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In-situ Measurement of Physico-Chemical Parameters of Geothermal Waters and Brines – Results of R&D Project PETher

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ABSTRACT

PETher was a research project implemented on behalf of the German Federal Ministry for Economic Affairs and Energy (BMWi). The project team consisted of KIT (Karlsruhe Institute of Technology; technical project coordination), GeoT (GeoThermal Engineering GmbH; geoscientific project coordination), gec-co (Global Engineering and Consulting GmbH) and GTN (Geothermie Neubrandenburg GmbH). The objective of PETher was to determine physico-chemical properties (specific isobaric heat capacity, kinematic viscosity, and density) of geothermal water under conditions that reflect the conditions to be found in geothermal utilizations (pressure, temperature, salinity of the brine). The knowledge of these physico-chemical properties is crucial in order to estimate the thermal output and therefore the economic viability as well as to optimize the plant or heating station design during the development and operation of a geothermal project. Up to now, only a limited number of measurements of selected physical properties have been made, usually under laboratory conditions as well as for individual geothermal plants. Currently available mathematical formulae describing the physico-chemical properties are typically not valid for the conditions to be found in geothermal applications. Also, geothermal waters in Germany have not been subject of detailed measurements systematically performed under operational conditions. In this project, the thermo-physical properties of geothermal water are measured under in-situ-conditions as functions of pressure, temperature, and salinity. The measurements were taking place directly at several geothermal sites located in Germany's hydrogeothermal key regions. Those are the Molasse Basin, the Upper Rhine Graben, and the North German Basin. For doing the in-situ measurements, a mobile testing unit was developed and refined with instruments specifically designed in-house (KIT) to meet any geothermal reservoir conditions to be found in Germany. The obtained results were compared with standard analytical methods as well as used to calibrate systematic laboratory measurements that simulate the encountered in-situ conditions. The modelled type curves contribute to a more realistic prediction of the thermal output of future geothermal plants. The results cannot only be applied in Germany but are representative for all NaCl-dominated geothermal brines of sedimentary basins with underlying crystalline basement in the investigated temperature range (up to 170 °C) all over the world.

1. INTRODUCTION

Energy content and mass flux are important parameters for dimensioning geothermal plants. Besides temperature, thermo-physical water properties like for instance isobaric heat capacity and density determine the available heat which is delivered by the thermal water flow and which can be used for power generation and/or district heating. Friction loss of the water flow in the boreholes and in the plant components influences the energy demand of the pumps and is determined by water viscosity and density. Both, heat input and energy consumption affects the plant efficiency and thus its economic feasibility. Knowledge of these physical parameters in an early stage of plant dimensioning enables the optimization of the plant design and dimensioning.

Depending on the rock composition of the reservoir, thermal water can be highly saline which in turn has a strong impact on thermo-physical water properties. Usually the thermal water composition is complex, containing a broad spectrum of dissolved ions and gases. Literature data on saline brines lack of reliable information on thermo-physical properties in particular of such multicomponent systems at high salinities. Furthermore thermodynamic calculation models are not validated with respect to their scope of applicability at geothermal conditions due to the lack of existing measurements.

Some investigations on physico-chemical parameters of sodium choride solutions and seawater can be found in Sharqawy et al. (2010), Nayar et al. (2016), Bromley et al. (1967), Jamieson et al. (1969), Millero et al. (1973) and Thurmond and Brass (1988) for heat capacity. Though geothermal water and seawater are similar in composition calculation models for seawater properties, especially heat capacity, are validated for lower salt amounts and are not necessarily appropriate for extrapolation to the high salinities as occurring in geothermal brines, which in particular go up to saturation point. Data on aqueous salt solutions up to six molal for kinematic viscosity and density are reported in Kestin et al. (1981), Phillips and Ozbeck (1980), Mao and Duan (2008, 2009), Rowe and Chou (1970) and Driesner (2007) but the data are limited to NaCl solutions which does not reflect the complexity of geothermal brines. Against this background the necessity of measuring the physico-chemical parameters of geothermal brines for generating a data base as a look up table and further for establishing and validating calculation models with respect to their applicability in geothermal energy usage is recognized. Off-site measurement does not seem to the adequate method because the water samples might be affected by salt precipitation on their way to the laboratory. Usually, in geothermal plants thermal water is kept under elevated pressure of 0.5 to 2.6 MPa in order to avoid degasification, which in turn affects the solubility of the brine's salt matters. In order to circumvent the precipitation problem when taking water samples for physical property analysis in-situ measuring techniques are favored. Against this background, measurement techniques for isobaric heat capacity, density and kinematic viscosity detection were developed at KIT and installed in a mobile test facility, which can be connected to the pipe system of geothermal plants thus allowing for maintaining system pressure during the measurements.

