The experimental study of heat extraction of supercritical CO_2 in the geothermal reservoir

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Abstract. The heat transfer phenomena of supercritical CO_2 are experimentally investigated in a horizontal tube for improving the efficiency of CO_2-EGS.This studydiscuss the experimental verification of the numerical simulations. The experiment is conducted for the pressure, the flow rate, and particle size 1.54mm.In addition, theexperiment and simulation that the maximum heat extractionis occurred at the 9MPa pressure and mass flow rate of 0.00109 kg/s. Themaximumspecific heat extraction at 9MPa and flow rate of 0.00082 kg/s.The results show that thenumerical model has been experimentally verified of the feasibility. Furthermore, the pseudo-critical point had a significant influence on the heat extraction, temperature difference and specific heat extraction.

1 Introduction

The global warming of the earth becomes more and more serious. The use of green energy is a good choice. Geothermal energy is a renewable energy, it can be sustainable developed the new type energy [1]. Many researchers have rated it highly.

The geothermal system is divided into traditional geothermal system and non-traditional geothermal system. Non-traditional geothermal systems are normally called enhanced geothermal system (EGS). The operated process of EGS exists two stages. First, the injection well shall be at least drilled three kilometersdeep and the temperature shall be more than 250˚C. Second, the high pressure working fluid composed of chemical component (depend on geologic condition) is used to create the fracture in the reservoir though the injection well. The high pressure water is used to absorb the heat from the fracture of the reservoir and then flow out from the production well. Finally, the extracted heat from the working fluid can be used to generate power. In the past, water is used as working fluids, but previous studies have suggested that CO_2can bethe possible EGS working fluid forits chemistry property and density. It is a new breakthrough in the geothermal development. Brown first proposes CO_2-EGS in 2000 [2].

In recent years, there are many researchers to conduct the study of CO_2. The CO_2exists unique feature, in areas with scarce water resources using CO_2 as an alternative to water as a working fluid [3]. The thermal siphon power generation and analysis between water and carbon dioxide is presented byAtrens et al. [3].In 2014, Xu et al. investigated fluid and rock chemical interaction in CO_2-EGS [4].Hsieh et al. [5]discussed the heat transfer phenomena of supercritical CO_2 are experimentally investigated inupward flow vertical tube with silica-based porous media. For the availability of CO_2-EGS, researchers have discussed several topics, including CO_2 mineralization by injecting CO_2 into granite and sandstone [6], carbon capture utilization and sequestration[7],geothermal production and CO_2 sequestration in CO_2-EGS [8].

Researchers have investigated heat transfer phenomena related to CO_2-EGS,determine that buoyancy effects are significant for all flow orientations [9, 10, 11]. Most of these studies show that the flow rate and pressure are the most important parameters in the EGS. However, all of these studies have been limited by the absence of an experimental system for investigating the performance of supercritical CO_2 in a reservoir.

This study is to determine the efficiency of EGS by using the supercritical CO_2 to perform the heat extraction ofthe silica-based porous media in the experimental scale.

2 Experiment

2.1. Experimental apparatus

The schematic diagram of the experimental system is shown in figure 1. The experimental system consists of a CO_2 pressure vessel, high pressure pump, preheated water bath, cooling water bath, heating unit, test section, differential pressure gage, flow meter, and data logger. The photograph of experimental system is shown in figure2. Here, CO_2 pumped into the preheated water bath and reaches the supercritical status. Then, the supercritical CO_2 flows into the test section and extracts the heat to simulatethegeothermal reservoir. The temperature profile, pressure, and mass flow rate are measured and recorded. The test section composes of stainless tube, and ten calibrated T-type thermocouples and differential pressure gage inserted into the test section to record experimental data. The inside, outside diameter and length of test sections is 29.9,55and 235mm, respectively. The test section is filled with silica-base particles. To determine the behavior of supercritical CO_2, various experimental parameters are applied during the experiment including the system pressure (7.5MPa, 9MPa, ,10MPa, 11MPa and12.5MPa), mass flow rate (0.00082and 0.00109 kg/s), and the particle size1.54mm. In addition, the initial test section temperature is pre-set at 200℃ by a constant heat flux to simulate the actual reservoir temperature.

