Carbon Dioxide Thermosiphon Optimisation

Atrens, A.D.[1, 2], Gurgenci, H.[1,2] and Rudolph, V.[1,2]
[1] *Queensland Geothermal Energy Centre of Excellence*
[2] *School of Engineering, The University of Queensland, St Lucia, Queensland 4072, Australia*
Email: aleks.atrens@uq.edu.au; h.gurgenci@uq.edu.au; v.rudolph@uq.edu.au

Geothermal power has the potential to become a major baseline power source (Tester et al. 2006). Large-scale generation requires the use of Engineered Geothermal Systems (EGS). The standard engineering assumption would be to use water as a heat extraction fluid, however water may not provide the optimum economics. Carbon dioxide is the only cheap, abundant alternative with favourable properties. The characteristics making CO_2 a potential competitor are (Brown, 2000; Pruess, 2006; Gurgenci et al., 2008):

- Abundance
  - as geothermal reservoir flow can involve significant losses of geofluid, a large source of fluid is needed.
- Sequestration potential
  - there are economic benefits involved in loss of CO_2 into the reservoir (providing it is appropriately sealed) through carbon credit schemes.
- No process scaling (deposition of low-solubility minerals on surfaces) issues
  - as CO_2 is a non-polar fluid with low solubility of ionic compounds, a geothermal plant utilising CO_2 will not have the issues with scaling in process equipment often encountered in traditional hydrothermal power generation.
- Buoyancy drive
  - a CO_2-based system would have high-density fluid in the injection well and low-density fluid in the production well, providing additional impetus for flow through the reservoir and decreasing pumping requirements.
- Suitable thermodynamic & transport characteristics
  - while the heat capacity and density of CO_2 are lower than water, the viscosity is also lower, allowing similar flows of thermal energy when utilising CO_2.

The interaction of CO_2 with the reservoir is investigated in a separate project by the Queensland Geothermal Research Centre.

PROJECT AIMS

A PhD project has been commenced to examine the usage of CO_2 in a geothermal power plant design, particularly from an economic point of view. The main goals of the project are to:

- Examine the merits of CO_2, and conduct comparative analysis between CO_2- and H_2O-based power plant designs;
- Identify efficient designs and appropriate modifications for CO_2-based geothermal power plants;
- Construct a model for the economic optimisation of CO_2-based geothermal plant designs; and
- Utilise model to examine the impacts of key parameters (such as process pressures, heat exchanger sizes, well spacing and depth), and how they can be optimised for site constraints.

CURRENT PROGRESS

Current work has been focussed on a thermodynamic study comparing a number of basic plant designs. The purpose of this comparative study is not to give definitive analytical results but to validate CO_2-based designs as viable alternatives to H_2O, and indicate appropriate directions of further research. The plant designs examined are:

- CO_2 thermosiphon;
- Binary water/isopentane;
- Binary water/CO_2;
- Binary CO_2/isopentane; and
- Air thermosiphon.

The additional binary alternatives are used to examine the benefits gained from utilising CO_2 in different parts of the plant. Air is included as a comparative indicator of how the non-ideal gas properties of CO_2 make a significant difference to design viability.

Plant Design and Model Setup

The design of the plants for comparative analysis differs as required for the different styles of plant (as shown in Figure 1). All plants include an injection wellbore, a reservoir model, a production wellbore, a turbine, and condenser. The plants utilising water as a heat extraction fluid include a water pump, and binary plants include an additional heat exchanger and working fluid pump/compressor.

The plants have been modelled using MATLAB, utilising Helmholtz free energy-based equations of state (IAPWS, 1996; IAPWS, 2007; Lemmon and Span, 2006; Lemmon et al., 2000; Span and Wagner, 1996). Most components in the system have been considered ideal – compression, expansion, and wellbore flows have been considered isentropic. Heat exchange operations have been considered as isobaric processes, except in the case of the reservoir. The reservoir has been modelled as a single channel of Darcy flow, with linear temperature increase with distance between