Geothermal energy use in Germany focuses on three main areas, which dispose of hot aquifers at moderate depths. The Molasse Basin is located in the southern part of Germany south/south east of the Bavarian Forest and ranges to the rim of the Alpes. Here the formation of the Upper Jurassic, which spreads from surface in the northern Molasse Basin down to 5000 m near the Alpes is of interest. Related to the increasing depth of this formation, water temperature of the aquifer rises to 150°C in the southern parts of the Molasse Basin. In the Upper Rhine Graben, the middle and the lower Triassic as well as the crystalline formation come into account for geothermal use providing water temperatures of 150°C at 3000 m depth. The same temperature level but at greater deepness of 4000 m is present in the Rhaetian and Rotliegend formations of the North German Basin, which spreads from the Weser low mountains to the North Coast. Thermal waters of these aquifers are quite different in composition and salt content. Salinity covers a range of 0.5 g/l in the Molasse Basin up to more than 300 g/l in the North German Basin. Moreover, salt composition leads from carbonate and sulfate dominated waters of the lower Triassic to sodium chloride rich waters of the Rhaetian, Rotliegend and Chrystalline brines. Consequently, it is expected that the physico-chemical properties of Germany´s deep waters will cover a wide range. In order to get a deeper insight into the thermal water's physical properties and its relation on chemistry the project PEther was started, which was financed by the German Federal Ministry for Economic Affairs and Energy (BMWi). In cooperation with GeoT (GeoThermal Engineering GmbH), gec-co (Global Engineering & Consulting-Company GmbH) and GTN (Geothermie Neubrandenburg) ten geothermal sites were visited and the physical data like heat capacity, density and viscosity were recorded for various temperatures at site-specific pressure. In addition, based on analysis of many borehole data in Germany, typical thermal water compositions could be identified and classified into groups with respect to perform experiments with artificial brines. Based on in-situ and model water results, characteristic curves were established for better prediction of fluid properties.

2. MEASURING TECHNIQUES

For conducting in-situ measurements a mobile test plant was designed and build up at KIT. It allows for being connected to the pipe system of geothermal plants. The mobile test plant contains three instruments for measuring isobaric heat capacity, kinematic viscosity and fluid density, which are interconnected via heated pipes. The measurements are performed in through-flow conditions for heat capacity and viscosity whereas density is measured in batch mode gravimetrically. Operating plant pressure is maintained during the measurements by adjusting pressure retention valve at the outlet of the test plant. Downstream of the calorimeter thermal water is cooled by a water/water cooler to ambient temperature. Thereafter, a Coriolis mass flow meter detects the mass flux of the fluid. The arrangement of the instruments is shown in Fig. 1. A detailed description of the facility is given in Schröder et al. (2015 a, b).

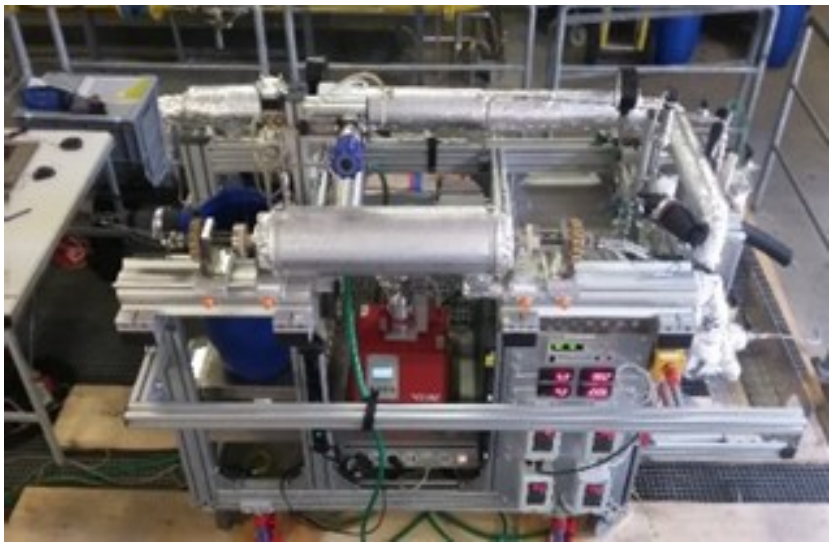

Figure 1: Mobile test plant containing the flow calorimeter (in the front), the flow viscometer (in the rear) and a pressure vessel (right hand) for determining fluid density.

2.1 Specific Isobaric Heat Capacity

The calorimeter consists of a tube, 735 mm long with an inner diameter of 16 mm. The tube material is PEEK (polyetheretherketone) which has a low heat conductivity. The fluid inlet and outlet are arranged perpendicular to the tube shell. At each tube end, a probe heat is inserted axially into the tube. The probe head at the fluid´s entrance is equipped with a static mixture, three k-type thermocouples and an electric heating rod. The probe head at the tube's outlet contains a static mixer as well and four k-type thermocouples. The tube itself is insulated by a surrounding vacuum chamber complemented by a 100 mm thick layer of ceramic fibers. When entering the tube the fluid temperature is recorded by the three thermocouples at the inlet probe head. The outlet temperature is detected at the outlet probe head. After a certain time of constant mass flow thermal equilibrium is reached which implies, that the inlet and the outlet temperature are equal. After switching on the electric heating rod the outlet temperature increases. Once a stationary temperature difference between the inlet and outlet is reached, heat capacity can be calculated taking the temperature difference, the electric power of the heating rod and the mass flux into account.

