efficiency	35.5%
Thermal combustion power	61.6 MWth
Waste heat power (@ 15℃)	39.7 MWth

Preliminary design of supercritical CO_2 recuperated for waste heat recovery system is suggested in Table 1 and Fig. 1. The heat source is LM-2500. The compressor inlet condition of supercritical CO_2 cycle is controlled close to the critical point (30.98℃, 7.3773MPa) due to the low compression work. The design variables and operating condition for the supercritical CO_2 cycle is discussed in previous work [1]. With the design variables for the supercritical CO_2 cycle, the sensitivity study of pressure ratio and mass flow rate is conducted and the maximum pressure and flow rate are selected as 20 MPa and 115 kg/s, respectively.

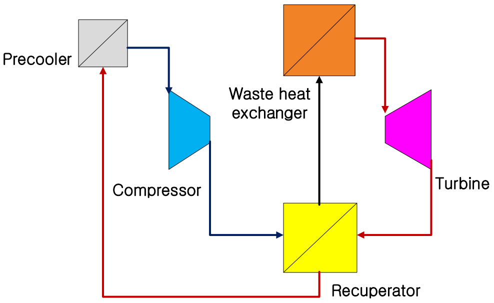


Fig. 1. Simple recuperated layout

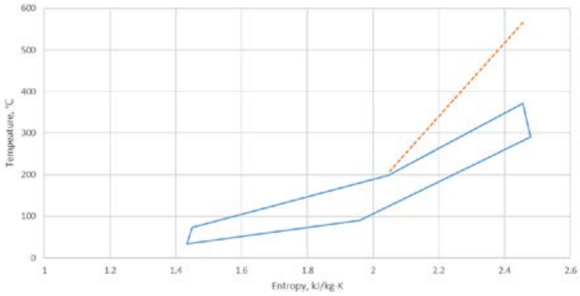
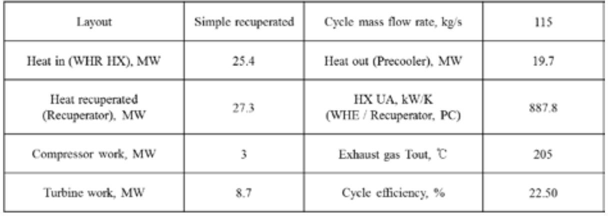


Fig 2. Supercritical CO_2 cycle T-s diagram

Table II. Supercritical CO_2 cycle T-s diagram

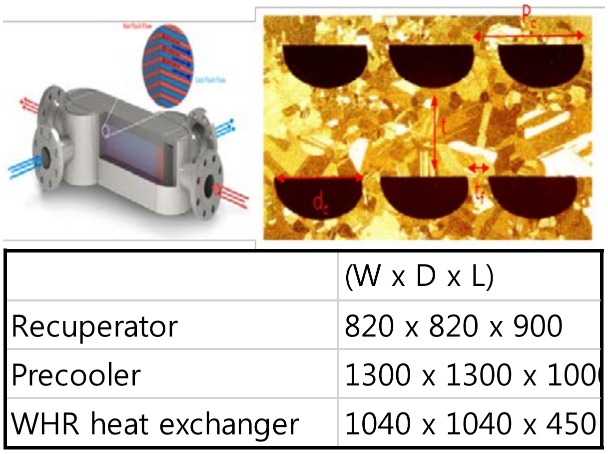


Layout	Simple recuperated	Cycle mass flow rate, kg/s	115
Heat in (WHR HX), MW	25.4	Heat out (Precooler), MW	19.7
Heat recuperated (Recuperator), MW	27.3	HX UA, kW/K (WHE / Recuperator, PC)	887.8
Compressor work, MW	3	Exhaust gas Tout, ℃	205
Turbine work, MW	8.7	Cycle efficiency, %	22.50

For supercritical CO_2 cycle application, printed circuit heat exchanger (PCHE) in Fig. 3. is widely used for high compactness and wide operational range.

In-house code for PCHE design is developed in previous work [2]. The preliminary design of S-CO_2 heat exchangers is shown in Table III.

Based on the pre-designed off-design map of supercritical CO_2 turbine and compressor, on-design and off-design performance is assessed shown in Fig. 4 and Fig. 5.



