



## **PRACTICAL EXPERIENCE IN THE REINJECTION OF THERMAL WATERS INTO SANDSTONE**

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### **ABSTRACT**

Intensive investigations into the utilisation of the geothermal potential in the North German Basin began in the early 1980s. The first production and reinjection tests from / into sandstone reservoirs started in 1982 and led to the commissioning of the first geothermal heating plant for heat supply to a residential area in the town of Waren (Müritz) in 1984. More plants were put into operation in Neubrandenburg, Neustadt-Glewe, Berlin, and Neuruppin.

More and more sites and plants are being prepared for geothermal heat and power generation in Germany.

The use of these sandstone reservoirs for heat storage produced new technical solutions. A precise knowledge of the geological and geochemical conditions forms an essential prerequisite for the successful planning, construction and operation of geothermal plants. Percolation experiments, geochemical and hydraulic-numerical modelling as well as their combinations are applied for this purpose. This paper describes the geological and geochemical conditions as well as the technical solutions and practical experience acquired so far.

### **1. HYDROGEO THERMAL ENERGY USE AND HEAT STORAGE**

In hydro-geothermal energy utilisation, the thermal water is carried via a well from deep formations up to the surface (production well); after heat extraction the spent fluid is injected back into the host formation (reinjection) through a second well (injection well).

Reinjection of the cooled down water back into the underground is a technique used both to maintain the hydraulic regime, and, in particular, to get rid of mineralised waters without discharging them into surface water bodies, with the risk of damaging the environment. The thermal water is circulated between the production and injection wells in a primary closed loop.

The heat is absorbed from the thermal water via heat exchangers and supplied to the consumers through a secondary loop. As a rule, a geothermal storage system consists of two wells or two groups of wells developing the same aquifer. Both wells are equipped with pumps and an injection casing allowing flow-through in either direction. Heat exchangers integrated into the surface pipe system connecting both wells allow the energy to be charged and discharged. The conditions described here

refer exclusively to the North German-Polish Depression. The North German-Polish Depression forms the core of the Central European Depression which also includes the Danish-Polish and the North Sea Depression (Hoth et al., 1997).

## 2. HYDROGEOLOGICAL AND GEOCHEMICAL CONDITIONS

### 2.1 Reservoir characteristics

Pore reservoirs are characterised by considerable intergranular pore spaces. Reservoir rocks of this type are mainly formed by sandstones. Size and form of the reservoir, sediment structures, texture and mineral composition are the primary properties; porosity, permeability, density and fluid saturation are the secondary ones – all being equally important for the description.

The economically efficient use of low-enthalpy (40 - 100 °C) hydrothermal reservoirs requires large-scale thermal water resources and flow rates (50 - 100 m<sup>3</sup>/h/well). Their use is therefore tied to a number of geological conditions (Seibt et al., 2003):

- the existence of a productive water-bearing rock formation (productive horizon);
- a sufficient vertical and lateral extension of this rock formation to guarantee long-term production (productive reservoir);
- an economically interesting temperature level in the productive reservoir;
- the suitability of the deep water for the technological process of heat production (material and system compatibility in the thermal water loop);
- Along with a sufficient lateral extension of the productive horizon, high flow rates and the guarantee of long-term stable production and reinjection entail, in particular, certain minimum values of porosity, permeability and net thickness. We are looking for thick, high-porosity and low-matrix sandstones whose primary pore space and grain structures have changed little diagenetically. Definite limits can be set for real, site-specific conditions.

During the previous decades, the reinjection into sandstone reservoirs was the subject of extensive investigations and is applied successfully at different sites. In particular in Germany, profound experience could be gathered in the operation of geothermal doublets in sandstone reservoirs in the recent years/decades (Seibt, P. & Kellner, T., 2003).

The most important criterion of successful reinjection is the injectivity index which characterises the hydraulic behaviour of the reservoir as a cumulative parameter. The following parameters decide on the achievement of sufficiently high injectivity indices:

Principally, sandstone reservoirs are usable for geothermal purposes providing they show

- mean effective porosities > 20 %
- permeabilities > 0.2 μm<sup>2</sup>
- sandstone thickness minimum 20 m

and are characterised simultaneously by

- percentage of large pores (radius > 5.000 nm) > 60 % or of small and medium pores < 50 % of the pore volume
- pore radii medians in the large pore share range > 5.000 nm
- good to very good pore radii sorting > 0.4 – 0.5
- pore radii maximum within a range > 10,000 nm with a pore volume percentage > 20 %
- < 0.063 mm fine grain (silt and clay) percentage < 10 – 12 %

- average content of binding agents and cement not exceeding 8 – 10 %  
Such sandstones are found in the North German Basin down to depths of approx. 3,000 m (Figure 1).