2.2 Kinematic Viscosity

Kinematic viscosity is determined by measuring the pressure drop of a fluid flow through a capillary. The stainless steel capillary, which is used in the mobile test plant has an inner diameter of 4 mm and is surrounded by an electrical trace heating for heat loss compensation. Temperature of the capillary is detected by two thermocouples located at the respective ends of the capillary. The

pressure measuring points, which are 800 mm in distance, are connected to a differential manometer. In the case of a laminar fluid flow, kinematic viscosity can be calculated by means of the Poisseuille equation taking pressure difference, inner diameter of the capillary, distance of pressure measuring points and mass flux into consideration.

2.3 Density

Thermal water density is measured by filling a small pressure vessel with thermal water and determining its mass by weighting. The filling capacity amounts to one liter. The vessel is installed in the mobile test plant and filled with the fluid from bottom to top. Fluid pressure is adjusted by the pressure retention valve of the mobile test plant. For compensating heat losses, the vessel walls are equipped with an electric trace heating. Temperature of the fluid inside of the vessel is detected by a thermocouple, which is installed inside of vessel. Mass and volume of the empty vessel are determined by calibration measurements and the thermal expansion of the vessel is calculated with respect to manufacturer's specifications.

3. RESULTS

3.1 In-situ measurements

3.1.1 Molasse Basin

Deep waters of the Upper Jurassic in the Molasse Basin can be subdivided into five groups characterized by the composition of the main ions, Birner (2013). Group I is present in the northern rim of the Basin and corresponds to water type Ca-(Mg)-HCO3 at relatively low salinities of 497 mg/l. In the center part of the Molasse Basin group II is existing which is characterized by water type Na-Ca-Mg-HCO3 at salinities of 588-689 mg/l. In the north eastern part of the Basin water type Na-HCO3-Cl can be found which belongs to group III and IV. Salinity lies in between 1000 -1500 mg/l whereby chloride content of group IV is higher compared to group III. In the south-western part of the Molasse Basin group V has the highest salinity of 2600 mg/l and is characterized by the water types Na-Cl-HCO3 and Na-Ca-Cl. In general thermal water salinity in the Molasse Basin increases from north to south.

Within the scope of the PETher-project three sites in the Molasse Basin were identified for performing in-situ measurements covering typical deep waters of the Upper Jurassic aquifer. The water of the thermal bath in Erding belongs to group II of water type Na-Ca-HCO3-Cl. The borehole is 2350 m deep, providing hot water of 65°C. Pressure within the plant system is kept at 0.8 MPa. Water type III was measured in-situ in the heat plant of Riem and in the heat and power plant of Sauerlach. The thermal water of Riem originates in depth of 2746 m and its pressure is kept at 0.5 MPa inside of the heat plant. Temperature of the Riem water amounts to 93°C. The thermal water of Sauerlach comes from the Upper Jurassic aquifer in 4480 m depth with a temperature of 140 °C. Pressure within the plant amounts to 1.2 MPa.

The in-situ measurements were performed at corresponding plant pressure at various temperatures for instance production temperature, injection temperature and a least one intermediate value. Furthermore, 70 litres of thermal water were collected for control measurements in the laboratory. Additionally water samples for chemical analyses were taken. The laboratory experiments were performed by adopting pressure to the in-situ measurements at production and injection temperature in order to examine, whether cooling and pressure reduction during sample taking influences the physical fluid properties. The results of in-situ measurements of all investigated sites in the Molasse Basin are given in Figs. 2 - 4 for heat capacity, viscosity and fluid density. Data of physical properties of deionised water, as can be found in NIST database, Lemon (2010), are given in the diagrams for comparison. As shown in Figs. 2 - 4 in-situ measured data do not differ from pure water values due to the fact, that thermal water of the Molasse Basin is low in salt content. The deviation from the water values lies within the measurement error of one per cent (relative difference to pure water data). Laboratory experiments with thermal water samples confirmed these findings. The heat capacity values of the Sauerlach measurements are slightly above the water data, which might be a result of the heater concept of the calorimeter. The heater construction was changed in a later stage of the project in order to improve the reliability of the measurements and to avoid subsequent calibration.

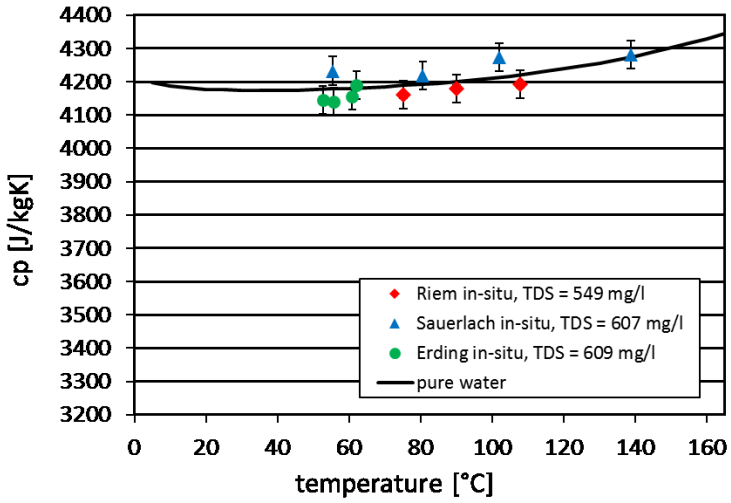

Figure 2: Specific isobaric heat capacity of thermal water from different geothermal sites in the Molasse basin. Values are measured in-situ.