	(W x D x L)
Recuperator	820 x 820 x 900
Precooler	1300 x 1300 x 100
WHR heat exchanger	1040 x 1040 x 450

Fig. 3. Printed circuit heat exchanger configuration

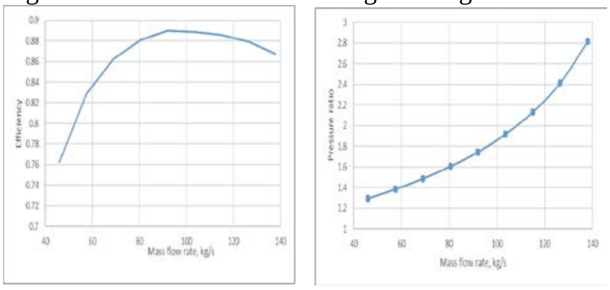


Fig. 4. Supercritical turbine performance map

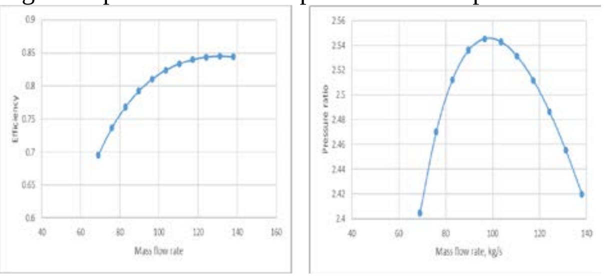


Fig. 5. Supercritical compressor performance map

2.2 Off-design performance of supercritical CO_2 cycle

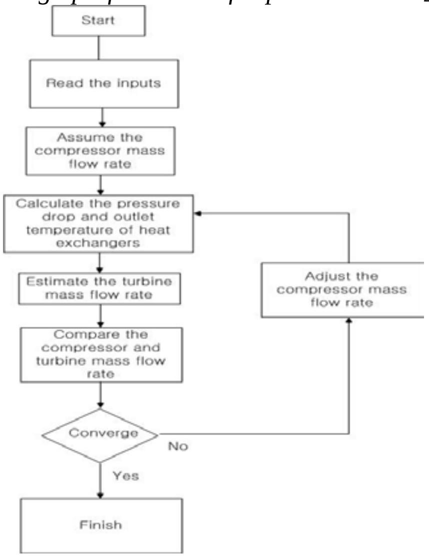


Fig. 6. Off-design performance analysis code algorithm

With the preliminary component design and performance parameters, off-design performance analysis code is developed and the code algorithm is shown in Fig. 6. The thermal efficiencies are predicted for the compressor inlet temperature variation as shown in Fig. 4. As the compressor inlet temperature decreases, the thermal efficiency increases.

Off-design performance with the variation of cooling water temperature change is shown in Fig. 7. As the cooling water temperature increases, the cycle mass flow rate and thermal power decreases.

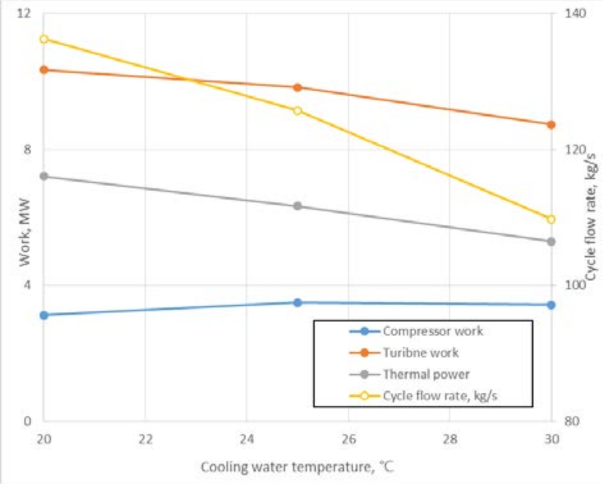


Fig. 7. Off-design performance with cooling temperature variation

3. Summary and further works

Supercritical CO_2 power system for waste heat application is designed to generate marginal power from the flue gas of a conventional gas turbine. The cooling temperature of the area can influence the compressor inlet temperature. To estimate the S-CO_2 cycle performance for various environmental conditions, off-design performance analysis code is developed.

Further works are required to predict performance under the condition of gas turbine part load and cooling water flow change.

Acknowledgement

This work was supported by the Civil-Military Technology Cooperation Program of the Republic of Korea (No. 17-CM-EN-04).

References

[1] Y. Ahn, J. E. Cha, H. Seo, H. J. Chung, 2018, Layout Study of Supercritical CO2 Power System for Waste Heat Recovery System, Transaction of the Korean Nuclear Society Metting, Jeju, Korea, May 17-18, 2018

[2] Y. Ahn, J. I. Lee, Study of various Brayton cycle designs for small modular sodium-cooled fast reactor, Nuclear Engineering Design, 2014, Vol. 276.