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Density and viscosity of brine: An overview from a process engineers perspective

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ABSTRACT

The aim of our study is to evaluate the sensitivity of the volumetric flow rate of a downhole pump in a geothermal production well on different density and viscosity functions during the startup and stationary operating phases. The geothermal fluid is modeled as an aqueous sodium chloride solution and functions for its density and viscosity are compared and applied to a model of the geothermal fluid cycle. It is shown that the deviations between viscosity functions have negligible impact on the volumetric flow rate, while the impact of the deviations between different density functions is up to 52% of the volumetric flow rate.

1. Introduction

Geothermal heat and power plants use hot geothermal fluid as a transport medium to extract thermal energy from the deep underground. A downhole pump in the production well lifts the brine up to the surface, where it is cooled in a heat exchanger and reinjected subsequently (Fig. 1). As the downhole pump consumes a significant quantity of energy, special attention should be paid to its dimensioning (Saadat et al., 2008). For this task, knowledge of thermophysical and transport properties of the brine are indispensable. These properties are determined by pressure, temperature and chemical composition.

Functions for the calculation of property values are usually mathematical expressions fitted to reproduce experimentally measured values. Adams and Bachu (2002) reviewed various functions for the calculation of brine density and viscosity.

Champel (2006) used different density functions to calculate the density change resulting from the temperature change of the fluid inside the wells after initiation of fluid extraction.

Two important aspects of pump dimensioning consist of the calculation of the volumetric flowrate and the power needed to produce this flowrate. During the planning period of a geothermal site exact fluid properties are usually not available. The aim of our study is to evaluate the sensitivity of the volumetric flow rate on different density and viscosity functions during the startup and stationary operation of a sample power plant. The boundary conditions assumed are similar to those found in our test site in Groß Schönebeck, 50 km north of Berlin, constituting a representative example for a geothermal system in the North German Basin (Zimmermann et al., 2009).

2. Methodological approach

The general approach of this study is to apply different property functions from literature to a model of the geothermal fluid cycle and evaluate the resulting impact on the volumetric flow rate.

2.1. Geothermal fluid property functions

Geothermal fluids with salinities higher than 10 g/l are generally Cl-dominated, with Cl accounting for over 95% by mass of anions. In low to moderate salinity fluids, Na is the dominant cation. As brine salinity increases, the relative proportion of Na decreases and the proportions of K, Mg and Ca increase. Most notable is the increase in Ca, which typically is the dominant cation by mass in fluids whose salinities exceed 300 g/l (Hanor, 1994).

Given the dominance of Cl and Na ions over a wide range of salinity relevant for geothermal fluids, these fluids are frequently modeled as aqueous NaCl solutions (Adams and Bachu, 2002). The total of dissolved solids in the fluid found in Groß Schönebeck sums up to 265 g/l (Huenges and Winter, 2004). We modeled the

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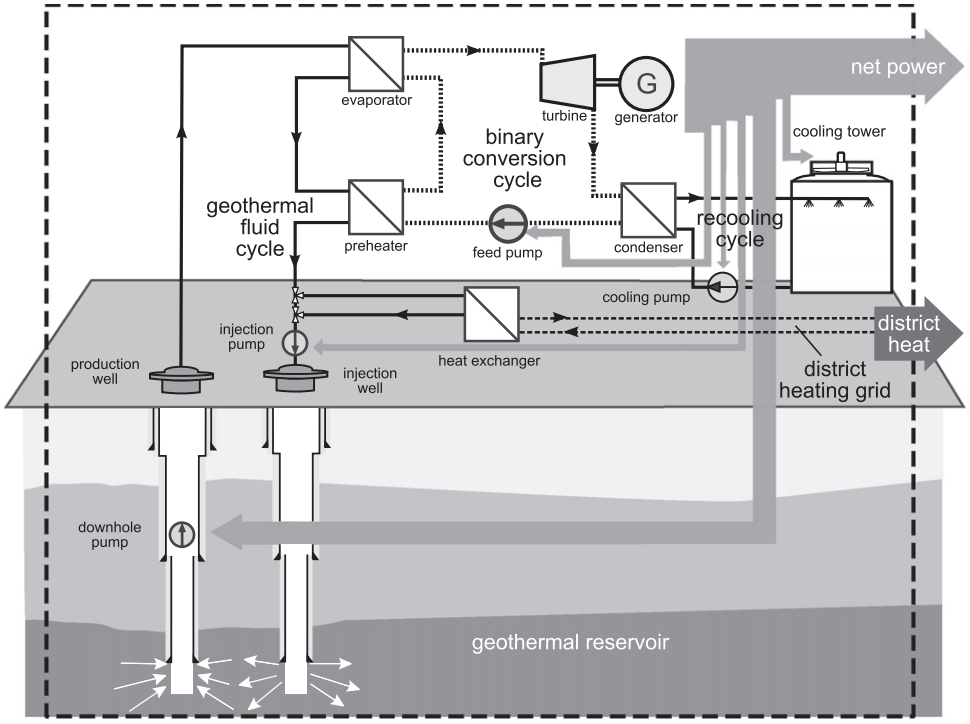