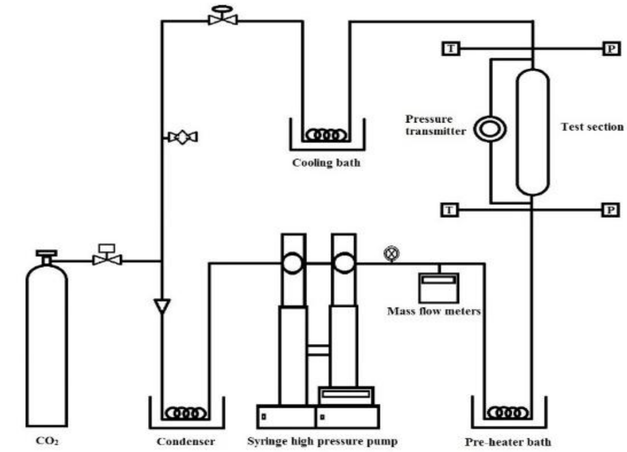

Figure 1. Schematic diagram of experimental apparatus.

Figure 2. The photograph of experimental apparatus.

2.2Experimental parameters

This studyinvestigates the heat extractionof thesupercritical CO_2at different pressure and mass flow rate.

The heat transfer rate from the tube wall to CO_2iscalculated in a steady state as follows:

$$\dot{Q} = \dot{m}(\, h_{out} - h_{in}) \quad (1)$$

where $\dot{m}$ indicates the mass flow rate, h_{in} is the inlet enthalpy, h_{out} is the outlet enthalpy of supercritical CO_2.

$$Q_{in}(W) = \dot{Q}(W) + Q_{LOSS}(W)(2)$$

where$\dot{Q}$ indicates the heat extraction rate of supercritical carbon dioxide, Q_{loss} is heat loss.

$$q = \frac{\dot{Q}}{\dot{m}}(3)$$

where $\dot{Q}$ indicates the heat extraction rateof supercritical carbon dioxide, $\dot{m}$indicates the mass flow rate.

3Experimental results and discussion

In the present study, the experiments are carried out with various supercritical pressures from 7.5 to 12.5MPa, and various mass flow rates 0.00082and 0.00109 kg/s at the initial wall temperature 200 ℃ . As the initial wall temperature reached a steady state, the supercritical $CO_2$is poured into the test section. All the experimental data reported in this study isprocessed based on the physical properties of CO_2 provided by the NIST Refrigerants Database [12]. Figure 3 shows the relationship of specific heat with temperature in the critical region under different pressure by using the NIST Refrigerants Database. As shown in this figure, the pseudo critical temperatures are 31.7℃ (7.5 MPa), 40℃ (9 MPa), 45.02℃ (10 MPa) 49.7℃ (11 MPa) and 55.95 ℃ (12.5 MPa) for CO_2 at these pressures.

The profilesof temperature difference are shown in figure 4. The temperature difference with different pressure (7.5, 9, 10, 11 and 12.5 MPa), mass flow rate (0.00082and0.00109 kg/s) are presented. Through figure 4, we can observe that thetemperature difference decrease as the mass flow rate increases. The reason is thatthe lower velocity of supercritical $CO_2$is benefit to heat extraction. In addition, the temperature difference is nonlinear with the pressure variation. It is dependent on the complex supercritical thermal properties of CO_2. We observe that the maximum temperature difference is happened at 7.5MPa pressure. Theminimumtemperature difference is happened at 9MPa pressure.It corresponds the maximum specific heat is occurred at the same pressure, it`s pseudo critical temperatures are 31.7℃and pressure at 7.5MPa. The temperature difference in heat extraction is one of the important factors.The larger temperature difference is, the better heat extraction is.

For saving the experimental cost, the simulated model is built to fit the experimental system. The optimization of simulated model can provide the range of the operated parameters. Then, the best operated parameters can be found based on the experiment. First, the comparison of heat extraction between experiment and simulationwith different pressure (7.5, 9, 10, 11 and 12.5 MPa), mass flow rate (0.00082 and0.00109 kg/s)are shown in figure 5.

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Through figure 5, we can observe that the heat extraction increases as the mass flow rate. The results show that the maximum heat extraction is occurred at the 9MPa pressure and 0.00109 kg/s. The error of heat extraction between the numerical model and experiment is 0.61%.In addition,simulation model has been experimentally verified.It proofs that the numerical model is suitable forsimulating the supercritical CO_2 porous flow tostudy the complex phenomena. Therefore, it find the combination of pressure, flow rate, and particle size for the optimal heat extraction.