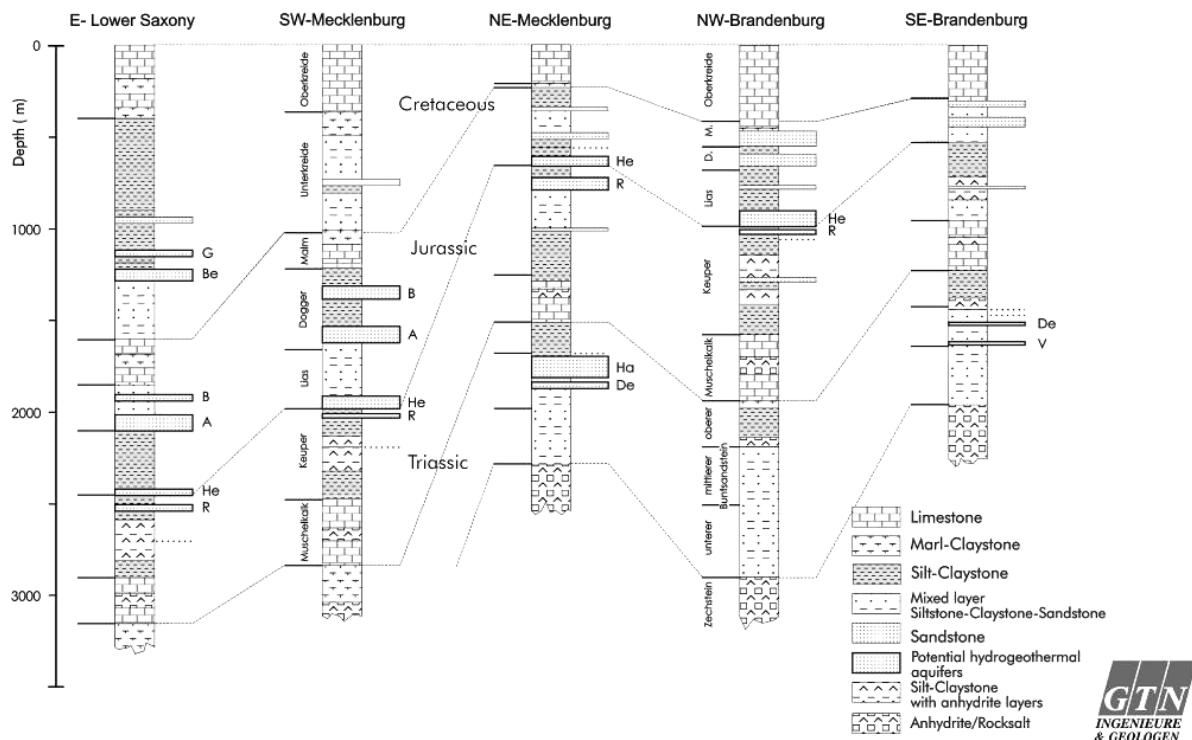


FIGURE 1: Survey of the thermal water-bearing sandstones in NE Germany

## 2.2 Thermal water characteristics

The Mesozoic deep waters developed in NE Germany are classified as high-salinity Na-(Ca-Mg)-Cl waters. The depth-depending salt concentration can exceed 300 g/l. The main components are chloride ions with maximum 49 mmol(eq) % and sodium ions with 43 - 47 mmol(eq) %. Magnesium, calcium, potassium, iron, strontium, manganese, barium as well as sulphate, bromide and iodide ions are dissolved in the thermal water as secondary and trace components. Even when cooling-down, the contents of the solute ions remain below the saturation limit. Carbonated precipitations may occur when CO<sub>2</sub> escapes. Silica acid and borate ions play a minor role only.

The thermal waters contain small percentages of solute gases, so called “formation gases”, mainly nitrogen and carbon dioxide. Methane may occur as a secondary component. Ethane, hydrogen and helium can be detected in traces only.

The Mesozoic deep waters exhibit a reduced condition; the pH values indicate that the waters are acid in character (Hoth et al., 1997, Naumann, 2000).

