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Experimental Study of the Injection System for CO_2 Geologic Storage Demonstration

Seok Ho Yoon[a], Kong Hoon Lee[a], Jungho Lee[a], Young Kim[a], Byoung-Woo Yum[b]*

[a]Korea Institute of Machinery and Materials, Daejeon 305-343, Republic of Korea
[b]Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, Republic of Korea

Abstract

The worldwide issue of greenhouse gas reduction has recently drawn great attention to carbon capture and storage (CCS). Almost CCS studies have been focused in the capture technology of carbon dioxide and the geological investigation for underground storage. The study of mechanical injection system for carbon dioxide has not implemented nearly. We are intended to develop a ground system for underground injection of carbon dioxide. In this study, we made lab-scale underground injection system and implemented injection simulation test experimentally. The 10,000 ton/year pilot plant for geological storage of carbon dioxide will be designed on the base of these test results. Major components of the lab-scale underground injection system include a pressure pump and an in-line heater to bring liquid carbon dioxide into its supercritical state. Test results assure that this system readily achieves the designed injection pressure and temperature, showing satisfactory control performance.

Keywords: carbon dioxide; geological sequestration; underground injection; supercritical

Nomenclature

T	Temperature (°C)
P	Pressure (bar)

* Corresponding author. Tel.: +82-42-868-3375; fax: +82-42-868-3414.
E-mail address: ybw@kigam.re.kr

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1. Introduction

The typical CCS process is shown in Fig. 1. Carbon dioxide generated from CO_2 source such as power plant is captured in the sequestration plant, and then transferred to the injection field. The transported carbon dioxide is injected into the underground by the ground injection system. The main function of ground injection system is the conversion into the state of carbon dioxide to the injection pressure and temperature and transfer to wellhead. The ground injection system consists of pressurizing facility, piping, heating devices, and control system, etc. We are developing the CO_2 underground injection pilot plant which has 10,000 ton/day of injection capacity in the research project of KIMM and KIGAM. It is planned that the carbon dioxide is supplied as a liquid state using a tank lorry from the liquefaction plant for this pilot plant. The injection system is designed that carbon dioxide is injected into the downhole through the wellhead as a supercritical state. The supercritical state has an advantage for injection into the underground due to its properties. The injection condition of carbon dioxide is set as the 35^{o}C of temperature and the 90 bar of pressure under which the carbon dioxide is in the supercritical. To raise the pressure of liquid carbon dioxide, the four-stage centrifugal pump will be adopted as a main injection pump. The inline heater using an electric cartridge heater is used to raise the temperature of carbon dioxide. Thus the injection system of carbon dioxide consists of the main injection pump, booster pump, inline heater, and control valves.

The study about mechanical equipment and facility for carbon dioxide injection system has been hardly found among the technology for the geologic sequestration of carbon dioxide. In this study, the lab-scale experimental setup was built for the investigation of the thermo fluidic characteristics of the injection system. Through the simulating of the injection pilot plant, the operation algorithm to optimize the energy consumption of the injection system can be suggested.

