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Data Gaps in Thermophysical Fluid Data for Geothermal Applications

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ABSTRACT

An integrated development and use of geothermal sites for sustainable energy provision requires the fluid's thermophysical properties to be known and characterized in detail. Due to often highly complex fluid compositions, e.g. high salinity and mineralization of the brines, their properties generally depart significantly from those of pure water and are often unknown.

The principal parameters of interest are density, viscosity, sonic velocity, specific heat, thermal conductivity, and electrical conductivity. The experimental pressure and temperature space needed to cover all reservoirs to accessible depths of 5 km having a normal geothermal gradient is up to 50 MPa and 200°C, respectively. Dominant salts in geothermal fluids are NaCl, $CaCl_2$, and KCl with concentrations up to saturation.

We conducted a comprehensive evaluation of existing literature data identifying approximately 350 publications with thermophysical fluid data for the parameters mentioned above. In addition, a new laboratory has been installed at the GFZ-Potsdam that enables measurements of these fluid properties at conditions relevant for deep geothermal systems.

Here, we (1) present a statistical evaluation of the assembled literature database motivating further experimental measurement efforts in the context of geothermal applications and (2) we outline the laboratory installations highlighting in-house constructions where off-the-shelf solutions are not available, particularly for high pressure and temperature measurements.

1. INTRODUCTION

Fluids are the central element in geothermal technology. They act both as energetic medium and heat carrier. Knowledge of their physical properties is therefore essential for all stages of project development, starting from exploration (e.g. seismics and electro-magnetics), over drilling, logging, and reservoir engineering to power plant design and implementation. Depending on the site and its particular geological situation, fluid composition can vary significantly. In particular, high salt concentrations as found, e.g., in deep sedimentary basins, yield strong deviations in thermophysical fluid properties compared to those of pure water.

The geothermal system at the research platform Groß Schönebeck, Germany (e.g. Regenspurg et al., 2010) provides an example. **Fig. 1** shows the distribution in concentrations of major ionic species in this fluid having a content of total dissolved solids (TDS) of ca. 265 g/L. Furthermore, during production and reinjection of the fluid its thermodynamic pressure and temperature state varies significantly as exemplified in **Fig. 2** for the case of the Groß Schönebeck site. In conclusion, the site dependent properties of geothermal fluids have to be known as a function of pressure, temperature, composition and concentration.

We searched the literature for thermophysical data of density, viscosity, sonic velocity, specific heat, thermal conductivity, and electrical conductivity as the principal parameters of interest and for fluids containing NaCl, $CaCl_2$, KCl, and mixtures thereof with concentrations up to saturation (Section 2). In parallel, we set up a new thermophysical laboratory at the GFZ-Potsdam for measurements of these parameters that complements the database and that is continuously improved regarding measurement capabilities at higher temperature and pressure (Section 3). Focusing on geothermal applications we aim at maximum pressures of 50 MPa and maximum temperatures of 200°C which covers all reservoirs to accessible depths of 5 km having a normal geothermal gradient.

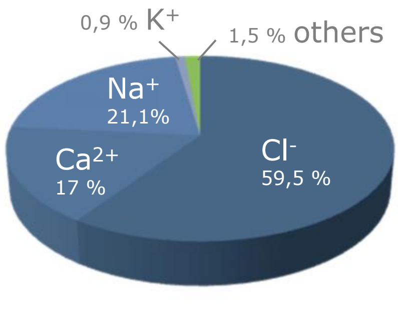

Figure 1: Example of variability in composition for the fluid at the research platform Groß Schönebeck, Germany (e.g., Regenspurg et al., 2010). Total content in dissolved solids (TDS) is 265 g/L.