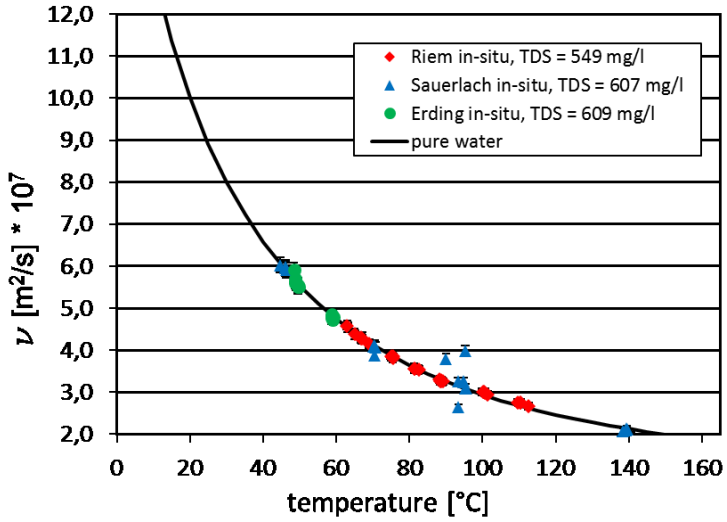

Figure 3: Kinematic viscosity of thermal water from different geothermal sites in the Molasse Basin. Values are measured in-situ.

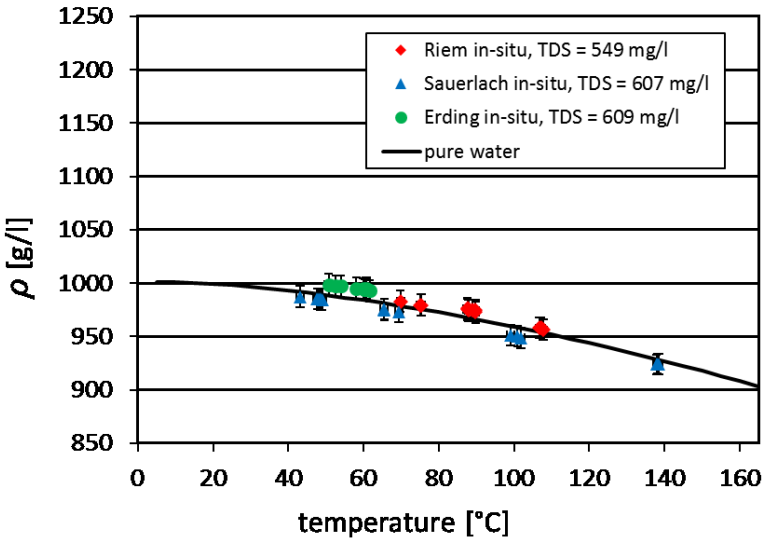

Figure 4: Density of thermal water from different geothermal sites in the Molasse Basin. Values are measured in-situ.

3.1.2 Upper Rhine Graben

The Upper Rhine Graben stretches from Basel in the South to Frankfurt in the North and covers both sides of the river Rhine. Here geothermal potential is high due to the hot aquifers, which can be found in the Middle Triassic limestone (Muschelkalk), the Lower Triassic sandstone (Buntsandstein) and the Dogger limestone (Hauptrogenstein) horizons. In some cases the Lower Permian sediments (Rotliegend) and the upper parts of the Crystalline also come into account. In the Hauptrogenstein formation located in up 500 m depth water type Ca-(Mg)-HCO_3 is present at low salinities of 1 g/kg. Locally much higher salinities occur. The Muschelkalk formation, which extends to 1200 m depth is characterized by water type Ca-Na-SO_4-HCO_3. In deeper layers Na-Cl content is increased. In general, salt content of the Muschelkalk waters is low and at most 20 g/l. Nevertheless much higher salinities can appear, for instance near salt formations. The Buntsandstein aquifer ranges from 1000 m – 3000 m below surface. In the upper parts of this formation small amounts of bicarbonate and sulfate occur, whereas in deeper parts NaCl is prevalent. Salinity is high and exceeds 130 g/l. The same order of magnitude in salinity is present in the Crystalline dominated by sodium and potassium chloride, Stober et al. (2013). The Upper Rhine Graben is characterized by a large number of fault zones, which leads to interconnection of different aquifers and inflow of high saline, NaCl dominated water from lower aquifers to higher ones thus makes it difficult to distinguish between the water types.

In order to cover a wide range of salinities and salt components, four geothermal sites were selected for in-situ measurements. Although the water originates from different horizons, they all are influenced by sodium chloride intrusion from below. The thermal bath in Bad Krozingen and the heat plant in Riehen/Switzerland exploit water from the Muschelkalk formation. In Bad Krozingen, the water type is characterized by Ca-Na-SO_4-HCO_3 but salinity is quite low. The borehole ends in 528 – 580 m depth. Water temperature and pressure amount to 37.6 °C and 0.3 MPa.