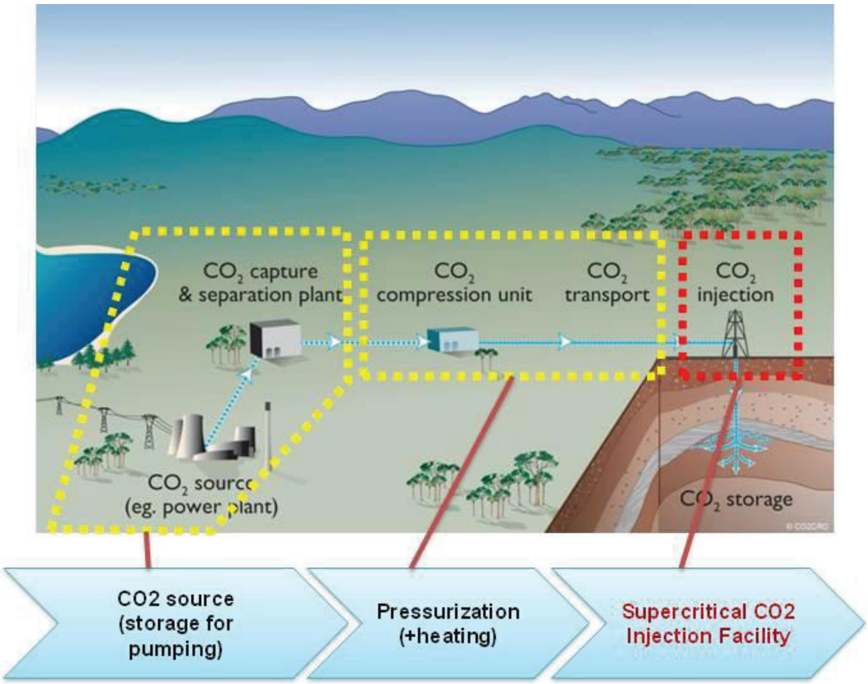

Fig. 1. The injection facility in the CCS process (graphic based on CO2CRC image)

2. Development of Injection System

2.1. Analysis of Injection Process

Before injection test apparatus is built, a process analysis was implemented to confirm the component specification. The injection process analysis is conducted by Aspen HYSYS which is widely-used process modelling software. Figure 2 shows the analysis result. In the process of lab-scale test, carbon dioxide is supplied as a two-phase saturated state from pressure vessel. To make similar state to state in the tank lorry, cooling and depressurizing is needed. After the supplying state is formed, carbon dioxide flows to the pressurizing pump and pressurizes up to the injection pressure over 90 bar. And then carbon dioxide is heated to make the supercritical state. Target injection condition is over 90 bar of pressure and over 32^{o}C of temperature. Test range of mass flow rate of carbon dioxide is designed from 10 to 40 kg/h. According to this fallow rate range, the component specifications of pressurizing pump, heater and heat exchangers are designed.

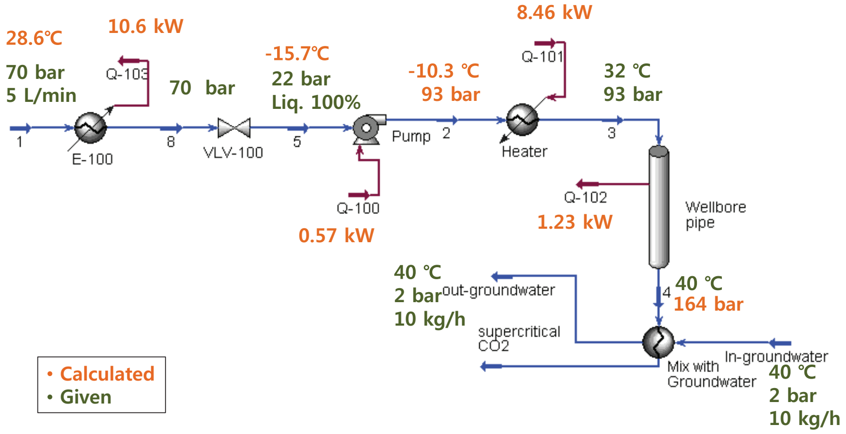

Fig. 2. Injection process analysis result

2.2. Experimental Setup

For simulating the actual injection system, the lab-scale experimental apparatus was built before developing the pilot system. The metering pump was used as a main injection pump in the lab-scale facility because the capacity of the centrifugal pump is too excessive for applying to the lab-scale. The booster pump isn't applied to the lab-scale system since the mass flow rate is small. In order to prevent the vapor formation at the pump inlet, the carbon dioxide was cooled down using the chiller. Instead of the tank lorry to supply the liquid carbon dioxide, the vacuum insulated cylinder was made and the chiller is used to lower the temperature of the liquid carbon dioxide. The temperatures and pressures are measured by T-type thermocouples and pressure transmitters, respectively. And the injection flow rate is measured by Coriolis type mass flow meter. All the measured data was saved to the PC. Final injection supercritical state is monitored through the sight glass on the cylinder located before vent. Figure 3 and 4 shows the 3D schematic diagram and photo of experimental setup respectively. The specification of main component installed in the test rig is shown in table 1.