TABLE 1: Characteristics of the thermal water in the NE German geothermal heating plants

	<b>Berlin (Parliament buildings)</b>	<b>Neubrandenburg</b>	<b>Waren (Müritz)</b>	<b>Neuruppin</b>	<b>Neustadt- Glewe</b>
Temperature (°C)	19	54	61	64	99
Depth [m]	295	1270	1510	1620	2195
Stratigraphy	Hettangian	Postera	Contorta	Aalenian	Contorta
pH [T(°C)]	7.2	6.1 (25)	5.9 (25)	6.5 (50)	5.3 (52)
Redox conditions		reducing		reducing	
Total mineralisation (g/l)	28	134	160	199	219
Density (g/cm <sup>3</sup> )	1.01	1.089	1.108	1.124	1.147
Gas (vol.%)	trace	approx. 10	approx. 3	approx. 5	approx. 10
<b>Cations (mg/l):</b>					
Potassium	52	210	260	446	800
Sodium	11,000	49,000	58,000	74,700	80,000
Calcium	300	2,000	2,800	1,540	8,400
Magnesium	250	630	780	1,070	1,410
Strontium	20	97	150	44	441
Iron	1.1	12	20	31	82
Manganese	0.03	0.7	1.5	1.2	10
<b>Anions (mg/l):</b>					
Chloride	17,000	81,000	96,000	116,800	137,000
Bromide	17	98	170	111	390
Sulphate	1	1,000	900	3,830	470
Hydrogen carbonate	300	165	130	247	40

### 2.3 Pre-investigations to dimension the geothermal plant

The injection behaviour and fluid-fluid as well as fluid-rock interactions can be described in core cross-flow experiments both under laboratory and field conditions (Wildemann, 1991, Vichon et al., 1993, Kühn et al., 1997, Martin et al., 1997, Kühn, 1997, Tchistiakov, 2000, Ungemach, 2003, Wolfgramm et al., 2004).

In the recent years, a series of cross-flow experiments was done on natural and artificial samples and different fluids. Providing thorough preparation of the samples and selection of adequate equipment materials, these laboratory and field tests proved effects which may lead to a restricted permeability of the reservoir rock. The selection and preparation of the samples and, in particular, the accompanying programme of investigations have a major influence on the meaningfulness of the experiments.

The reduced permeability in NE German thermal water reservoirs proven by the cross-flow experiments are caused by (not considering some clogging due to the technical structure of the experiment):

- mechanical processes of particle entry and rearrangement depending on the flow rate;
- chemical precipitation of iron hydroxide followed by clogging due to the entry of oxygen.

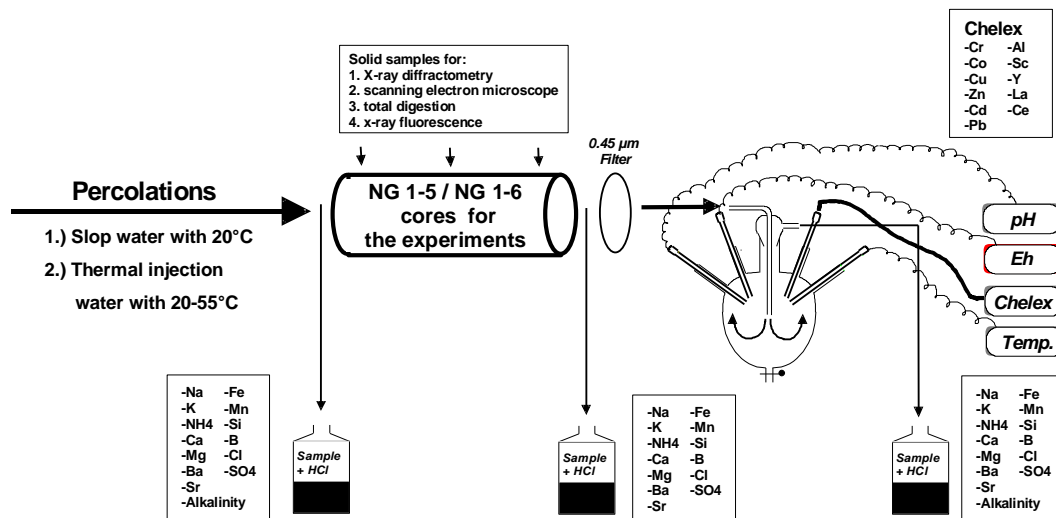


FIGURE 2: Example of a percolation experiment (Kühn, 1997)

Mineral turnover, precipitation of carbonates, sulphates, silicic acid and aluminium hydroxide as well as clay swelling did not play any role in these experiments with a view to permeability reduction. The experiments were accompanied by chemical modelling which confirmed the chemical precipitations.

All experiments have only a model character and cannot be transferred directly to the conditions of a geothermal plant and the reservoir rock. It is possible to describe and prove special effects to be considered when dimensioning the geothermal plant (e.g., well, filter, freedom from oxygen, injection, temperature).