Second, the heat extraction of numerical model are shown in figure 6.The heat extraction of numerical model with different pressure(7.5, 9, 10, 11 and 12.5 MPa) and mass flow rate(0.00082 and0.00109 kg/s) at particle size 1.54mmis presented.Through figure 6,we canobserve thatthe maximum heat extraction is occurred at the 9MPa pressure.Finally, theoptimal heat extraction profiles of experiment are shown in figure 7. Theoptimal heat extraction with different pressure (8.9, 8.95, 9, 9.05 and 9.1 MPa), mass flow rate0.00109 kg/s is presented.Through figure 7, we can observe that themaximum heat extractionis happened on 9 MPa.

For the consideration of cost of realistic practice, the heat extraction of working fluid per kilogram is necessary to study. The specific heat extraction is defined as the heat extraction per kilogram supercritical CO_2.The specific heat extraction profiles are shown in figure 8. The specific heat extraction with different pressure (7.5, 9, 10, 11 and 12.5 MPa), mass flow rate (0.00082and0.00109 kg/s) atparticle size 1.54mmis presented. Through figure 8, we can observe that the specific heat extraction increases as the mass flow rate decrease. The results show the maximumspecific heat extraction is occurred at the 9MPa pressure and 0.00082 kg/s.Moreover, the specific heat extraction at 9MPaof 0.00082 kg/sis approximately 13.2% higher than that of 0.00109kg/s.The specific heat extraction can pointout what kind of pressure and flow rate to approach economic efficiency better.Better the specific heat extraction, theeconomic efficiency is.

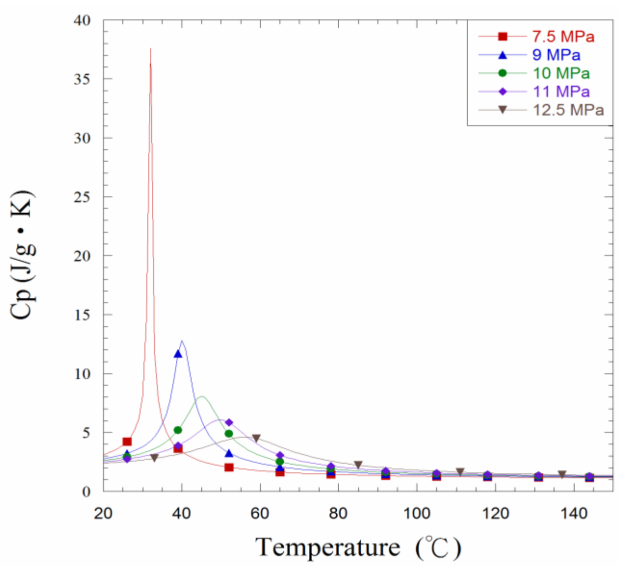

Figure 3. Specific heat of supercritical CO_2 with various temperature and pressure in the critical region [12].

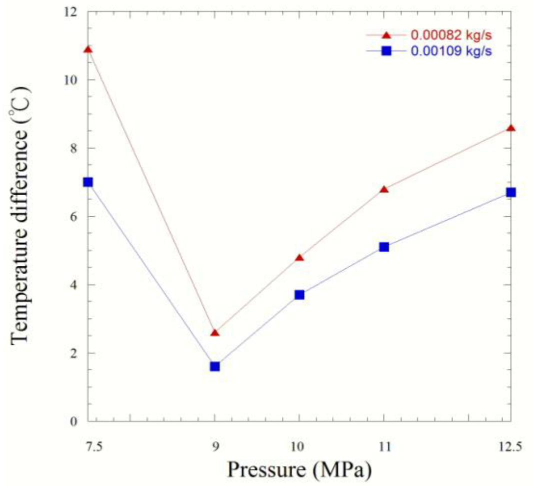

Figure4. The profiles of temperature difference with different pressure and mass flow rate.