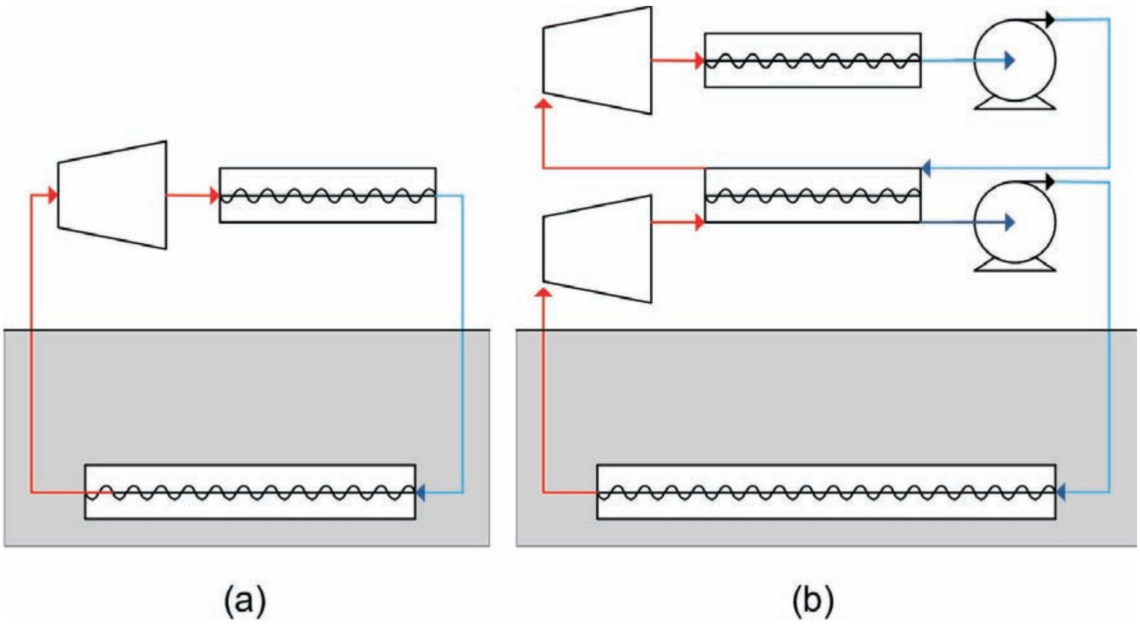

Figure 1. Geothermal (a) thermosiphon plant design, and (b) H_2O-based binary plant design.

injection and production wells. Preliminary calculations indicate that the buoyancy of CO_2 results in a net gain of ~12MPa through the subsurface section of the design. The effect of this on the viability of the power generation system is being examined. Examination of transport properties of CO_2 indicates that the average ratio of viscosity to density (the critical factor for reservoir pressure drop) is about 1/3 of that of water.

FUTURE DIRECTION

Planned directions of additional future research include both assessment of a range of design modifications, and design of an economically optimised plant.

Plant Design Alternatives

There are a number of interesting options that may be explored for increased thermodynamic and economic optimisation of the process, such as:

- Thermosiphon design vs. compressor usage
  - Higher cycle pressures generally increase power generation efficiency, with the drawback of increased equipment cost.
- Intermediate heat exchange transfer fluid
  - Removal of the significant amounts of waste heat from geothermal plants is a significant obstacle. If a CO_2 thermosiphon design is used coupled with air cooling (as is likely the case in arid climates), there is an opportunity to examine using an intermediate heat exchange fluid flowing in a cycle between different pressures to remove the need for very thick heat exchanger piping (due to the high pressures of CO_2 used).
- Solar heating
  - As Australian sites with large geothermal temperature gradients generally also have a high influx of solar radiation, there is the potential to include solar heating in the power plant design for improved efficiency, in a role of superheating or reheating.

Design alternatives such as these require cost-benefit analysis to assess their suitability for inclusion in a power plant design.

Plant Optimisation

The eventual goal is a system for optimising a design for maximising economic benefit. There are a number of key system parameters that must be selected, based on the constraints of the plant location. The purpose of plant optimisation should not only be to determine the parameters for an economic maximum, but also examine how the constraints affect both the economics of the design, and the way in which the parameters must be changed in response.

REFERENCES

Brown, D. W. 2000. A Hot Dry Rock Geothermal Energy Concept Utilizing Supercritical CO_2 Instead of Water. *Twenty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.*

Gurgenci, H., Rudolph, V., Saha, T. and Lu, A. M.. 2008. Challenges for Geothermal Energy Utilisation. *Thirty-Third Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, California

The International Association for the Properties of Water and Steam. 1996. Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

The International Association for the Properties of Water and Steam. 2007. Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.

Lemmon, E. W., Jacobsen, R. T., Penoncello, S. G. and Friend, D. G.. 2000. Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon, and Oxygen from 60 to 2000 K at Pressures to 2000 MPa. *Journal of Physical and Chemical Reference Data*, **29**, 331pp.

Lemmon, E. W. and Span, R. 2006. Short Fundamental Equations of State for 20 Industrial Fluids. *Journal of Chemical Engineering Data*, **51**, 785pp.

Pruess, K.. 2006. Enhanced Geothermal Systems (EGS) Using CO_2 as Working Fluid—a Novel Approach for Generating Renewable Energy with Simultaneous Sequestration of Carbon. *Geothermics*, **35**, 351pp.

Span, R. and Wagner, W. 1996. A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point Temperature to 1100 K at Pressures up to 800 MPa. *Journal of Physical and Chemical Reference Data*, **25**, 1509pp.

Tester, J.W. and 11 others, 2006. *The Future of Geothermal Energy. Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century*. Massachusetts Institute of Technology. http://geothermal.inel.gov.