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Description of Supercritical CO_2 Compressor Experiment Loop

Jekyoung Lee [a*], Jeong Ik Lee [a], Yoonhan Ahn [a], Seong Gu Kim [a],
Je Eun Cha [b]
[a]*Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Republic of Korea*
**Corresponding author : jeongiklee@kaist.ac.kr*

1. Introduction

With the growing interest in developing an advanced nuclear power plant, power conversion cycle innovation has been the part of this effort to secure high economics and enhanced safety. One of the main activities of power conversion cycle innovation is the development of Supercritical CO_2 Brayton cycle technology. S-CO_2 Brayton cycle concept was suggested in 1960s but the development and realization of the technology has been delayed up to now. In Korea, KAIST, KAERI and POSTECH are conducting research and development of Korean S-CO_2 Brayton cycle technology by erecting the Supercritical CO_2 Integral Experiment Loop (SCIEL). The full scope of SCIEL project is to demonstrate high efficiency with simple recuperated cycle layout or recompressing layout, which the final cycle layout will be determined by the obtained compressor performance data. As a part of SCIEL project, S-CO_2 compressor experiment facility has been constructed in KAERI. In this paper, current status of S-CO_2 compressor experiment loop will be reviewed.

2. General Description

There are many components in a S-CO_2 Brayton cycle, compressor, turbine, heat exchanger, pre-cooler, etc. Due to high thermodynamic property variation of S-CO_2 near the critical point of CO_2, a compressor technology is considered as the most uncertain component since the compressor operates closest to the critical point of CO_2. Another uncertain component is a pre-cooler. In this facility, PCHE (Printed Circuit Heat Exchanger) type heat exchanger is utilized for the pre-cooler and this component operates near the critical point also. This is the main reason why SCIEL project is started from the construction of the compressor experiment loop.

Fig.1. Overview of SCIEL experiment room (Water circulation pump is temporarily installed)

Main goals of the compressor test are:

1. Verification of compressor technology
2. Verification of domestic manufactured PCHE technology
3. Loop control logic development

3. Hardware setup

All hardware design is based on cycle analysis results. Before hardware was installed, cycle analysis was performed to determine facility technical specifications [1]. Without cycle operation variables such as mass flow rate, temperature and pressure, useful work and power, actual hardware design and facility construction cannot be started.

3.1. Piping and Fitting

Since the maximum design operating conditions of SCIEL are 200bar and 550^{o}C, all piping and fitting are selected for high pressure and high temperature service (schedule 160 for piping, 2500 lb fittings). Compressor experiment loop alone will not experience the top temperature operating conditions. But this experiment loop will be expanded for the full scale integral experiment and therefore even at current stage heavy duty equipments are installed to the compressor test loop. Thus, all mechanical components and materials were concerned with the most extreme operating conditions. SUS316 is used for the main piping and component to prevent any corrosion issues.

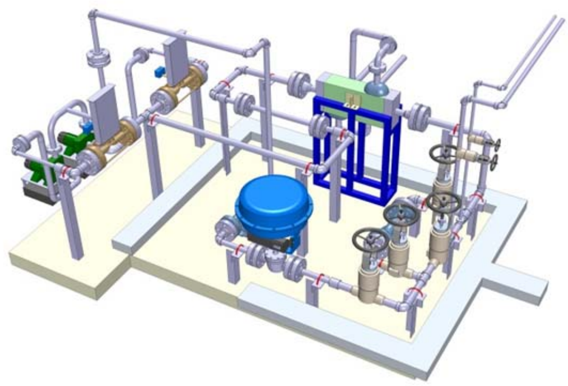

Fig.2. Overview of SCIEL compressor test section (Water circulation pump is temporarily installed)

