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Methods for Measuring the Density and Viscosity of Saline Geothermal Fluids under Reservoir Conditions

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ABSTRACT

For the sustainable operation of a geothermal system, it is important to know the flow characteristics of the geothermal fluid as exactly as possible. Therefore, viscosity and density are important thermophysical parameters. In sedimentary basins, as prominent targets for geothermal energy exploitation, fluids are mostly highly saline and mainly consist of sodium chloride and calcium chloride. To obtain systematic knowledge about the viscosity and density of sodium chloride and calcium chloride solutions and mixtures of both salts, a laboratory study was conducted. For geothermal applications, salt solutions with different concentrations need to be measured at pressure and temperature conditions up to 200°C and 500 bar. For the viscosity measurement, a flow-through apparatus originally designed for rock-physical measurements was converted into a capillary viscometer. So far, measurements up to 125 bar and 90°C were conducted. Viscosity data of the salt solutions were obtained relative as deviation from pure water, used as the calibration agent for each temperature and pressure step. In this contribution, the general concept and the modifications of this apparatus are outlined. Density measurements are obtained by using an oscillating u-tube densitometer (DMA HP from Anton Paar). The results obtained so far are presented.

1. INTRODUCTION

In order to ensure a safe, economic and sustainable operation of geothermal plants, among others, the knowledge of the fluid properties as accurately as possible is required. Since the fluid is a key element in the geothermal cycle, the system has to be designed in accordance with its site-specific conditions. Viscosity describes the flow behavior and how quickly and effectively the fluid may be produced from the reservoir. The density implies the reservoir pressure and the prevalent stress in the subsurface.

This laboratory study is based on the research platform Groß Schönebeck operated by GFZ Potsdam in Northern Germany. In a depth of 4300 m, the fluid has a temperature of 150°C at about 450 bar (Huenges et al. 2002) and its value of total dissolved solids (TDS) is 265 g/L. During the operation, the fluid is exposed to changes in temperature and pressure. On its way out of the borehole, pressure decreases. In the above-ground facilities, temperature decreases. Before reinjection, the fluid temperature is about 70°C at 10 bar.

Sodium chloride and calcium chloride are the main solutes in fluids being found in the North East German Basin. Depending on the specific site, the ratio of the salts, their total molality within the fluid and the composition of other elements may differ. However, the physical properties of a geothermal fluid are determined by the main salts as those mentioned before.

Site specific differences in the salt concentrations result in varying density and viscosity of the fluids. Taking into account the changes in temperature and pressure, only estimating the fluid properties can have a severe impact on plant operation and may thereby also cause financial losses. An exact knowledge of the properties of the geothermal fluid as a function of temperature, pressure, and composition is crucial for an understanding of the parametric dependencies involved. Therefore, systematic investigations on model fluids have to be performed.

In an earlier publication, the results for atmospheric pressure and temperatures up to 80°C were presented (Hoffert and Milsch 2015). This study is aimed to extend the temperature and pressure range of the systematic measurements preferably up to reservoir conditions, i.e., 200°C and 500 bar.

2. MATERIALS AND METHODS

2.1 Sample preparation

In order to observe the actual influence of the salts on the properties of pure water, all measurements were performed with synthetically prepared brines. These solutions shall model possible geothermal fluids similar to those in the North German Basin. In addition, solutions were prepared with magnesium chloride in order to be able to distinguish the influence of the calcium chloride from that of divalent chlorides in general. The purity level of all three salts was above 99%. The reproducibility of the scale[1] is 0.1 mg which is equivalent to a deviation of less than 1‰ relative to the weighed quantities.

2.2 Measuring devices

2.2.1 Density

The density measurements were conducted with an Anton Paar DMA HP cell combined with a 100DX ISCO syringe pump. The device was calibrated with pure water and ethanol using the manufacturer's 'Excel Tool for Wide Range Adjustments'. Test

[1] KERN & SOHN GmbH. ABJ 220-4M

measurements with pure water showed a relative deviation from REFPROP[2] of 1% at maximum. The samples were stirred and heated up before injection to avoid the formation of air bubbles.

2.2.2 Viscosity

For measuring the viscosity of geothermal brines up to reservoir conditions encountered at the Groß Schönebeck site (150°C and 450 bar), a GFZ-built flow-through apparatus originally designed for rock-physical measurements was converted into a capillary viscometer (details about the original structure are described in Milsch et al 2008).