Deeper parts of the Muschelkalk are reached in Riehen, in 1547 m depth. Water temperature and pressure are 63 °C and 1.2 MPa. Riehen-water is higher in salinity showing a TDS of 17.7 g/l compared to Bad Krozingen-water having 4.6 g/l salt content. The intrusion of NaCl from lower aquifers into the Muschelkalk formation can be clearing seen by the enrichment of NaCl in the Riehen water. Water of the NaCl rich Crystalline aquifer in 3300 m depth is used in the power plant of Insheim. Water temperature

exceeds 164 °C while pressure is kept at 2.0 MPa. Finally water of the Tertiary formation is examined in the thermal Bad Miramar in Weinheim. Salinity here is about the same as in Insheim and amounts to 104 g/l. Due to intrusion effects, water in Weinheim is as well dominated by NaCl. The production temperature is 64°C, pressure is kept at 1.1 MPa. As in the case of the measurements in the Molasse Basin, thermal water properties were determined at production and injection temperature and one or two intermediate values at site specific pressure. The in-situ measured physical water properties are shown in Figs. 5-7.

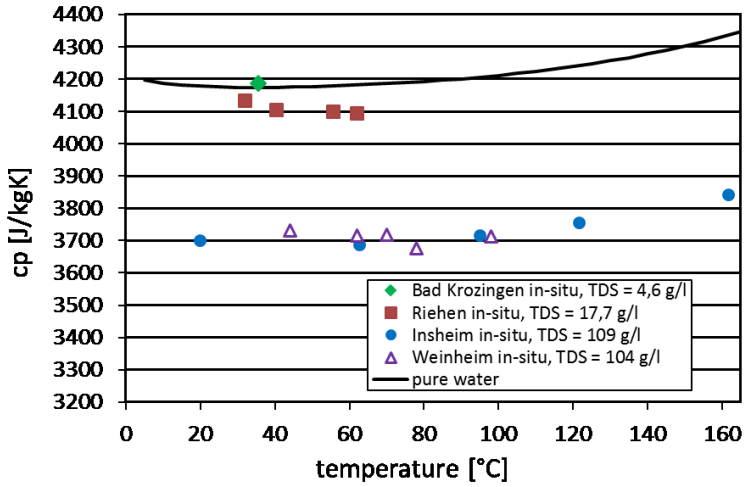

Figure 5: Specific isobaric heat capacity of thermal water from different geothermal sites in the Upper Rhine Graben. Values are measured in-situ.

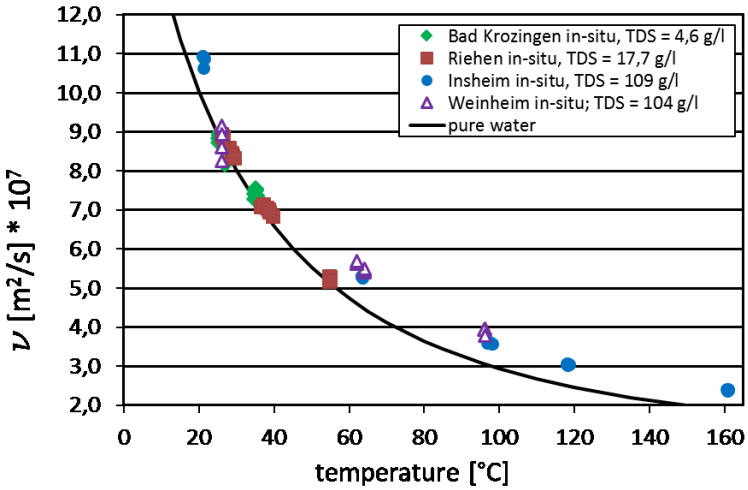

Figure 6: Kinematic viscosity of thermal water from different geothermal sites in the Upper Rhine Graben. Values are measured in-situ.

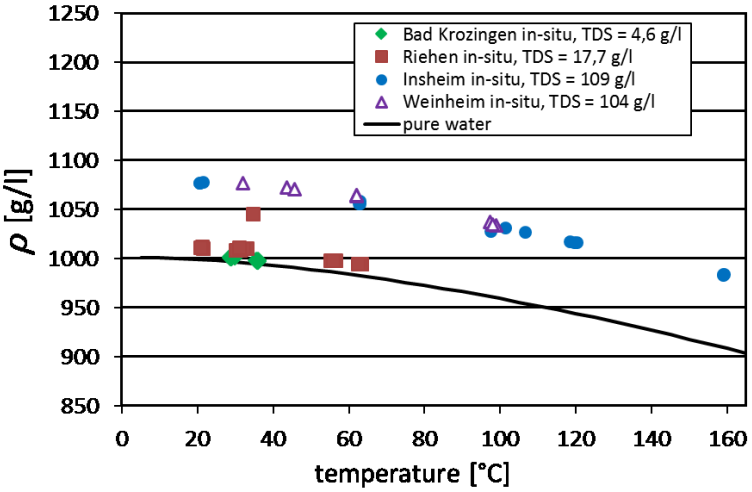

Figure 7: Density of thermal water from different geothermal sites in the Upper Rhine Graben. Values are measured in-situ.

