Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Design on Small-Scale Supercritical CO2 Cycle Integral Test Facility

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1. Introduction

Supercritical CO_2 (S-CO_2) generation technology is a technology that uses S-CO_2 instead of water as a working fluid to produce electricity. The supercritical state refers to the state in which both liquid and gas properties are held when the temperature and pressure conditions are higher than the critical point, and the S-CO_2 is 31.4°C and 7.4 MPa. Since S-CO_2 has the same density as liquid water and viscosity as air, it can minimize the power consumption required for compression and circulation. Due to these characteristics, the S-CO_2 generation technology is a miniaturized power generation system technology that has better power generation efficiency than conventional generation technology. In addition, the S-CO_2 generation technology is a system applicable to various energy sources because it has high efficiency characteristics in wide temperature zone. we designed and constructed a small-scale integral test facility to study a S-CO_2 generation system.

2. Methods and Results

In this section, we are going to introduce the process of designing the small-scale integral test facility. The small-scale integral test facility was designed and constructed through the process of T-s diagram, heat and mass balance diagrams, flow diagrams, and 3D modeling.

2.1 T-s Diagram

The S-CO_2 cycles generally are designed in the form of Breton cycles, which are driven above the critical point. However, there were no commercial compressors and turbines available for the small-scale integral test facility because compressors and turbines that compress and expand S-CO_2 were in the research and development step. As a solution, we were chosen to make CO_2 to liquid state and pressurize it into a pump instead of a compressor. To do this, we designed a S-CO2 cycle in the form of a Rankin cycle. To expand the S-CO_2, a relief valve was used instead of a turbine. Since the small-scale integral test facility does not have turbines, it cannot produce electricity.

The CO_2 at point 1 is liquid. The CO_2 in the liquid state is pressurized through the pump to the high-pressure liquid state at point 2. Point 2' is derived considering the pump efficiency of 60%. The high-pressure liquid CO_2 at point 2 receives heat from the heater and becomes the supercritical state at point 3. The S-CO_2 at point 3 expands through the pressure relief valve and becomes the gas state at point 4. The gas CO_2 at point 4 is release heat through a heat exchanger and returned to the liquid state at point 1. The ideal cycle process is a 1-2-3-4-1 process, but the actual cycle process is a 1-2'-3-4-1 process. The property values of CO_2 shown in Fig. 1 is obtained from the PEFPROP 7.0 program.

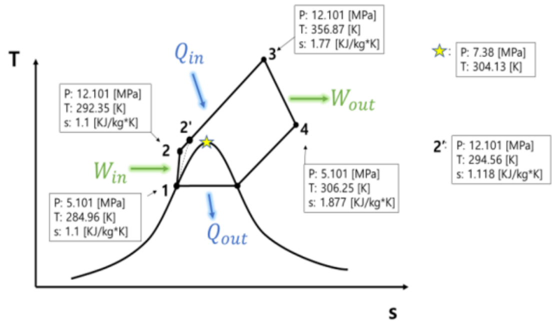

Fig. 1. T-s diagram

2.2 Flow Diagram

We designed flow diagrams to identify the flow of working fluid and to select the location of major components, valves, and sensors. Fig. 2 is a flow diagram of a small-scale integral test facility. Both the part where the CO_2 enters the experimental loop from the boombe and circulates within the experimental device loop are shown in the flow diagram. The operation and experimental procedures of the integral test facility were written based on the flow diagram.

