A Small Turbomachinery Laboratory for Geothermal Energy

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INTRODUCTION

Over the next few years, the Queensland Geothermal Energy Centre will be developing technology to assist with the exploitation of the hot-rock thermal reservoirs in western Queensland. It is hoped that, if the geothermal power systems can use carbon dioxide as the working fluid, we can obtain electric power at the same time as sequestering significant amounts of the carbon dioxide produced by traditional coal-fired power stations in other parts of the state. Within the new centre, we are establishing a small laboratory for the development of suitable turbomachinery.

Geothermal Power Cycle

As discussed by Gurgenci et al. (2008), one option for the power-generation cycle is a "geothermal siphon" with turbine, using supercritical carbon dioxide as the working fluid. Figure 1 shows the arrangement of the major components of such a system.

The keys to getting this cycle to work are (1) the use of carbon dioxide as the working fluid as suggested by Brown (2000) and (2) that, over the 5 km descent to the hot-rock thermal reservoir, gravity does approximately 49 kJ/kg of work compressing the carbon dioxide. The relative buoyancy of the heated fluid in the production well drives the mass flow around the cycle.

The ambient conditions in western Queensland are such that, with an air cooled low-temperature heat exchanger, we estimate the minimum temperature in the cycle to be 47 °C. If we set a pressure

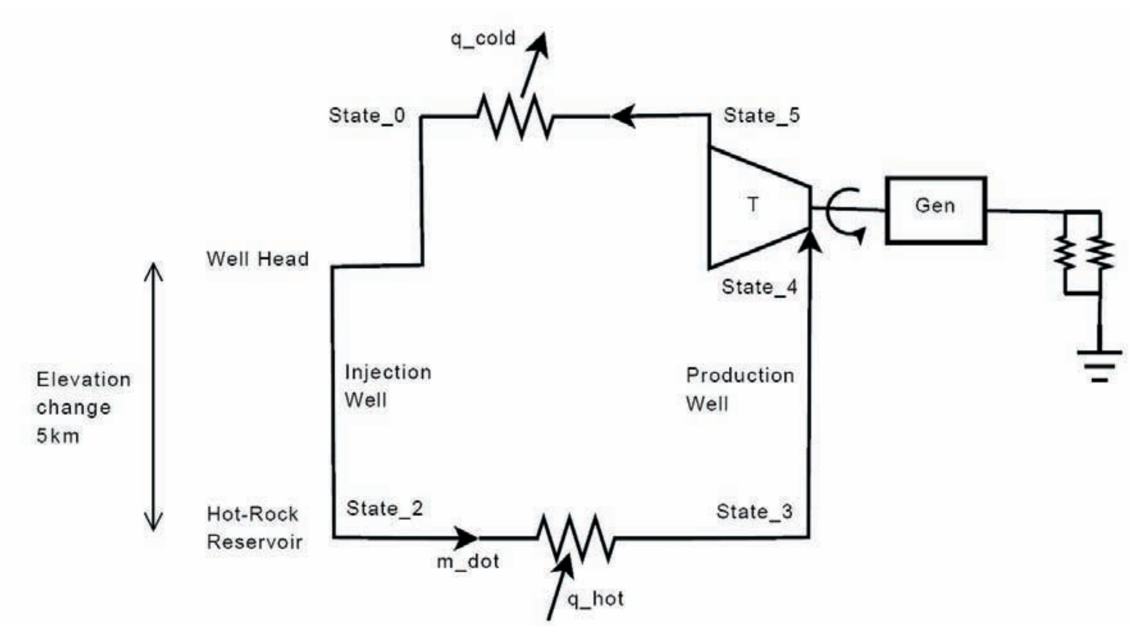

Figure 1. The geothermal siphon with carbon dioxide as the working fluid.

of 8 MPa leaving the cooler (State_0) and entering the injection well, the carbon dioxide is expected to maintain supercritical conditions throughout the cycle. The key states (labelled in Figure 1) are shown in Table 1. These have been calculated using the equation of state developed by Reynolds (1979).

Table 1. Key states in the thermodynamic cycles. Note that the undashed states are for the ideal cycles while the dashed states are for compressor and turbine efficiencies of 70%.

