Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Design Study of Supercritical CO_2 Integral Experiment Loop (SCIEL)

Yoonhan Ahn[a], Jaekyoung Lee[a], Jeong Ik Lee[a], Jae Eun Cha[b]
[a]*Department of Nuclear and Quantum Engineering, Korea Adavanced Institute of Science and Technology*
373-1,Guseong-dong Yuseong-gu, Daejeon, 305-701, Korea
Tel: 82-42-350-3829, Fax: 82-42-350-3810
Email: yoonhan.ahn@kaist.ac.kr, leejaeky85@kaist.ac.kr, jeongiklee@kaist.ac.kr

[b]*Fast Reactor Technology Development Division, Korean Atomic Energy Research Institute,*
305-353, DukJin-Dong 150, Yuseong-gu, Daejeon, Korea
Email : jecha@kaeri.re.kr

1. Introduction

As the global warming becomes more substantial, the development of highly efficient power conversion system gains a lot of interests to reduce CO_2 emission. Supercritical CO_2 (S-CO_2) cycle is considered as one of the promising candidates due to the competitive efficiency in the mild turbine inlet temperature range (450-650^{o}C), and the compact footprint with compact turbomachinery and heat exchangers. With these advantages, S-CO_2 cycle can be utilized as the power conversion system of fossil power, advanced nuclear reactor, renewable energy system and a bottoming cycle for gas turbine or high temperature fuel cell, as well. In addition, the S-CO_2 cycle is considered as the alternative power conversion system of a Sodium-cooled Fast Reactor (SFR) as the violent Sodium-Water Reaction (SWR) can be replaced with the mild Sodium-CO_2 Reaction (SCR).

To demonstrate the S-CO_2 cycle performance, the integral test facilities were constructed and the operational results were reported by several countries [1, 2, 3]. In Korea, the development of Supercritical CO_2 Integral Experiment Loop (SCIEL) has been carried out by the joint research team of KAERI, KAIST and POSTECH. This paper will address the summarized design process, cycle condition and current status of SCIEL.

2. The development of SCIEL

2.1 The SCIEL design process

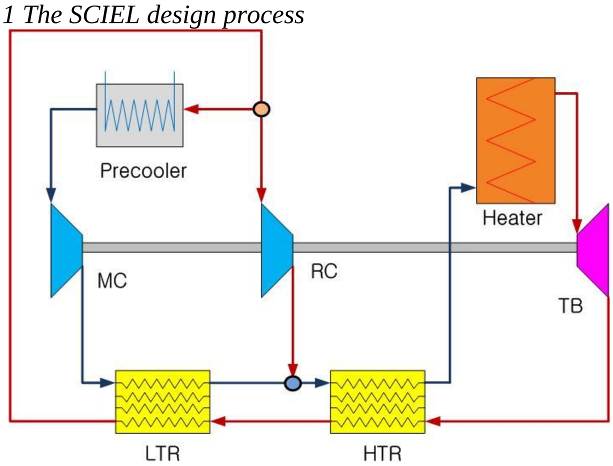

Fig.1. Recompressing cycle layout

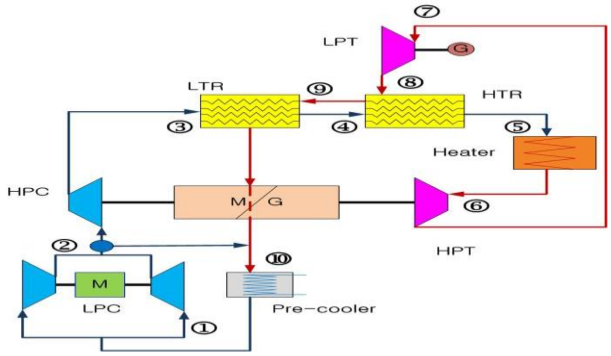

Fig.2. Recuperated cycle layout (SCIEL final layout)

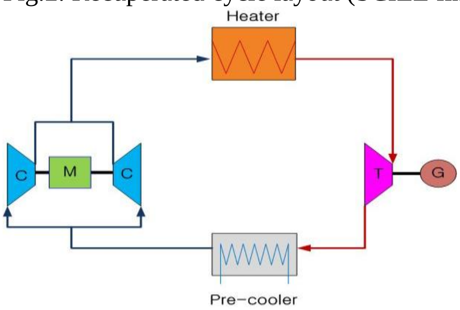

Fig.3. Simple cycle layout (SCIEL 2014 layout)

In S-CO_2 cycle designs, the recompressing cycle shown in Fig.1 is widely accepted as the most efficient and compact layout. However, in the small sized power systems, the radial compressor design is challenging due to the high rotating speed as the mass flow is small. Therefore, the split-flow (recompressing) process is discarded in the SCIEL design. To maximize the recuperated heat with Printed Circuit Heat Exchanger (PCHE), a series of recuperation process is suggested. The final layout and design condition are shown in Fig.2 and Table I, respectively. To evaluate the cycle performance, the simple layout shown in Fig.3. will also be tested. The detailed cycle description will be followed in the next section.