As shown in Figs. 5-7 physical properties do not differ significantly from pure water data if salinity is lower than 10 g/l. For instance the measured data of Bad Krozingen water is close to the water line. The data lie within the measurement error of 1 per cent. Significant deviation from water properties can be detected by the measurements of the Riehen-water. In this case heat capacity is 1.5-2 % lower, whereas kinematic viscosity and density are 3% resp. 1.3% higher than pure water data. A great influence of salinity on the physical properties can be recognized by the results of Insheim and Weinheim measurements. Heat capacity deviate to 11%, density to 8% and kinematic viscosity to 20 % from the water data. Similar to the measurements of the Molasse basin water, the results of the laboratory experiments with thermal water samples of the Upper Rhine Graben do not differ from the in-situ measured data.

3.1.3 North German Basin

The North German Basin covers the area between Hannover and the Northern coasts of Germany. The thermal waters of the North German Basin are very salty because of their either marine origin or formation under evaporitic conditions. Salinity reaches up to 300 g/l and more, especially in deeper formations like in Schilfsandstein, Zechstein and Rotliegend. Sodium and Chloride are the dominating ions in each formation followed by calcium, which characterizes the water in the deeper parts of the Rhät formation. Sulfate and bicarbonate are present to only a minor proportion in the waters of the North German Basin, significant magnesium amounts can be found in the Rhät and Malm formation.
The thermal waters of the visited sites in the North German Basin originate in the Rhät formation showing similar chemical water composition but different salinities. They are dominated by NaCl, whereby mass ratio of calcium is up to 3%. The thermal water of the geothermal heat plant in Neubrandenburg originates from 1250 m depth. Salinity is 130 g/l whereas temperature and pressure are 70°C and 0.6 MPa respectively. The thermal water of the heat plant in Neustadt-Glewe is extracted from deeper parts of the Rhät formation. The borehole ends in 2450 m below surface and produces highly saline water of 220 g/l salt content at 96°C in temperature and 0.6 MPa in pressure. The thermal bath in Waren uses water from 1560 m depth. Its salinity ranges in between the values of Neubrandenburg and Neustadt-Glewe waters and amounts to 165 g/l. Production temperature and pressure are 63 °C and 0,37 MPa. The physical water properties, which are measured in-situ are shown in Figs. 8-10.

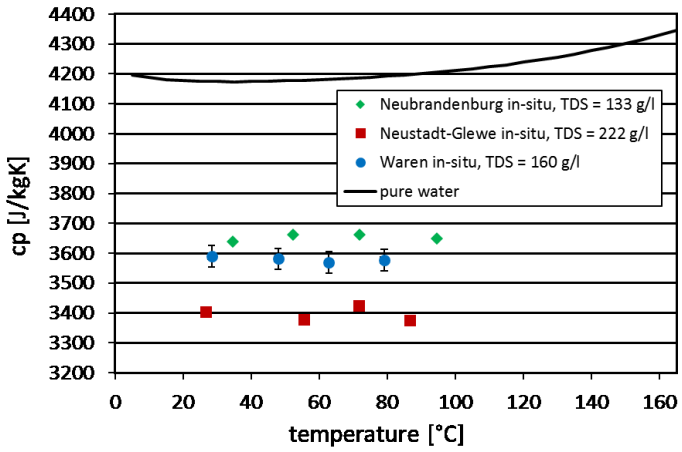

Figure 8: Specific isobaric heat capacity of thermal water from different geothermal sites in the North German Basin. Values are measured in-situ.

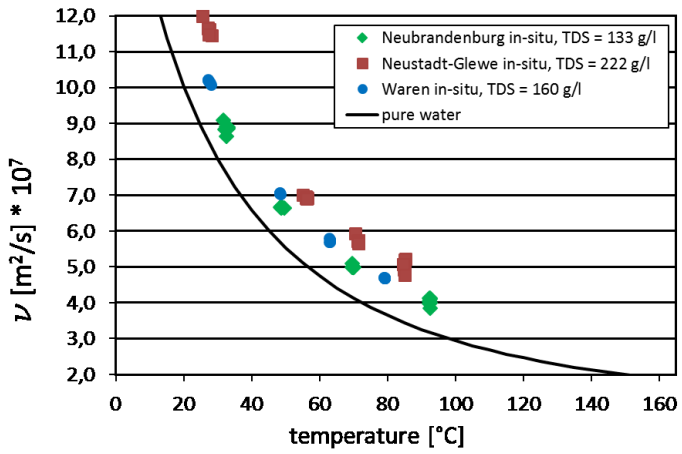

Figure 9: Kinematic viscosity of thermal water from different geothermal sites in the North German Basin. Values are measured in-situ.

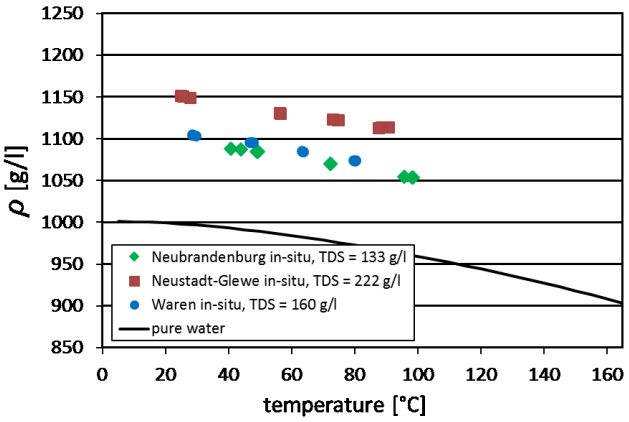

Figure 10: Density of thermal water from different geothermal sites in the North German Basin. Values are measured in-situ.