## 2.4 Reinjection of the thermal water

The operator of a geothermal plant has to be particularly careful when reinjecting the cooled thermal water back into the porous and permeable layer, as economic operation is guaranteed only when the thermal water can be reinjected over longer periods of time at little expenditure of energy, i.e., no clogging must occur in the injection horizon. Reductions in permeability are in fact mainly due to solids which are likely to be caused by (Rockel et al., 1997, Ungemach, 2003):

- mobilisation of particles (erosion) as a result of excessively high injection and production flow rates;
- chemical incompatibility of the cooled injected fluid with the formation fluid and the aquifer matrix (e.g., clay, carbonate);
- oxidation or corrosion products coming from the thermal water loop;
- bacterial activity;
- technical inefficiency of the installation and / or equipment.

The zone at greatest risk is the near-well area.

Reinjection of the spent water (i.e., the flow of thermal water through the screen, in the near-well zone, and the flow through the reservoir rock) is equal to filtration. That is why high requirements are put on the quality of the thermal water intended for injection.

The potential risks of thermal water reinjection are considered below.

### 2.4.1 Precipitation reactions

Thermal water assessment requires special methods of chemical analysis (Hoth et al., 1997) to create a reliable database. Such an assessment can be done by means of geochemical model calculations. Geochemical modelling demonstrated that only iron precipitates if in contact with oxygen when using the waters of the type found in NE Germany for energetic purposes – provided that they do not mix with external waters.

Other sulphate, carbonate and silicate mineral turnovers are not assumed to be neither in the surface thermal water loop nor in the reservoir rock. The cross-flow experiments done on the cores drilled from the reservoirs produced the same results (Martin et al., 1997, Kühn, 1997, Wolfgramm et al., 2004).

#### 2.4.2 Oxygen entry

Oxygen may enter into the surface thermal water loop which will make the redox potential change. This contact of the thermal waters with oxygen has to be assessed critically not only with regard to the precipitation of iron – the main problem is the entry of oxygen into the reservoir horizons. If blending with the iron-containing solutions in the reservoir, the permeability may be reduced by precipitation processes causing permanent damage to the reservoir.

The experience acquired in the operation of the three geothermal plants existing in NE Germany exhibits that the Mesozoic sandstone reservoirs react differently to the reinjection of oxygen-containing thermal waters (Hoth et al., 1997).

For better assessment of the potential risk of oxygen entry, regular oxygen measurement is needed during continuous operation and when re-starting a plant after standstill, e.g., due to maintenance and repair. The thermal water quality required for reinjection can be guaranteed in this way only.

#### 2.4.3 Corrosion

The acid fluid, the content of electrolytes (solute ions, particularly chloride), aggressive gases (carbon dioxide, sometimes hydrogen sulphide and secondarily introduced oxygen) and high temperatures cause and accelerate corrosion (Schröder et al., 2006).

As the composition of the thermal water must not be changed (e.g., through the removal of components, addition of inhibitors, elevation of the pH up to the basic range), anti-corrosive measures are restricted to the selection of adequate materials and coating / lining (Wolfgramm et al., 2004a).

#### 2.4.4 Microbiology

Chemical changes within the thermal water loop caused by microbiological activities which may lead to the formation of solids in the thermal water are known. In particular, if hydrogen sulphide is formed – induced by bacterial activity – the pH will shift, corrosion will accelerate and sulphide will precipitate. In addition, the bacteria themselves contribute to the solids loading (Hoth et al., 1997, Wolfgramm et al., 2004a, Würdemann et al., 2006).

### 3. TECHNICAL CONCEPT OF THE THERMAL WATER LOOP

#### 3.1 Underground installations

##### 3.1.1 Drilling engineering

Geothermally productive horizons are developed by means of well-known drilling techniques of the oil and gas industry. Rotary drilling is applied mainly. Development can be distinguished by the well configurations:

- Classical doublet (vertical)
- Doublet (vertical + trajectory)
- Doublet (double-trajectory)

The classical doublet with two vertical wells requires a respectively large (surface) area to provide the necessary internal distance. In addition, the expenditure is increased as two separate drilling sites are needed and later two points of operation with a connecting pipeline.

Trajectory drilling allows for the restriction of the required internal distance to the underground reservoir section, and thus, for the drilling of both wells from one site. The variant preferred is “vertical + trajectory” since the first well must be drilled vertically and at little expenditure of exploration. This applies also to the potential development of a replacing horizon. As soon as the resource is proven, the second well can be developed and completed rather exactly based on the drilling profile of the first well (Seibt et al., 2003).

The sedimentation behaviour in trajectory wells and their potential negative effects on the injection behaviour are subject of ongoing investigations.

##### 3.1.2 Completion

Once the well has been drilled properly, it has still to be completed. The final part of a geothermal well in the reservoir itself can be completed in either an “open-hole” or “cased-hole” mode. In the case of an open-hole, the last casing set ends above the reservoir formation, thus leaving it open (i.e., the reservoir formation is not cased) (Figure 3).