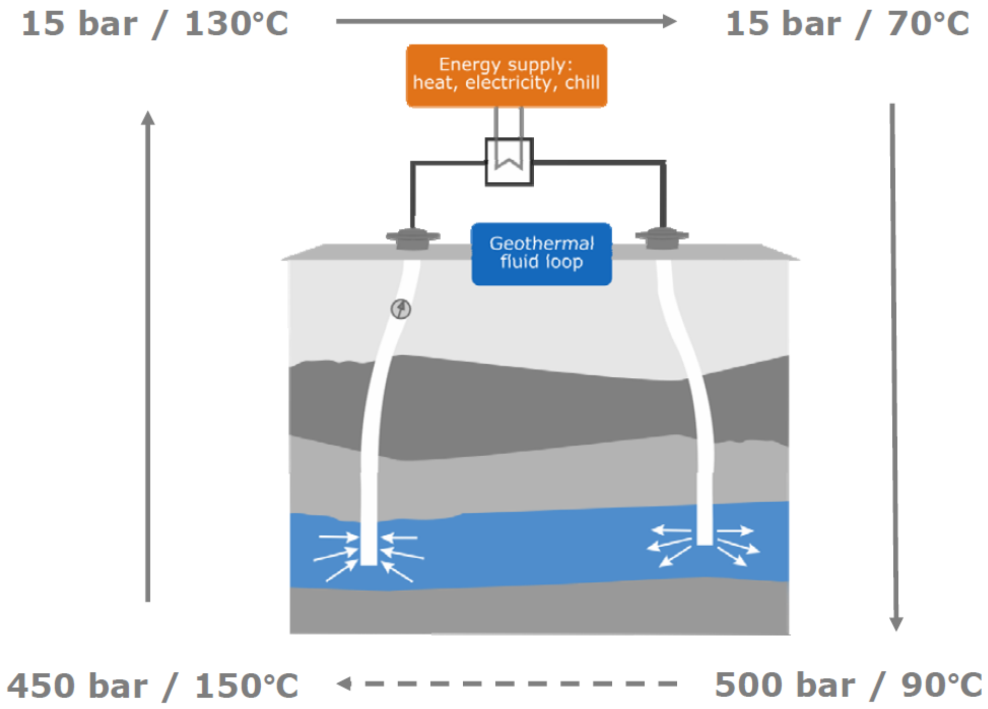

Figure 2: Example of variability in pT-conditions during production and injection for the fluid at the research platform Groß Schönebeck, Germany (e.g., Regenspurg et al., 2010). Reservoir depths is ca. 4300 m.

2. DATA AVAILABILITY

Existing literature was searched for the parameters, conditions, and fluid compositions listed in **Fig. 3** and approximately 350 publications were screened yielding a statistically relevant evaluation. **Fig. 4** summarizes the outcome of this evaluation where it showed that density is by far the most well characterized fluid property followed by viscosity, thermal conductivity, electrical conductivity, specific heat, and finally, sonic velocity. Furthermore, the more complex the fluid composition and the higher the temperature and/or pressure range is, the least data exists, independent on the type of parameters. Also, it can be concluded that, even when the required pT-space appears complete for some properties of binary electrolytes, e.g. the density of aqueous KCl-solutions (**Fig. 5**), the full concentration range of interest is not covered by existing data.

- Parameters:
  - density
  - heat capacity (cp)
  - sonic velocisty
  - dynamic viscosity
  - thermal conductivity
  - electrical conductivity
- Conditions:
  - Temperature T
    - 20 – 200°C
  - Pressure p
    - 1 – 500 bar
  - Concentration c
    - 0 – 5 mol/kg (or saturation)
- Solutions:
  - NaCl
  - $CaCl_2$
  - KCl
  - pure and mixtures thereof

Figure 3: Relevant thermophysical properties, conditions, and fluid compositions for deep geothermal systems with normal geothermal gradient (ca. 30°C/km). A comprehensive search of data availability was conducted for this matrix.