The influence of salinity on physical water properties is clearly visible. Heat capacity is reduced to more than 80% of pure water values whereas density and kinematic viscosity are enhanced by a factor of 1.1 and 1.3 respectively. Due to the low concentration of other ions, their influence on the physical water properties cannot be indicated. The results of the laboratory experiments with water samples of the North German Basin sites differ slightly from the in-situ measured data due to the fact, that a small amount of deposit could be found in the sample vessels. The deviation to the in-situ measured data was around 1.5%.

3.2 Experiments with artificial thermal water

The in-situ measured data were accomplished by laboratory experiments with artificial thermal waters. The composition of these mixtures was adopted to the water types, which were characterized after data mining of all available and reliable borehole data in Germany by GTN and GeoT. Around 70 litres of each water type were mixed under atmospheric pressure. Due to the low pressure, some of the model waters could not be prepared without salt precipitation. Especially those solutions, which were adopted to deep waters or Muschelkalk waters of the Upper Rhine Graben could not be mixed due to their relatively high concentration of bicarbonate and sulphate. In order to overcome the precipitation problem bicarbonate and sulphate were lowered to the saturation point at atmospheric pressure taking less correspondence to the theoretical composition into account. Resulting from this Upper Rhine Graben deep waters were dominated by NaCl thus becoming more similar to the Crystalline waters of the Upper Rhine Graben. An overview of the model water composition is given in Tab. 1 in mass percentage within the salt fraction.

Table 1: Salt composition of artificial thermal water

	artificial water: mass percentage [kg/kg] in salt mixture									
Ion	Molasse Group III	saline water Upper Rhine Valley			Upper Muschelkalk			Cystalline	Rotliegend	Rhaetian, Northern Basin
Na^+	0,2288	0,3050	0,3037	0,3042	0,2222	0,1812	0,2862	0,2794	0,3004	0,3600
K^+	0,0000	0,0270	0,0260	0,0248	0,0000	0,0124	0,0320	0,0371	0,0309	0,0000
Ca^{2+}	0,0459	0,0529	0,0529	0,0529	0,0825	0,0966	0,0264	0,0768	0,0530	0,0200
Mg^{2+}	0,0092	0,0067	0,0068	0,0080	0,0000	0,0053	0,0183	0,0015	0,0078	0,0068
Sr^{2+}	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Ba^{2+}	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Cl^-	0,1062	0,6069	0,5956	0,6063	0,0862	0,0352	0,4277	0,6041	0,6079	0,6031
HCO_3^-	0,6073	0,0000	0,0087	0,0028	0,3001	0,3321	0,0763	0,0000	0,0000	0,0000
SO_4^{2-}	0,0026	0,0015	0,0063	0,0009	0,3090	0,3372	0,1332	0,0010	0,0000	0,0101
CO_3^{2-}	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
sum	1	1	1	1	1	1	1	1	1	1
TDS [g/l]	**0,5490**	**103,50**	**50,00**	**130,00**	**14,80**	**4,25**	**14,80**	**104,00**	**300,00**	**165,00**

The measurements of the physical properties with the artificial thermal waters were performed in the laboratory by adjusting fluid pressure to the corresponding geothermal site pressure. Concerning the Molasse Basin waters, there was no difference between the in-situ data and the laboratory measurements with Molasse Group II water visible. The low salt content has no detectable effect on the physical properties of the waters. Crystalline and Rhaetian model waters correspond to the results of the related in-situ measurements. In particular, physical properties of Crystalline model water are the same as the Insheim-water properties and the values of Rhaetian water correspond to the data of the Waren-water at same TDS. The water data of Bad Krozingen is in accordance with the Upper Muschelkalk model water data at TDS of 4.25. Precipitation did not occur in this case because saturation point of the model water was not reached. Data of the in-situ measurements in Riehen is in accordance with model water Upper Muschelkalk of TDS = 14.8 and bicarbonate mass fraction of 0.0763. Due to the low amount of bicarbonate no precipitation in the model water was observed. The situation was different when bicarbonate concentration was enhanced to 0.3001 at TDS of 14.8. This solution could only be stabilized by adding nitric acid for reducing pH value. Pressure dependence of physical properties is of minor influence within this parameter range compared to temperature and salinity effect as described in Sharqawy et al. (2010) and Kestin et al. (1981).

3.3 Model curves

Based on the in-situ and the laboratory results with artificial thermal waters, model curves were calculated in order to better predict physical properties once water composition is known. As can be concluded from the measurements TDS is the dominant influence factor on the thermophysical water properties. The influence of individual ions on the fluid properties could not be clarified because either the total ion concentration was too low for observing significant differences from pure water data (Molasse Basin water and Bad Krozingen water) or the waters were dominated by NaCl, so that the influence of bicarbonate, sulfate or calcium for instance is not detectable. Thus, the modelling curves describe thermal waters which are NaCl rich but representative for many aquifers in Germany.