Fig. 1. Schematic diagram of an exemplary geothermal fluid cycle. Exemplarily a power plant and district heating station are shown as thermal energy consumers. The downhole pump consumes a significant quantity of energy.

Table 1
Applicability range of various algorithms for calculating brine density.

Study	T (°C)	p (MPa)	Electrolytes	b (mol · kg^{-1})
Rowe and Chou (1970)[a]	20–150	p_{sat}-35	NaCl	0–5.7
Phillips et al. (1981)	10–350	p_{sat}-50	NaCl	0–5
Magri et al. (2005)	0–350	p_{sat}-100	NaCl	0–6
Driesner (2007)	0–1000	0.1–500	NaCl	0–∞
Mao and Duan (2009)	0–846	0.1–100	various	0–6

[a] Converted to SI units by Kestin et al. (1981b).

Table 2
Applicability range of various algorithms for calculating brine viscosity.

Study	T (°C)	p (MPa)	Electrolytes	b (mol · kg^{-1})
Phillips et al. (1981)	10–350	0.1–50	NaCl	0–5
Kestin et al. (1981b)	20–150	0.1–35	NaCl	0–6
Mao and Duan (2009)	0–350	0.1–100	NaCl, KCL, LiCl	0–6

fluid as an aqueous sodium chloride solution with a NaCl mass fraction of 0.225 $kg_{NaCl}/kg_{Solution}$, corresponding to a molality of 4.968 mol_{NaCl}/kg_{H_2O}. For the conversion between mass fraction w, mole fraction x and molality b see Appendix A.

2.1.1. Density

An overview on the density functions used is given in Table 1.

Rowe and Chou (1970) developed a function based on their own density measurements of NaCl aqueous solutions. They used three empirical coefficients for the specific volume of pure water. The deviation from pure water is represented by five additional coefficients.

Phillips et al. (1981) reviewed existing functions for various fluid properties and developed new ones for viscosity and density. The range of applicability starts at 0.25 mol_{NaCl}/kg_{H_2O} and therefore does not include pure water.

Magri et al. (2005) gave an algorithm for the calculation of the coefficients of thermal expansion and compressibility. Together with the solvent densities at a reference salinity and at solute saturation a factor is formed. Multiplying the reference density by this factor yields the solution density.

In a first study Driesner and Heinrich (2007) gave correlation formulae for phase relations in the system H_2O and NaCl. In a second study Driesner (2007) developed a set of correlations for the volumetric properties, enthalpies and heat capacities of the phases. The basic idea is that each property value at a certain temperature is equal to the property value of pure water at a different temperature. Driesner presents algorithms for the calculation of such a scaled temperature. Also a short review of various density correlations is given.

Mao and Duan (2008) developed a semi-empirical model for the density of various aqueous chloride solutions partly similar to the model by Rogers and Pitzer (1982).

2.1.2. Viscosity

Viscosity is one of the key factors in fluid flow simulation and much research has been done to measure and model brine viscosity. Table 2 lists four functions for brine viscosity calculation.

Phillips et al. (1981) modified a theoretical model proposed by Vand (1948). The ratio of solution viscosity to pure water viscosity is calculated using four coefficients.

In two publications Kestin et al. (1981a, b) developed correlations for KCl and NaCl aqueous solutions from their own experiments. For conversion from dynamic viscosity to kinematic viscosity, the density from Rowe and Chou (1970) was used.

Mao and Duan (2009) developed a model for the viscosity of aqueous solutions of LiCl, NaCl and KCl. The algorithm uses ten parameters to calculate the ratio of solution viscosity to pure water viscosity. For calculating the viscosity of ternary mixtures, they recommend Young's mixing rule (Correia et al., 1979).