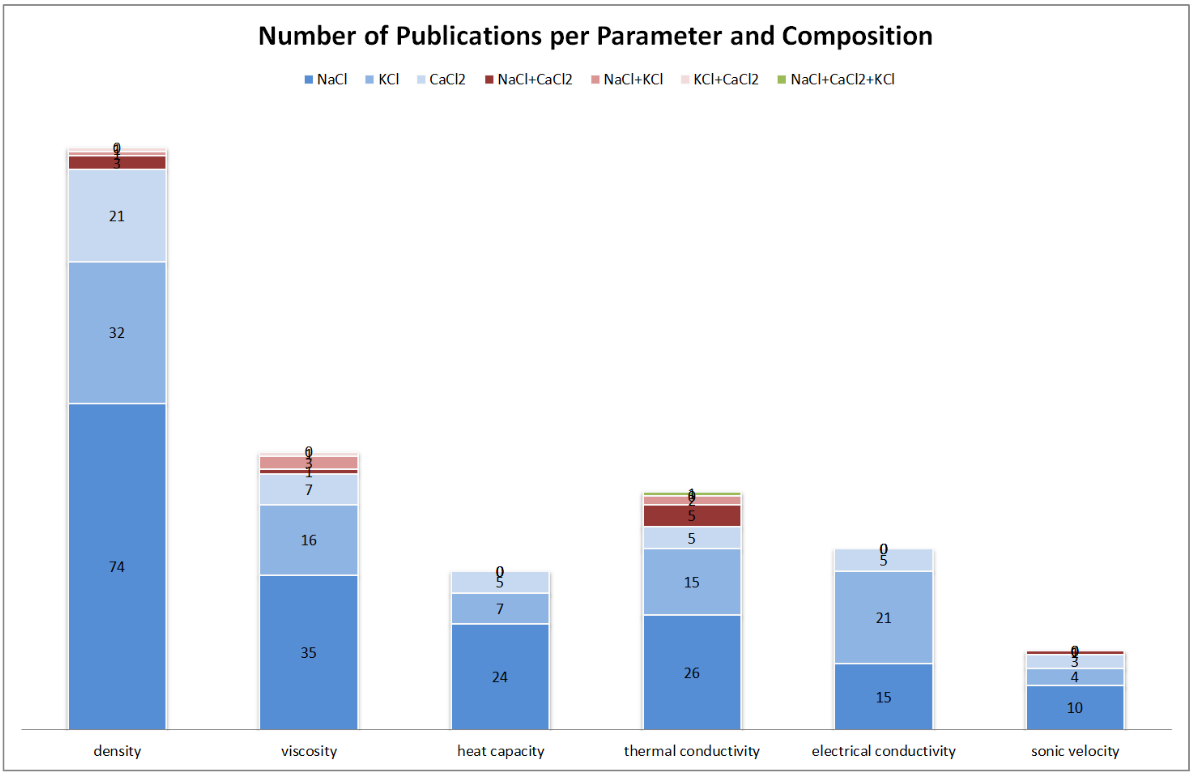

Figure 4: Statistical evaluation of literature with number of publications per parameter and composition.