The modelling consists of two interpolation steps. In the first step, the measured data of each cohesive measurement series are connected with a second order polynomial over the entire temperature range (up to fourth order polynomial for the kinematic viscosity) resulting in auxiliary modelling curves. In the second step, the remaining curves, which do not include measured salinities, between the auxiliary curves are created. This is achieved through linear interpolation between all auxiliary curves for small temperature steps. The modelling results are shown in Figures 11 – 13.

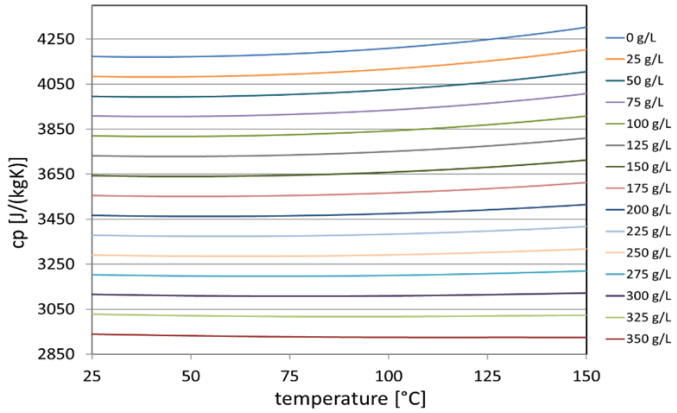

Figure 11: Modelling curves of isobaric heat capacity based on in-situ and laboratory measurements.

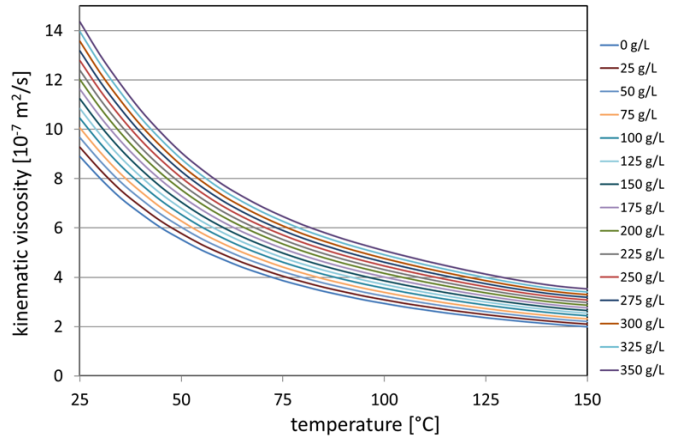

Figure 12: Modelling curves of kinematic viscosity based on in-situ and laboratory measurements.

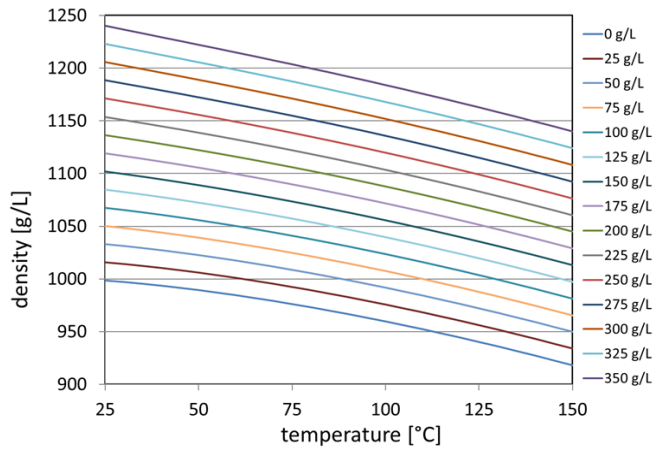

Figure 13: Modelling curves of density based on in-situ and laboratory measurements.

4. CONCLUSION

Size and efficiency of geothermal power and heat plants depend besides flow rate and fluid temperature on the thermodynamic water properties like specific isobaric heat capacity, kinematic viscosity and fluid density in particular. Based on classification of water types in Germany ten geothermal sites located in the Molasse Basin, the Upper Rhine Graben and in the Northern Basin were selected for performing in-situ measurements in order to determine aforementioned thermal water properties. In-situ measurements allow for keeping pressure constant so that precipitation of minerals by sample taking is avoided. Prior calibration measurements with pure water ensured accordance to literature data by a relative error of less than one per cent. As a result of the in-situ measurements no influence of ion types on the fluid properties could be detected because it laid within the measurement error. However, total salt content is the main factor of influence, which shifts heat capacity to lower and viscosity and density to higher values by contrast with pure water. Pressure influence is of minor importance and falls within the range of measurement error. The temperature dependence of the specific heat capacity of the brines follow the pure water function at salinities up to 50 g/l. Gradient of the curves degreases at higher salinities within the examined temperature range. Concerning kinematic viscosity influence of salinity is higher at low temperatures than at temperatures above 125 °C. Curvature of density-temperature function seems to remain unchanged when going to higher salinities. The model curves are shifted to lower values with increasing salinity while temperature dependence is unaffected.

Based on in-situ and laboratory measurements with artificial brines modelling curves allow to predict brine properties once its salinity is known. Therefore, these curves contribute to a more realistic prediction of thermal output of geothermal plants.

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