State	Pressure	Temperature	Enthalpy	Entropy
	(Mpa)	(Degree K)	(KJ/kg)	(KJ/K.kg)
0	8.00	320.0	348.1	1.219
1	13.39	359.7	367.4	1.219
1’	13.39	363.3	375.7	1.241
2	25.01	408.4	396.9	1.219
3	25.01	508.0	553.4	1.563
4	13.39	444.0	504.1	1.563
5	8.00	395.3	469.3	1.563
5’	8.00	403.8	479.8	1.599

In this idealised geothermal cycle, the process going down the injection well is considered to be isentropic and the end state can be determined by integration (Gurgenci et al., 2008). The heat is added to the working fluid as it flows through the hot-rock reservoir in a constant pressure process, that is, assuming no viscous losses. As the carbon dioxide flows up the production well, the work associated with gravity again causes a significant change in enthalpy. The fluid arrives at the turbine (State_4) with a pressure of 13.39 MPa and a temperature of 171 °C. Expanding the carbon dioxide through the turbine to 8 MPa makes available 34.8 kJ/kg of work and gives this idealised cycle a thermal efficiency of 22%.

Laboratory Cycle

For the laboratory-scale experiments, we will concentrate on the above-ground components and replace the wells and hot-rock reservoir with a compressor and an electrical heater, q_hot, as shown

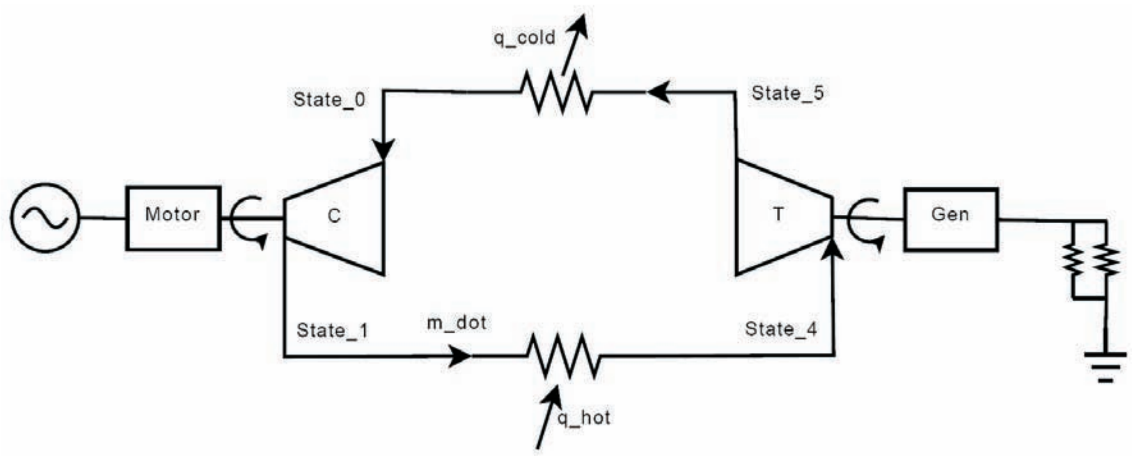

Figure 2. Thermodynamic loop proposed for the laboratory tests.

in Figure 2. Our interest is in developing efficient turbines for use with carbon dioxide as the working fluid.

The compressor and turbine are not mechanically coupled but are driven (or loaded) independently by electric motor and generator. This arrangement is now a simple Brayton cycle with heat being added at a pressure of only 13.39 MPa. Although the thermal efficiency of the ideal laboratory cycle quite low (11 %), our concern is really in providing an operating environment for the turbine that is similar to the full geothermal siphon.

In sizing the equipment for the laboratory, we have chosen the (somewhat arbitrary) value of 5 kW for the turbine output power. This leads to a mass flow of 0.144 kg/s within the loop, a compressor input power of 2.8 kW and a heat input of 19.7 kW at 171 °C. Presently, we are looking at modified automotive turbochargers as a cheap source of rotors for our initial exploration. It seems that typical turbochargers have efficiencies of about 70% for both the turbine and compressor so we show the laboratory cycle states assuming that level of performance. As compared to the cycle with ideal turbomachinery, the work from the turbine drops to 24.3 kJ/kg while the work required by the compressor rises to 27.5 kJ/kg. This highlights the importance of developing a very efficient turbine.

REFERENCES

Brown, D. 2000. A hot dry rock geothermal energy concept utilizing supercritical CO_2 instead of water. *In: Proceedings of the Twenty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University*, 233-238.

Gurgenci, H., Rudolph, V., Saha, T. and Lu, M. 2008. Challenges for geothermal energy utilisation. *In: Proceedings of the Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford University*, pages SGP-TR-185, January 2008.

Reynolds, W.C. 1979. Thermodynamic properties in SI: graphs, tables, and computational equations for 40 substances. Stanford University, Department of Mechanical Engineering, Stanford University.