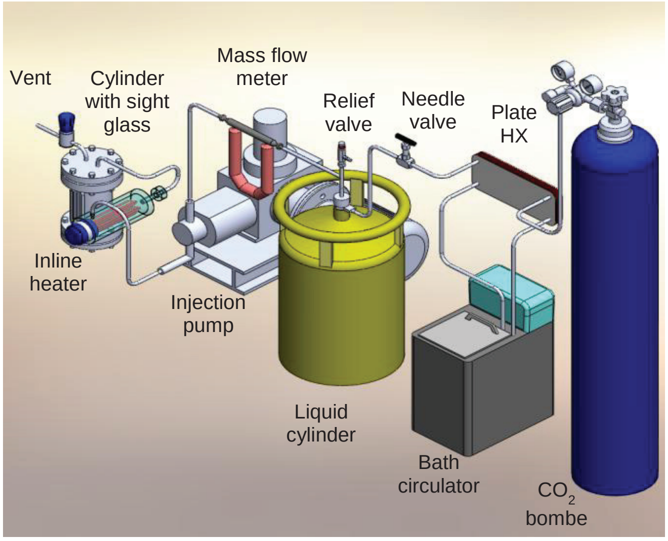

Fig. 3. 3D schematic diagram of test setup

Fig. 4. Photo of experimental apparatus

Table 1. Specification of main components in the test setup

Item	Specification
Heat exchanger	Welding type plate heat exchanger for CO_2,

Chiller	2 Hp compressor, temperature range: -30~80^{o}C
Liquid Vessel	20 L, sight glass, vacuum insulation
Pressurizing Pump	max. pressure: 100 bar, max. flow rate: 1.0 LPM
Heater	In-line cartridge type, max. 2 kW

3. Test Results

The experimental tests to simulate carbon dioxide injection were conducted in the various conditions. The injection simulation test was implemented with regard to variable storage condition. The storage tank is a liquid cylinder in this test setup. The liquid cylinder has a sight glass for monitoring the state and level of carbon dioxide. Tank lorry is a same position with liquid cylinder in case of pilot plant. According to the neighbour environment and tank lorry type, the storage condition of carbon dioxide is varied. In this study, the injection system performance is investigated with respect to the various saturation pressure of storage tank. Storage tank pressure is set to 30, 35, 40 bar as shown in Fig. 5, respectively. Storage tank pressure is adjusted by supplying carbon dioxide vapor from the pressure vessel to the upper side of storage tank. During the whole test period, the storage tank pressure was maintained as shown in Fig. 5. The storage tank pressure is affected to the suction state of pressurizing pump. And the performance of injection system is changed. To acquire the supercritical target condition (93 bar of pressure and 35^{o}C of temperature), carbon dioxide is pressurized and heated. The mass flow rate of injected carbon dioxide was measured and all the variations of monitoring parameters are investigated.