Providing the sandstone is stable, the open-hole option is definitely the most favourable in terms of cost, particularly when re-cycling old wells, as installing a liner may restrict its usability. In addition, this type of well offers better hydraulic conditions. Work in the open section of the well is, however, more hazardous from the technical viewpoint.

For example, if the reservoir rock proves to be of low stability (e.g., sandstone reservoirs tend to de-sand when under hydraulic load), special completion measures have to be adopted, e.g., gravel pack: when completing geothermal wells in sandstone reservoirs down to a depth of 2,500 m the annular space remaining after extension of the well into the reservoir section has to be filled and a wire-wrapped screen installed, with filter gravel adapted to the grain size of the reservoir sand (Figure 4).

Completion of cased holes consists of casing the reservoir layer and cementing the annulus between the casing and the reservoir. This seal between the reservoir formation and the borehole must be removed later by perforating the casing wall and the grouting behind it (Figure 5).

This type of completion job does not limit the technical options of stimulation measures and implies little technical risk.

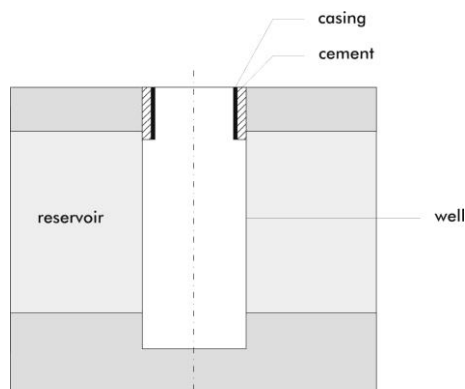


FIGURE 3: "Open-hole" completion

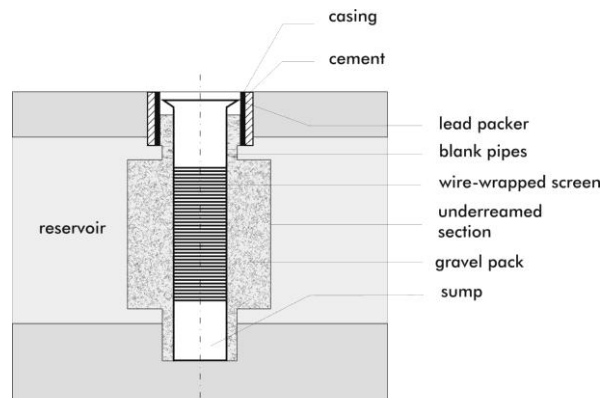


FIGURE 4: "Wire-wrapped screen" completion

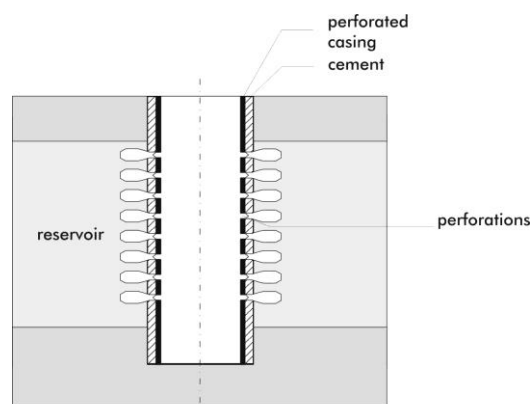


FIGURE 5: "Cased-hole" completion

### 3.1.3 Testing geothermal aquifers

Hydraulic tests serve for the characterisation of geothermal aquifers, which are commonly done as lift tests in the case of deep wells. According to common practice, nitrogen is applied for lifting in the case of deep water salinities  $\gg 1$  g/L, and air when facing salinities  $< 1$  g/L and small heavy metal contents which is fed into the well by a compressor via a lift casing. The tests are done stepwise with the flow rates of the mostly three steps being correlated with the later planned production flow rates on the one side and the technical limitations of the lift tests (max. approx. 80 L/s) on the other side. For the determination of the productivity of the well and the transmissivity of the aquifer around the well, the time-dependent determination of the flow rates and the determination of the pressures and temperatures in the aquifer zone (downhole pressure and temperature measurements) are required during these tests. In addition, the waters need to be analysed for their parameters and composition for the determination of more characteristics such as the permeability. Additional pressure measurements in observation wells allow statements concerning the aquifer between the point of measurement and the production well. The test duration is correlated with the flow rates and the pressure behaviour. For proper evaluation, the pressure should not change at all or very little only at a consistent flow rate. The most important statements concerning the reservoir can be made from the measurement of the rate of rise of the groundwater level. Such measurements should last at least as long as all the previous production phases.

Moreover, it is required to determine the inflow zones of the aquifer around the well (location, effective thicknesses) for sufficient characterisation of the aquifer. For this purpose, flowmeter logging is commonly applied; also temperature logging supplies indirect findings.