As shown in **Figure 1**, the apparatus consists of a vessel filled with oil, which is pressurized by a syringe pump (oil pump). The oil is heated by a thermostat. The sample fluid is pumped from a first pump (upstream) at a fixed flow rate through the capillary system, which is situated in the heated oil, to a second pump (downstream). The upstream pump regulates the flow rate, the downstream pump regulates the internal pressure of the capillary system. The actual measuring capillary consists of PEEK, is 1.6 m long and has an inner diameter of 130 µm. Several temperature sensors measure the temperature of the fluid and the oil. A differential pressure sensor records the pressure difference before and after the measuring capillary. The maximum temperature for this apparatus is 200°C. The maximum pressure depends on the equipped pumps and is currently 250 bar.

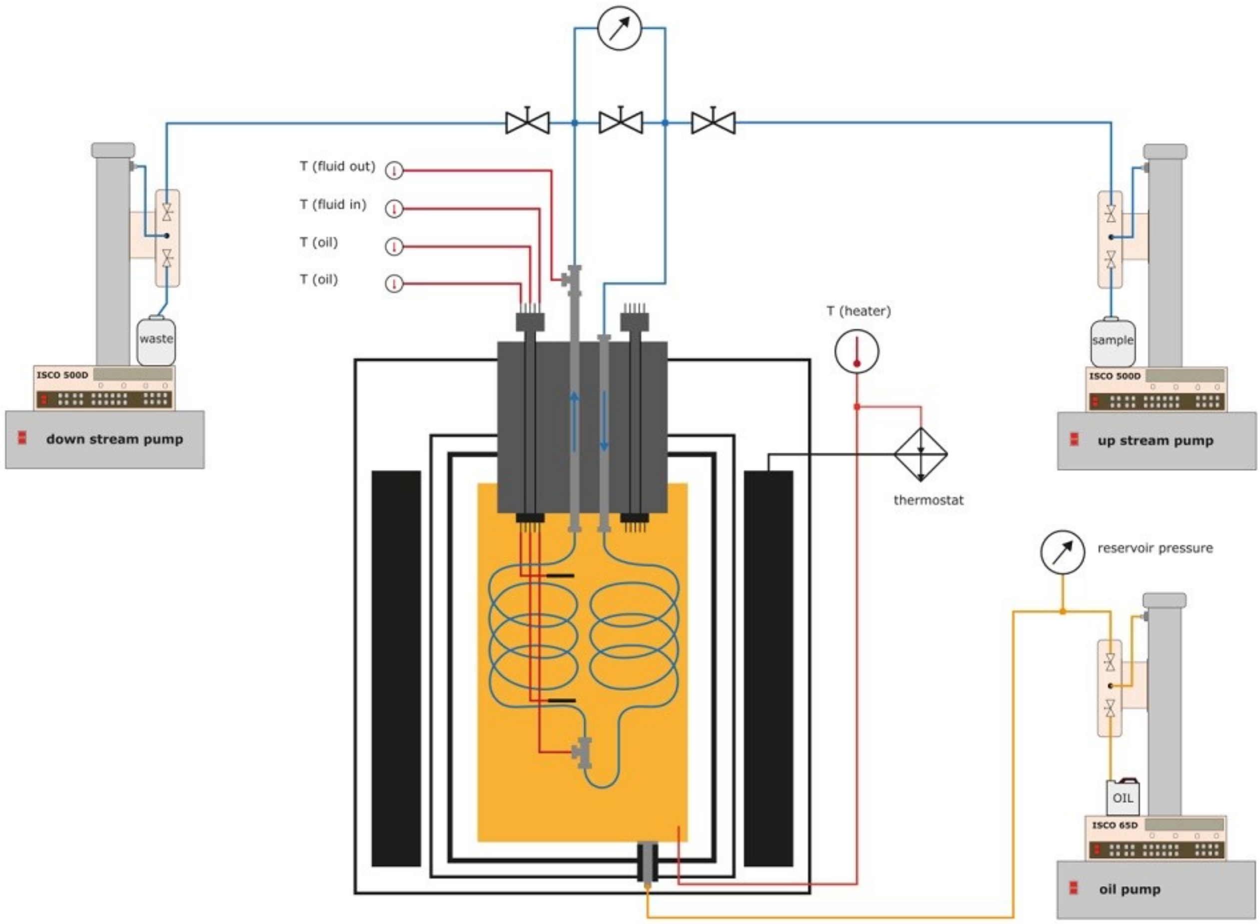

Figure 1: Schematic representation of the modified flow-through apparatus for measuring the viscosity up to reservoir conditions.