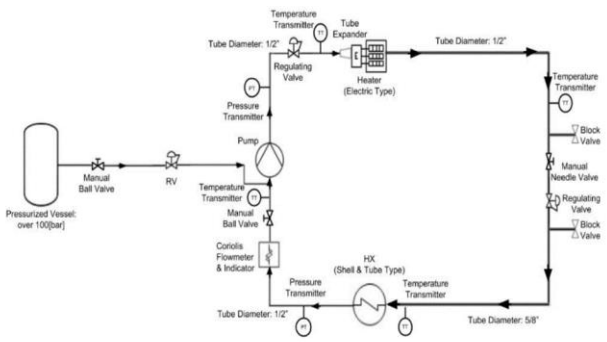

Fig. 2. Flow diagram

2.3 Heat and Mass Balance Diagram

Heat and mass balance diagrams were prepared to check the equilibrium of heat and work in the input and output within the small-scale integral test facility. Fig. 3 shows the Heat and mass balance diagram of the integral test facility we designed. Since the relief valve was used instead of the turbine, there is no output work and power generation. Fig. 3 shows that the amount of heat applied by the heater is equal to the amount of sum of remove heat and work done from the heat exchanger and the pump, respectably. This is, this shows that the sum of the input and output in the loop is balanced. as the designed cycle is the simple cycle, the mass flow in all sections is the same. Fig. 3 shows the mass flow rate and the volume flow rate in each section.

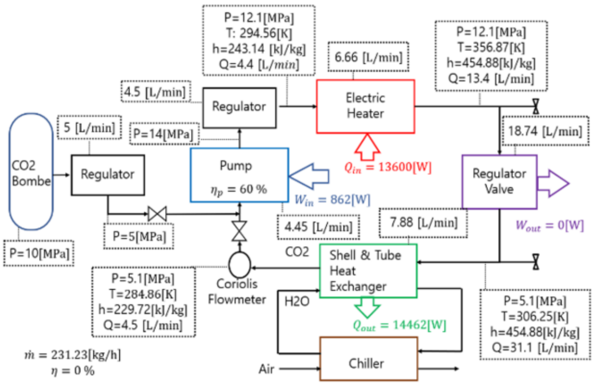

Fig. 3. Heat and mass balance diagram

2.4 3D Modeling

3D modeling was performed to select the three-dimensional position of the main components, valves, tubes, and sensors in the small-scale integral test facility. Fig. 4 shows 3D modeling of a small-scale integral test facility we designed. The proper distance was considered so that the main components do not affect each other, and the tube path was selected as the most compact. The area of a small-scale integral test facility is 3000 mm x 1700 mm. The area of the small-scale integral test facility is large because the shell and tube heat exchangers occupy a large volume. However, if the shell and tube heat exchanger replace by a plate heat exchanger, the volume of experimental device is greatly reduced.

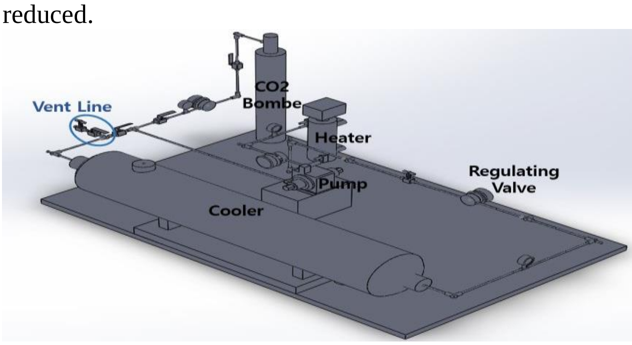

Fig. 4. 3D modeling

2.5 Small-Scale Integral Test Facilities

Fig. 5 is the small-scale integral test facility that we finally constructed. Temperature, pressure, and flow values can be found by an indicator connected to each sensor. In the future, we will prepare a CO_2 boombe and pressurize CO_2 into the integral test facility for a test drive. In addition, a data acquisition system will be established to acquire and analysis data.

Fig. 5. Integral test facilities

3. Conclusions

In this study, we designed and constructed the S-CO_2 the small-scale integral test facility. Due to the absence of several commercial components, S-CO2 cycle has been designed in the form of Rankin cycle. To design the small-scale integral test facility, T-s diagram, flow diagram, heat and mass balance diagram, and 3D modeling were performed, and the small-scale integral test facility was established based on this. In the future, it is necessary to verify the abnormalities of the integral test facility through the test drive and to establish a data acquisition system.

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