3.2. Component Installation

The compressor in SCIEL project has a special characteristic. It has twin impeller system to manage axial pressure loading which is very tough to manage with thrust bearing system. Since dimensions of S-CO_2 compressor are small so thrust bearing can only tolerate small amount of force. Furthermore, high density of S-CO_2 causes high friction loss on thrust bearing which reduces the compressor performance significantly. Thus, twin impeller compressor was selected and compressor work at design point was selected as 55~60kW for each impeller. It should be noted to the readers that in Fig.2, the actual S-CO_2 compressor is not shown. Fig.2 only shows two water pumps (colored in green) for water circulation test. The two water pumps will be substituted with the actual compressor when the manufacturing of the component is finished. However, all piping and fittings will be the same in Fig.2. Main components which compose compressor experiment loop are shown in Fig.2. The pre-cooler is located near the wall to interface with heat sink which is constructed outside the building. The pre-cooler was designed and manufactured to remove 300kW of heat. For accurate measurement of each side of compressor inlet, two mass flow meters and two sets of measurement points are installed. To prevent compressor and heat exchanger failure from small particles entering the component, multiple strainers are installed.

3.3. Measurement Device Installation

CO_2 near the critical point has large variation of thermodynamic properties with a small change in pressure and temperature. Thus, measurement uncertainty should be carefully considered. Thus, high accuracy RTDs, absolute pressure transmitters, differential pressure transmitter, density meter, Coriolis mass flow meter were used for accurate measurement. For mass flow measurement, both of Coriolis mass flow meter and density meter are installed for cross checking.

3.4. Supporting System Installation

Construction of other supporting system such as air compressor, booster pump, vacuum pump and heat sink facilities are finished. And polycarbonate wall is constructed for operator safety. Most of supporting devices are ready-made devices except heat sink. About 600kW heat sink facility was designed for SCIEL. Constructed heat sink facility can control 0.1^{o}C order of water temperature. Load bank for turbine work disposal and heating system is in design phase and these sub-systems will be added for the electricity production test in near future.

4. Primary Process

4.1. Pipe Line Cleaning

For the pipe line construction, 2500lb socket welding fitting was utilized. Thus, small contaminants from cutting and welding remain in pipe lines inherently. This is the reason that most of circulation loop facilities should go through cleaning process. In SCIEL, cleaning process was particularly difficult due to the micro channel in PCHE. Thus, cleaning process was performed for both normal flow direction and reverse flow direction. Air purge and water purge were performed and two strainers filtered small particles in pipe lines.

4.2. MAWP Test

Since target operating conditions are extreme, there is a chance of unforeseen accident. Thus, maximum allowable working pressure (MAWP) test was carried out first. Since pressure setting of the installed safety relief valve is 225bar, up to 205bar of MAWP test was conducted. Test fluid was city water and there no leak was observed. 10 steps of pressurization was performed and pressure holding, no leak was detected at every step. At final pressure (205bar), about 30 minutes of pressure holding was performed without any sign of leak.

4.3. Heat Sink Test

Manufacturer of heat sink is domestic vendor and they designed and constructed 600kW heat sink facility. This facility cools water by combination of cooling tower and chiller. Thus, internal circulation and cooling test was performed and result was acceptable. Temperature control system is now being tested and it will be done in near future.

5. Summary

As a part of advanced nuclear energy system, KAIST, KAERI and POSTECH works for S-CO_2 Brayton cycle technology development. So, SCIEL project was initiated and electrical power production of S-CO_2 Brayton cycle is planned and will be performed in near future.

As a start, compressor experiment loop is being constructed in KAERI. The first phase is very close to the end and actual compressor test will be performed in very near future. Compressor experiment facility will be further expanded for the whole cycle experiment. When the full scope of SCIEL is finalized, SCIEL facility will be utilized for Korean S-CO_2 Brayton cycle technology development.

ACKNOWLEDGMENTS

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REFERENCES

[1] Yoonhan Ahn, et al., 2013, The Design Study of Supercritical Carbon Dioxide Integral Test Loop, Proceedings of ASME Turbo Expo 2013, Texas, USA