The viscosity is calculated using the equation of Hagen–Poiseuille:

$$\eta = \frac{\pi \cdot r^4 \cdot \Delta p}{8 \cdot l \cdot V} \tag{1}$$

where η, r, Δp, l and V are viscosity, inner radius of the capillary, pressure difference, length of the capillary, and fluid flow rate, respectively.

3. RESULTS AND DISCUSSION

3.1 Density

The temperature dependence at 100 bar and the pressure dependence at 50°C of the density data of the single salt solutions, containing only sodium chloride, calcium chloride and magnesium chloride, respectively, are shown in **Figure 2**. The density data

[2] NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP)

of the 1:1 mixture (sodium chloride: calcium chloride and sodium chloride: magnesium chloride, respectively) compared to those of the pure salt solutions are shown depending on temperature at 100 bars in **Figure 3**. Indicated in the figure legends are the respective total molalities of the solutions related to the cations.

As expected, density decreases with higher temperatures and increases with higher pressures. The density data of the mixtures are systematically between those of the individual solutions.

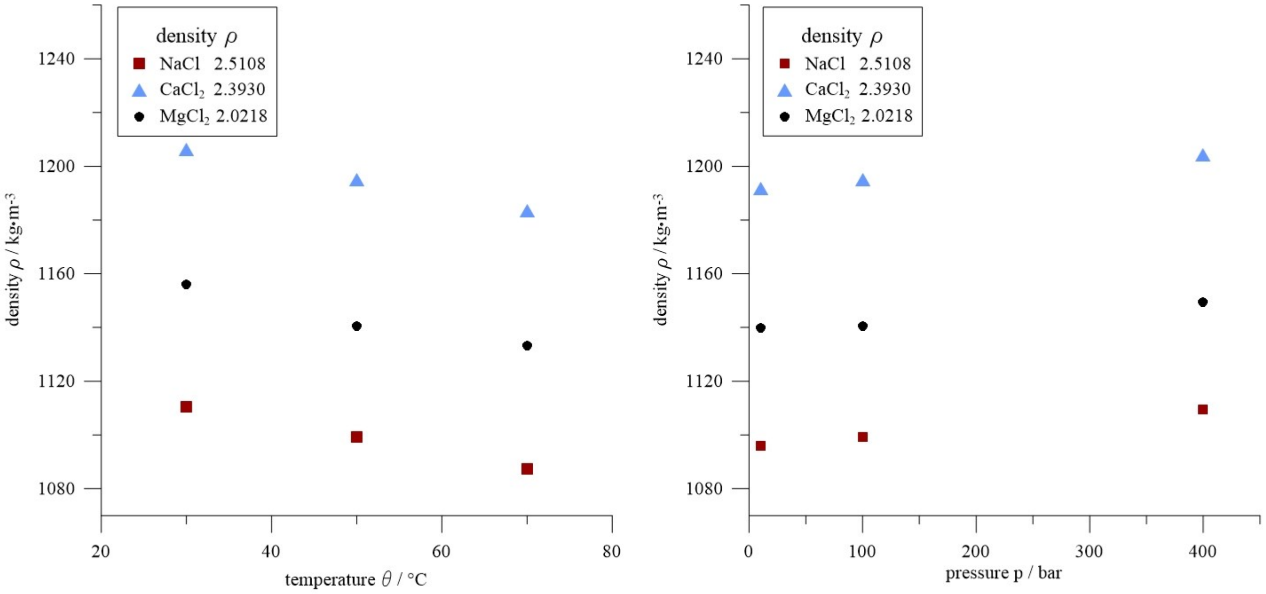

Figure 2: Measured density data of pure salt solutions of sodium chloride, calcium chloride and magnesium chloride in water; temperature dependence at 100 bar (*left*) and pressure dependence at 50°C (*right*). Numbers in the figure legends indicate the respective total molalities of the solutions related to the cations.