Wells intended to be used for injection are investigated too by means of lift tests, as injection tests are fraught with several problems and may lead to damages of the aquifer and the well. Along with geochemical problems, there has to be named the stress of the casing as a consequence of the injection of very cold water in very warm wells. But it is possible to conclude the injectivity from the productivities of a well as they are determined by means of lift tests. Empirically and based on different known tests as well as according to the operational data of geothermal plants, the injectivity is by the factor of 1.7 worse than the productivity.

### 3.2 Surface installation

The main components involved in the technical design of the surface installation are outlined below (Figure 6).

#### 3.2.1 Thermal water production

Due to the high salt content of the thermal water, special submersible motor pumps have to be used. The pump itself is made of corrosion-resistant materials (e.g., red bronze for the running wheels). The pipes are made of coated or inert material in order to prevent corrosion and eventual leakage into other aquifers, in particular groundwater-bearing beds with usable freshwater resources (Seibt et al., 1997).

#### 3.2.2 Prevention of oxygen entry

Whether operating or idle, the system is kept under permanent overpressure in order to avoid wherever possible the entry of oxygen and the consequences (cf. Section 2.4). Extensive protective gas systems are installed. The surface tank systems and the annular spaces in the wells are charged with nitrogen.

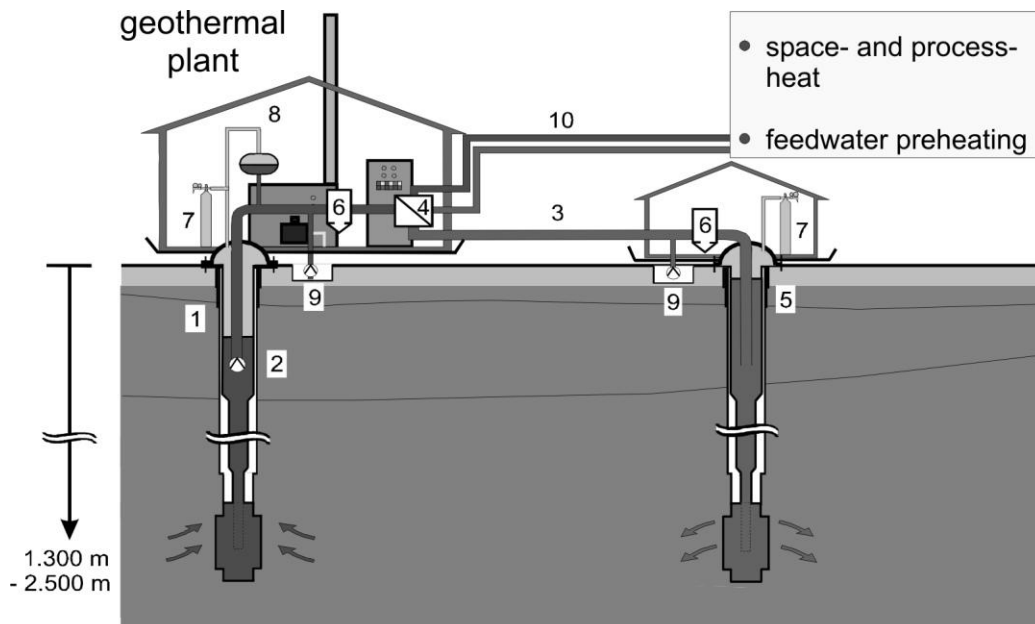


FIGURE 6: Principle scheme of the thermal water loop of a geothermal heating plant with the components: production well (1), production pump (2), production tube (3), heat exchanger (4), injection well (5), filter (6), N<sub>2</sub>-inert gas- (7) and pressure control system (8), slop disposal (9), and secondary (heating) loop (10).

### 3.2.3 Materials

Until the early 1990s, the GHPs [Geothermal Heating Plants] in Waren and Neubrandenburg were operated with unprotected metallic pipes. Corrosion damage indicated that it was impossible to prevent small amounts of oxygen from entering the system, so corrosion was uncontrollable, in particular of unalloyed and low-alloy steels.

However, a wide range of suitable materials is available for use in the thermal water loop. The choice depends on the particular type and temperature of the thermal water, the pressure and the adequate processing of the materials. Plastics and compounds (plastic / glass fibre), in particular, along with epoxy-coated metals and high-alloy steels are applied in different combinations (Seibt et al., 1997).

### 3.2.4 Thermal water filtration

Along with technological measures aimed at reducing or avoiding the precipitations described in Section 2.4, the thermal water has to be filtered in order to protect the geological reservoir from blockages (Figures 7 and 8). Depending on the reservoir and the solids contents in the thermal water, the pore width of the filtering material ranges from 1 to 25  $\mu\text{m}$ .