Table I: Cycle design condition of SCIEL

Turbine inlet temperature	^{o}C	550
Target pressure ratio		2.57
Turbine efficiency	%	85
Compressor efficiency	%	65
Maximum inlet and outlet temperature difference of recuperators	^{o}C	200
Total recuperation effectiveness	%	85

From previous studies, the high thrust loading and windage losses in the main compressor affected the design and operation of S-CO_2 cycle [1, 4]. In the early design stage, the high density and high rotating speed were expected in the main compressor even before the geometric parameters were set. Due to the high pressure difference between the inlet and outlet flow of compressors, high thrust loading is also expected. Therefore, the development of SCIEL requires step-by-step construction approach while examining the component performance carefully at each stage.

To achieve the target pressure ratio, the double stages of compression and expansion are adopted. The combination of LPC, LPT and TAC type HPC & HPT is considered for the SCIEL turbomachineries design. The and T-s diagram of SCIEL layouts is shown in Fig. 4.

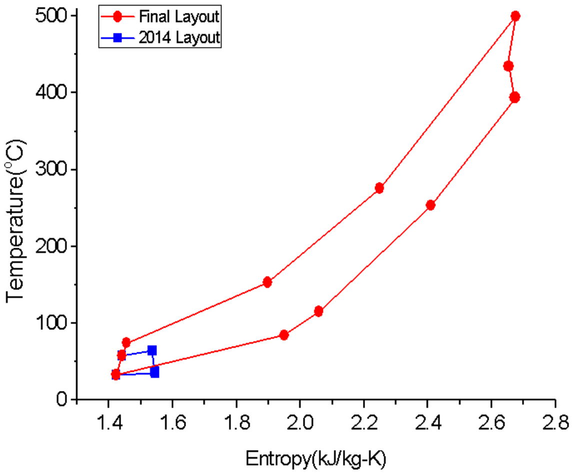

Fig.4. T-s diagram (SCIEL final and 2014 layout)

As the high pressure turbine and high pressure compressor are designed as the Turbine-Alternator-Compressor (TAC) type configuration, the assumed leakage flow from the compressor is considered for the turbine outlet flow. The pressure drop in the pipe section is assumed as well.

2.2 The SCIEL current status

Table II. Cycle performance (SCIEL)

Heater capacity	kW	1324
Cooler capacity	kW	1086
HP Turbine work	kW	211
LP Turbine work	kW	211
HP Compressor work	kW	76
LP Compressor work	kW	109
Total flow rate	kg/s	4.8
LP Compressor flow rate	kg/s	6.4
Cycle efficiency	%	19.6 for 4.8 kg/sec (17.9 including the bypass 1.6 kg/sec)

The S-CO_2 compressor test loop is installed in KAERI and the compressor configuration is twin-impeller type which compresses fluid at both impellers to cancel the thrust loads. Around 25% of the mass flow rate will be bypassed due to the limited infrastructure capacity. The overall cycle performance is shown in Table II.

The net cycle efficiency is 19.6% if only 75% of the flow is considered, and if the additional work for the bypass flow is considered 17.9% of cycle efficiency is expected.

3. Summaries and further works

The development of S-CO_2 cycle can be utilized as the power conversion system including the fossil power, next generation nuclear reactor, and concentrated solar power systems as the cycle efficiency is high in the mild turbine inlet temperature range (450-650°C) and the layout is simple with the physically compact system size. To demonstrate the S-CO_2 cycle performance, Supercritical CO_2 Integral Experiment Loop (SCIEL) has been under development by the joint research team of KAERI, KAIST and POSTECH.

The final layout of SCIEL is recuperated cycle with a double stage of compression and expansion to achieve 2.57 pressure ratio. Considering the temperature difference limit of PCHE, a series of recuperation process is utilized. As the control of thrust loads and windage losses of S-CO_2 compressors affected the operation of S-CO_2 test facilities from previous studies, SCIEL will be constructed with step-by-step approach while examining the component performance carefully at each stage.

In the current stage, the S-CO_2 compressor test loop is constructed. To minimize the thrust loads, twin-impeller compressor was designed and 25% of the total mass flow rate will be bypassed in the final layout. The expected net cycle efficiency is 19.6%.

AKNOWLEDGEMENT

Authors gratefully acknowledge that this research is financially supported by the Korean Ministry of Education, Science and Technology and by the Korean Atomic Energy Research Institute

REFERENCES

[1] R. F. Radel, T. M. Conboy, G. E. Rochau, 2010, Modeling and Experimental Results for Condensing Supercritical CO2 Power Cycles, SANDIA REPORT, SAND2010-8840

[2] E. M. Clementoni, L. C. Timothy, C. P. Sprague, 2013, Start and Operation of a Supercritical Carbon Dioxide Brayton Cycle, ASME Turbo Expo

[3] M. Utamura, H. Hasuike, K. Ogawa, T. Yamamoto, T. Fukushima, T. Watanabe, T. Himeno, 2012, Demonstration of Supercritical CO2 Closed Regerative Brayton Cycle in a Bench Scale Experiment, ASME Turbo Expo

[4] A. S. Lebedev, S. V. Kostennikov, Trends in Increasing Gas-Turbine Units Efficiency, Thermal Engineering, Vol. 55, No. 6, 461-468

.