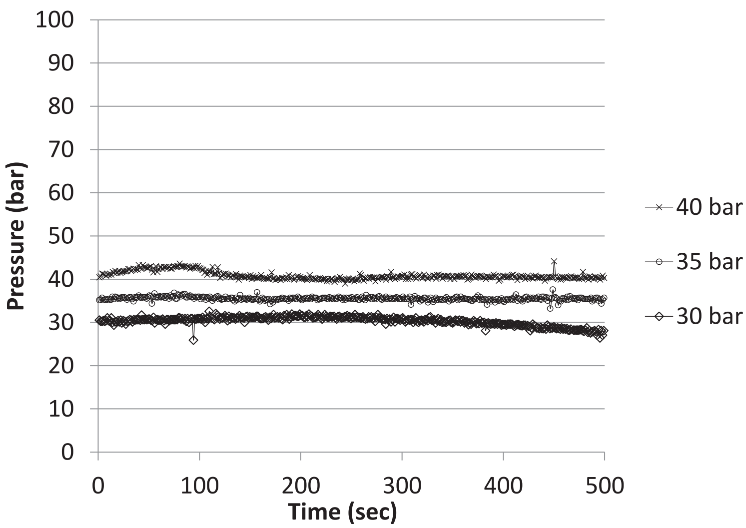

Fig. 5. Pressure of CO_2 storage tank (liquid cylinder)

Figure 6 shows the temperature variation of pump suction and injection port with regard to storage tank pressure. This temperature variation shows the trajectory from the initial condition to the steady injection condition. It took more time that high pressure case of the storage tank arrived the supercritical injection state. However, the temperature over shoot is smaller than that of low pressure case. Consequently, as the storage tank pressure is higher, the more time is needed to make the supercritical condition but the fluctuation of system is less. Even if the storage tank pressure is changed, the injection temperature and pressure is appropriately controlled as shown in Fig. 6.

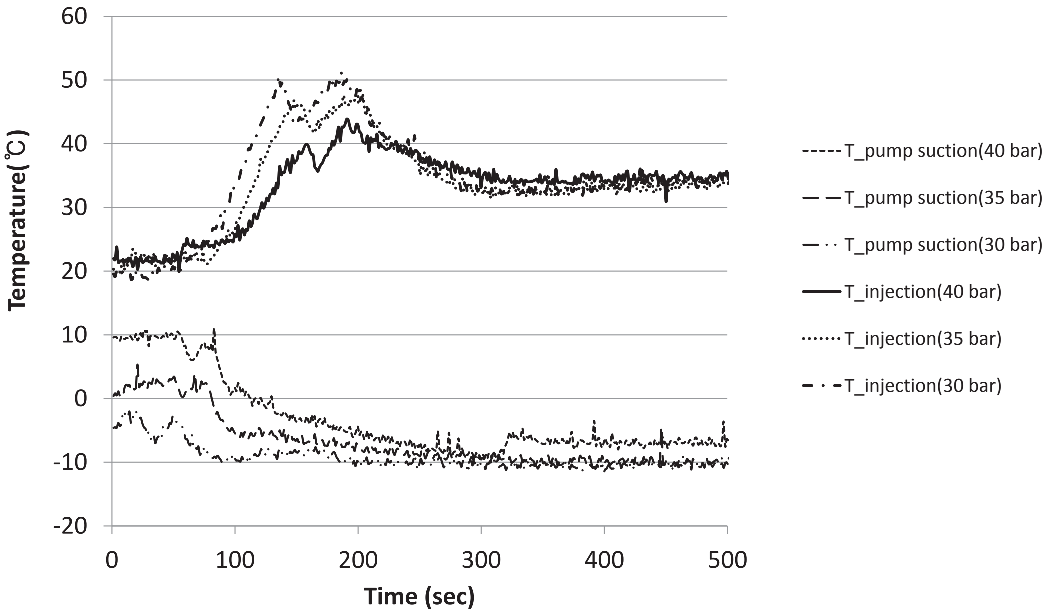

Fig. 6. Temperature variation of pump suction and injection port with regard to storage tank pressure

Figure 7 shows the mass flow rate variation of injected carbon dioxide with regard to storage tank pressure. The injection flow rate is a main performance parameter of underground injection system. When the same power is consumed and the more carbon dioxide is injected, it can be expressed that the system has high efficiency. The mass flow rate is measured for accurate comparison. As the system is operated, the mass flow rate is increased slightly. According to the inlet condition of the injection pump, the mass flow rate is varied. The injection flow rate of high storage tank case showed the higher value in the whole test period. This is due to the variation of subcooling at the inlet pump condition. The subcooling of pressurizing pump inlet condition affects the performance of carbon dioxide injection system.