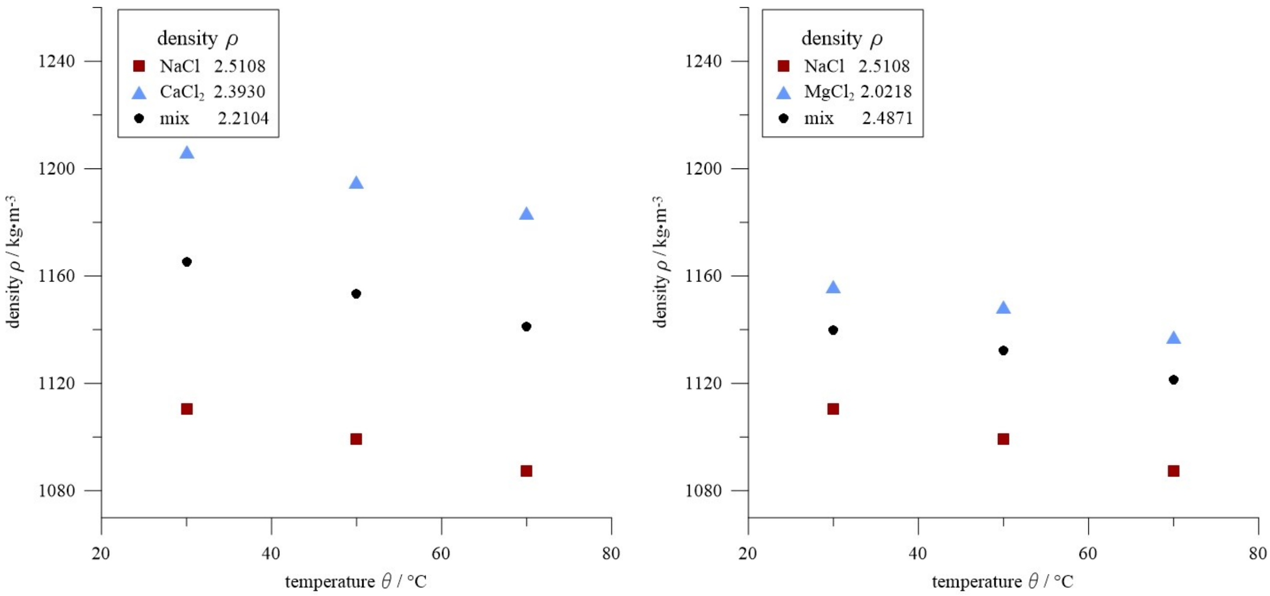

Figure 3: Measured density data of pure salt and mixed solutions of sodium chloride, calcium chloride and magnesium chloride in water; sodium chloride and calcium chloride (*left*) and sodium chloride and magnesium chloride (*right*) at 100 bar as a function of temperature. Numbers in the figure legends indicate the respective total molalities of the solutions related to the cations.

3.2 Viscosity

After the modification of the apparatus, systematic investigations with different capillary diameters and lengths as well as different flow rates were required. In addition, a sufficiently accurate determination of the fluid temperature within the measuring capillary had to be ensured. For measurements of pure water, the current structure (inner diameter: 130 µm and length: 1.6 m) allows an accuracy better than about 2% as shown in **Figure 4** where the relative error of the viscosity data of pure water compared to REFPROP is shown for different pressure and flow conditions.

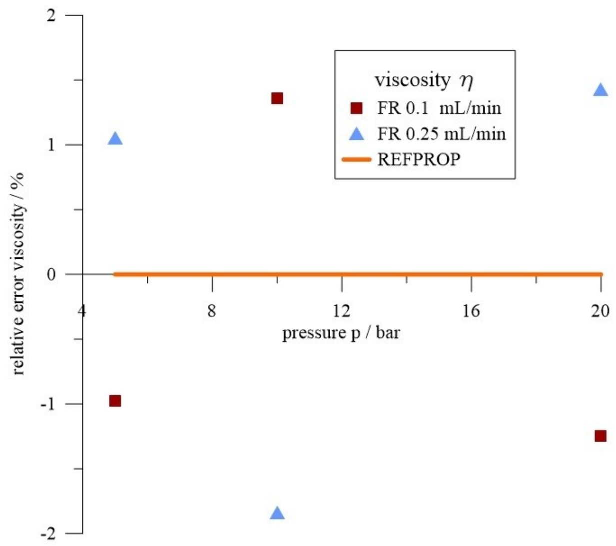

Figure 4: Relative error for viscosity measurements of pure water at room temperature, different pressures and flow rates, compared to REFPROP. FR in the legend indicates flow rate.

4. CONCLUSIONS

The present study provides new laboratory data for density of mixed solutions of sodium chloride, calcium chloride and magnesium chloride up to 70°C and 400 bar. A device for measuring the viscosity under reservoir conditions was presented.

In a previous publication, mixing rules were applied to the measured data in order to predict the properties of mixed solutions depending on their molality (Hoffert and Milsch 2015). Density and viscosity of mixed solutions ranging from 20°C to 80°C at atmospheric pressure were determined with high accuracy. The extension to higher pressures and temperatures is the subject of ongoing work.

Further modifications of the apparatus for viscosity measurements in order to further improve accuracy as well as to enable the simultaneous measurement of other properties such as electrical conductivity and sonic velocity is currently in planning and/or in the testing phase.

5. ACKNOWLEDGMENTS

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