The amount of the filtered solids is rather small considering the thermal water flow rate. In normal operation, the filter bags are replaced periodically when their service life is over – not because they are full, which is in compliance with the manufacturer's instructions. Loads like in Figure 8 will occur only after re-commissioning of a well after a longer standstill. According to the results of the mineralogical-geochemical investigations, the solids are mainly amorphous or crystalline iron compounds (sulphides, oxides), carbonates (calcite, aragonite) and particles mobilised from the reservoir, i.e., quartz, feldspars, clay minerals and carbonates. The contents of feldspars and carbonates are much lower than those of quartz and clay minerals (Figure 8).

Deep filtration techniques (precipitation of the solids inside the filter) achieve good or very good results. Surface filtration techniques (separation of the solids on the filter surface) are to be preferred for the separation of maximum particle sizes. Both filtration techniques have to be combined in geothermal plants to grant both good sedimentation and classification.

The technical details presented here are basic solutions which need to be adapted to the specific conditions of a site. The long-term stable and safe operation of geothermal plants does not represent any problem even under the complicated conditions of the thermal water reservoirs in NE Germany.



FIGURE 7: Filter unit (open)

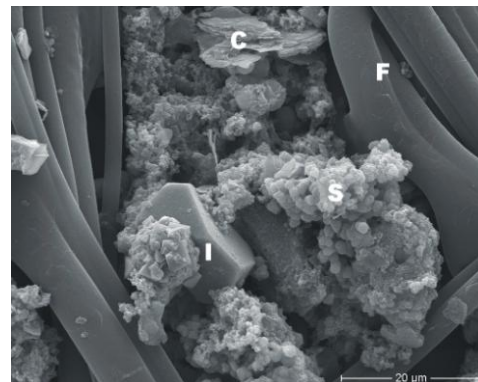


FIGURE 8: Surface of a loaded filter fabric after re-starting. F-fibre; I-iron sulphide; S-scaling of clay; C-clay

According to the results of a study made on the various technologies outlined above, reinjection is possible in the filtration regime, i.e., without using additional injection pumps.

## 4. IMPLEMENTED PROJECTS

### 4.1 Waren (Müritz)

Since 1985, i.e. for 20 years, cooled thermal water has been reinjected successfully via an injection well on the site of the first geothermal heating plant in Germany in the town of Waren (Müritz), Federal Land of Mecklenburg-West Pomerania. The aquifer is formed by Hettangian sandstones at a depth of 1,470 m (top) providing flow rates of around 60 m<sup>3</sup>/h. The thermal water temperature is 62 °C and ranges from 20 to 40 °C when reinjected. The salt content of this NaCl brine is 158 g/L, and iron content is 12 mg/L. In the early 1990s, the surface plant was modernised and completed with corrosion-proof equipment (Figure 9).



FIGURE 9: Geothermal plant in Waren – installation of the glass fibre-reinforced casings

### 4.2 Neustadt-Glewe

The site was explored in 1989 and found to be characterised by extreme conditions. With a thermal water temperature of 99 °C, a salt content of 220 g/L, iron about 80 mg/L, and high gas contents in the fluid, the heating plant has been basically in smooth operation since 1995. The thermal water is produced from, and injected back into, a sandstone layer at a depth of 2,200 m (top), at flow rates of max. 125 m<sup>3</sup>/h (Seibt et al., 1994, Menzel et al., 2000).



FIGURE 10: ORC unit at the Neustadt-Glewe site

An ORC unit was added to the geothermal plant in 2003 making it the first geothermal power generation plant in Germany (Figure 10) (Seibt et al., 2003). Since the end of 2003, the plant has been operated at an injection flow rate of 110 m<sup>3</sup>/h.

#### 4.3 Berlin

The aquifer store forming an essential part of the integrated energy supply system of the German Parliament buildings in Berlin (Reichstag plus new buildings) lies within a weakly consolidated sandstone at a depth of about 300 m. The water has an initial temperature of 19 °C and a salt content of 29 g/L (Poppei et al., 1998). Since 2000, waste heat coming from the vegetable-oil driven cogeneration plant has been stored at temperatures up to 60°C and recovered without any technical problem (Kabus and Seibt, 2000). The doublet is used alternately for production and injection (Figures 11 and 12).