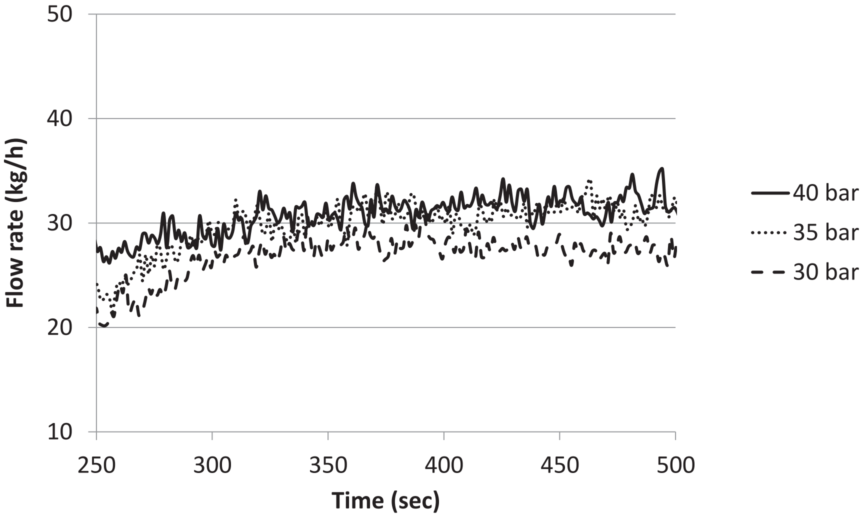

Fig. 7. Mass flow rate variation of injected carbon dioxide with regard to storage tank pressure

Figure 8 shows the subcooling variation with regard to storage tank pressure. As the system operated, the subcooling increased and then maintained steady value except lowest storage tank pressure. As the storage tank pressure is higher, the system shows the higher subcooling. Because the subcooling of pump inlet has an effect on the system performance, the carbon dioxide supplying condition has to be controlled for the higher system efficiency.

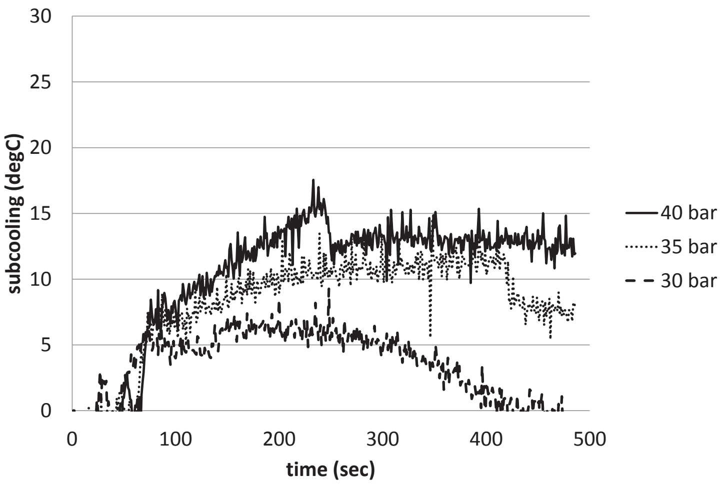

Fig. 8. Subcooling variation with regard to storage tank pressure

4. Conclusions

Because the study about mechanical equipment and facility for carbon dioxide injection system has been hardly found among the technology for the geologic sequestration of carbon dioxide, the lab-scale injection system was designed, analysed, and fabricated in this study.

The injection test was conducted with regard to the various condition of carbon dioxide storage tank. The lab-scale system was controlled to make the supercritical injection condition appropriately. And the injection system parameters such as injection mass flow rate were investigated. As the storage tank pressure is higher, the injection system shows the higher and more stable performance. It is caused by the subcooling of pressurizing pump inlet condition affects the performance of injection system. Therefore, the carbon dioxide supplying condition to the pressurizing pump has to be controlled efficiently for the higher system performance.

Acknowledgements

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