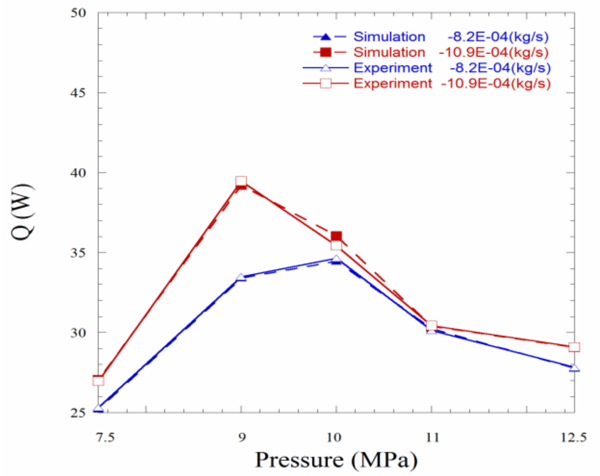

Figure 5. The comparison of heat extraction betweenexperiment and simulation.

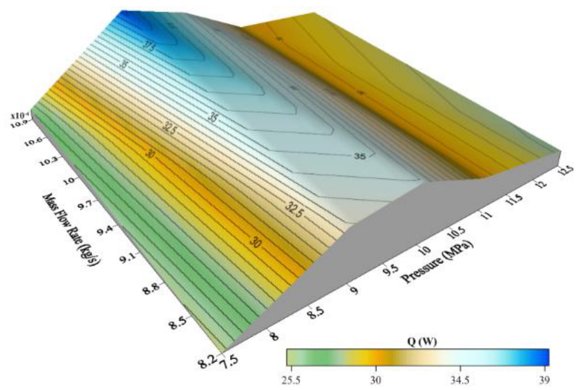

Figure6. The optimal heat extraction with various pressure and mass flow rate.

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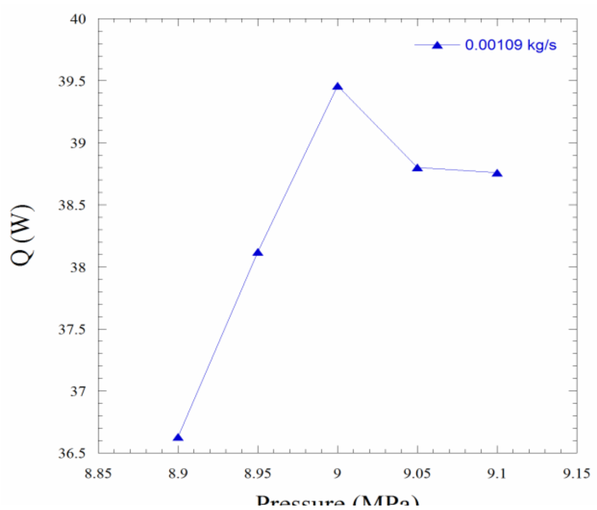

Figure 7. The optimal experimental heat extraction(mass flow rate is 0.00109 kg/s)

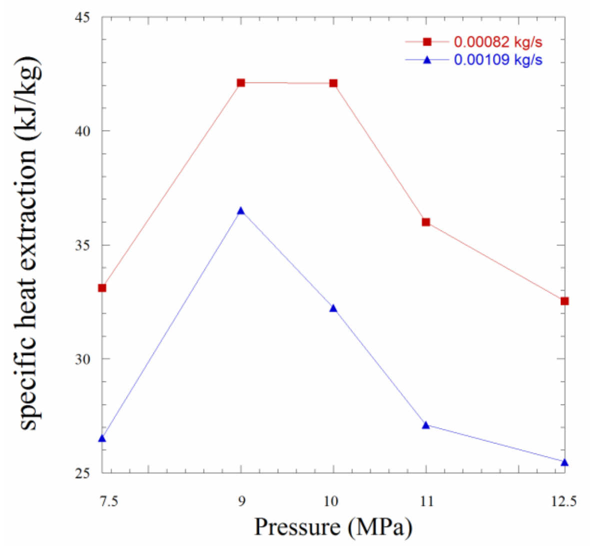

Figure 8. The specific heat extraction with various pressure and mass flow rate

4 Conclusions

In this study, the heat transfer performances for supercritical CO_2 flow in porous media are experimentally investigated and verificates the numerical simulations for the finding best combination of operated parameters. The results show that thesimulation model has been experimentally verifiedof the feasibility.The maximum heat extraction is happened at 9MPa.The maximum specific heat extraction happened at 9 MPaand flow rate of 0.00082 kg/s. We can observe that the heat transfer characteristics of supercritical CO_2affect the heat extractionstrongly.This study provides data regarding EGS operating conditions.We expect these results can enhance the heat extraction and reduce the cost of realistic test of enhanced geothermal system.

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