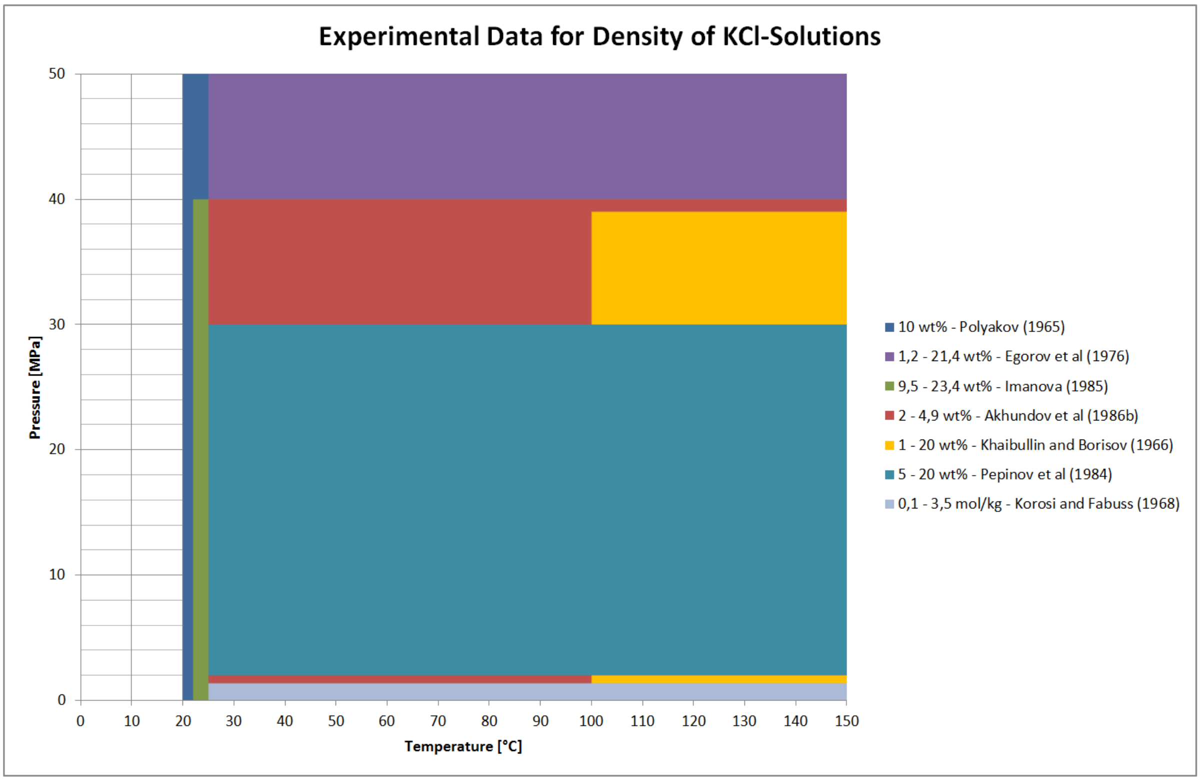

Figure 5: Example of best-case data coverage (density of KCl-solutions) with data gaps in concentration series.

3. THERMOPHYSICAL FLUID LABORATORY AT GFZ-POTSDAM

As concluded from Section 2 severe data gaps motivated the installation of a new thermophysical fluid laboratory at the GFZ German Research Centre for Geosciences. This laboratory should enable measurements of the most important thermophysical fluid properties at conditions relevant for deep geothermal systems and the related technical installations on the surface.

The parameters addressed in this laboratory are (**Fig. 6**): density, specific heat, speed of sound, viscosity, thermal conductivity, and electrical conductivity. Off-the-shelf solutions are complemented with in-house constructions where the former are not available, particularly for high pressure measurements. Special attention was given to materials selection issues in connection with the high corrosion potential of geothermal brines. We subdivided the experimental p-T space into three fields: (1) ambient pressure and $T < 80°C$, (2) $p < 20$ MPa and $T < 150°C$, and (3) $p < 50$ MPa and $T < 200°C$. For geothermal applications this covers all reservoirs to accessible depths of 5 km having a normal geothermal gradient.

For density, speed of sound, viscosity, and electrical conductivity solutions are available for all pT-fields mentioned above. At this stage, for the thermal properties specific heat and thermal conductivity devices are set up to cover field (1). However, a combination of density and speed of sound measurements also yields values for specific heat up to field (3).

Long-term experiences of our group in rock physical measurements of permeability, electrical conductivity, and P and S-wave velocities at in situ reservoir pT-conditions (Milsch et al., 2008 and **Fig. 7**) permitted to transform existing apparatuses into thermophysical devices for measurements on fluids. This is achieved by replacing the rock specimen assembly as shown in Fig. 7 by a complementary installation for fluid viscosity, electrical conductivity, and sonic velocity, respectively.

Fig. 8 shows the setup for viscosity as installed onto the top plug (left and center) and as introduced into the pressure vessel (right). Viscosity is measured relative to pure water with a PEEK-capillary of 250 µm inner diameter and a length of 1 m. Measurements of viscosity at elevated temperature and pressure conditions have been successfully conducted up to 150°C and 20 MPa and the full pT-range defined above is currently being explored. Furthermore, the assemblies for electrical conductivity and sonic velocity have been set up and will be tested for performance in the near future.

Parameter	p-T range (1) ca. p0 - 80°C ambient	p-T range (2) ca. 200 bar - 150°C reactor	p-T range (3) ca. 500 bar - 200°C stand-alone
(1) density	vibrating tube Paar DMA 4500 M	>	vibrating tube Paar DMA HP
(2) specific heat (cp)	calorimeter + vessel Setaram DSC 121		
(3) sonic velocity	>	ultrasonic SensoTech TS 24-24	flow-through apparatus
(4) dynamic viscosity	falling sphere Paar AMVn	>	flow-through apparatus
(5) thermal conductivity	transient plane source C-Therm TCI		
(6) electrical conductivity	4-electrode WTW TetraCon 325	2-electrode Pt-wire CorrInstruments Pt-(2)-10mm-10"-T-375-250 4-electrode Pt-thick film KSI N/A	flow-through apparatus

Figure 6: Overview of analytical devices and their pT-coverage deployed in the GFZ-Potsdam thermophysical laboratory.

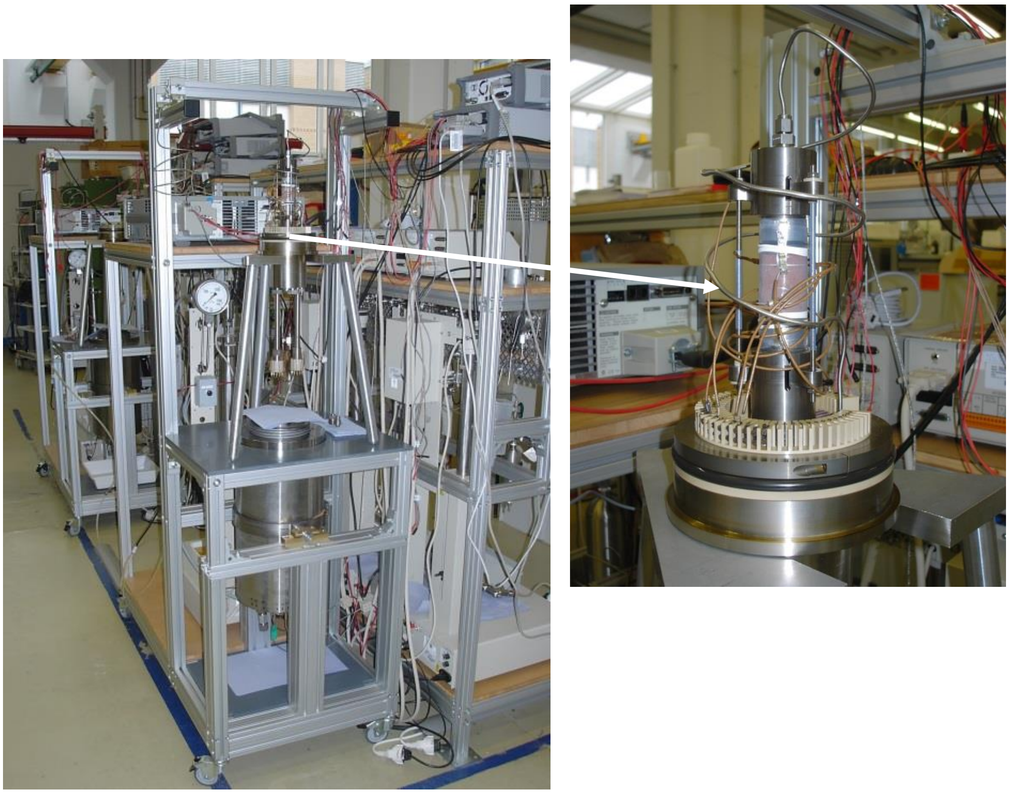

Figure 7: Rock physical flow-through apparatuses at GFZ-Potsdam to be transformed into devices for thermophysical measurements on fluid properties (viscosity, electrical conductivity, and sonic velocity).

Figure 8: Example of high pressure and high temperature device for fluid viscosity measurements to be used with the flow-through apparatuses shown in Fig. 7.

4. CONCLUSIONS

Successful development of geothermal sites depends on knowledge about the fluid's physical properties. As revealed by a comprehensive literature search, for complex, highly saline fluids severe data gaps exist for all thermophysical properties of interest. A new laboratory installed at the GFZ-Potsdam aims at contributing to close these gaps for relevant pT-conditions and fluid compositions. In addition to improving the fundamental database research within this framework addresses the evaluation and/or derivation of mixing rules for the most prominent thermophysical properties that will permit site-specific parameterization of geothermal fluids knowing their chemical composition only (Hoffert and Milsch, 2015).

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REFERENCES

Hoffert, U., and Milsch, H.: Experimental investigations on the thermophysical properties of synthetic geothermal fluids, Proceedings World Geothermal Congress, Melbourne, Australia (2015).

Milsch, H., Spangenberg, E., Kulenkampff, J., and Meyhöfer, S.: A new apparatus for long-term petrophysical investigations on geothermal reservoir rocks at simulated in-situ conditions, Transp. Porous Med., **74**, 73–85, doi: 10.1007/s11242-007-9186-4 (2008).

Regenspurg, S., Wiersberg, T., Brandt, W., Huenges, E., Saadat, A., Schmidt, K., and Zimmermann, G.: Geochemical properties of saline geothermal fluids from the in-situ geothermal laboratory Groß Schönebeck (Germany), Chemie der Erde - Geochemistry, **70** (Suppl. 3), 3-12, doi: 10.1016/j.chemer.2010.05.002 (2010).