FIGURE 11: Double pipe installation

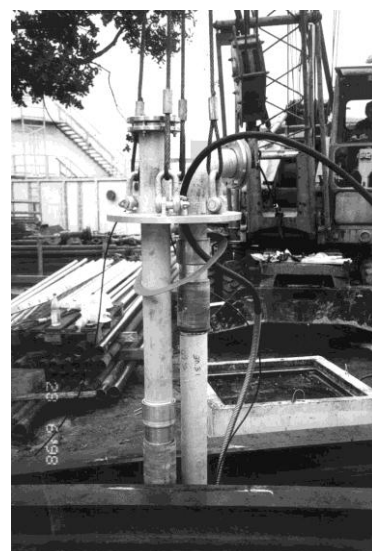


FIGURE 12: Well head in a heat store well

#### 4.4 Neubrandenburg

The geothermal heating plant was commissioned in 1989. The water comes from two fine sandstone horizons at depths of 1,150 m (top) and 1,250 m (top), at temperatures of 52 and 54 °C, salt contents of 113 and 133 g/L, respectively, at flow rates of up to 100 m<sup>3</sup>/h, and reinjected into the host aquifers (Hoth et al., 1997). In the early 1990s, the surface plant was rehabilitated, but without installing a nitrogen-charging system. Consequently, injectivity deteriorated continuously.

The GHP was reactivated in 2003 and retrofitted for combined use as geothermal plant and waste heat aquifer store of a gas and steam cogeneration plant plus the production of brine for therapeutic purposes. The new thermal water loop is installed according to the state-of-the-art (Figures 13 and 14).

The deepening of the wells allowed for the first time the investigation of rock samples taken from a sandstone horizon into which spent thermal water has been injected for years. The laboratory results give proof of an improvement of the permeability and do not indicate any clogging of the near-well reservoir zone by precipitation or rearrangement which was confirmed by production and injection tests.

Trial operation of the plant started in early 2004. Cooled (approx. 45 °C) thermal water is produced through the injection well, heated up with the waste heat arising from the gas and steam cogeneration plant and injected into the production well (summer operation). This heat will be recovered during winter, thus increasing the efficiency of the plant significantly (Kabus, 2003).



FIGURE 13: Well head installation of the combined production/injection well N 1/88



FIGURE 14: Geothermal plant in Neubrandenburg after retrofitting

#### 4.5 Neuruppin

The geothermal heating plant was commissioned in 2007 (Figure 15). The water comes from an Aalenian fine sandstone horizon at a depth of 1,620 m (top), at temperatures of 64 °C, salt contents of 199 g/L, respectively, at flow rates of up to 50 m<sup>3</sup>/h, and reinjected into the host aquifers. The geothermal wells were drilled from one drill site with a vertical production well and a trajectory injection well. The internal distance of the two wells in the aquifer is 875 m.

At present, the 3 MW Geothermal Plant supplies heat to a hotel complex and several more buildings as well as brine to a thermal spa. This iodine-bearing thermal brine serves for health care mainly. It is possible at any time and integrated in the design so far to increase the plant capacity up to 8 MW in order to connect the nearby residential area to the Geothermal Heating Plant.

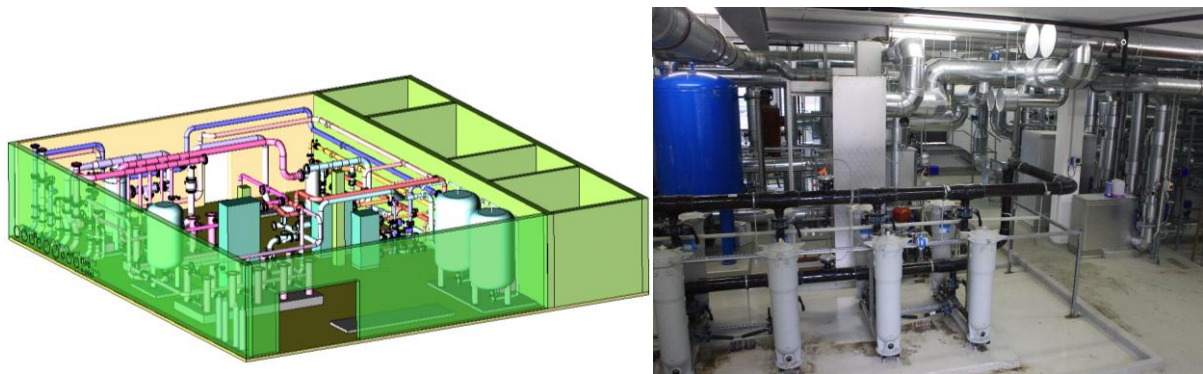


FIGURE 15: Geothermal Heating Plant (design and reality in August 2007)

## 5. EXAMPLES OF MEASURES AND INVESTIGATIONS TO BE TAKEN IN THE CASE OF INJECTION PROBLEMS

### 5.1 Neustadt-Glewe

In 1998 oxygen entered the otherwise closed system in the Neustadt-Glewe Geothermal Plant via a defective regulating valve over a short period of time, resulting in iron precipitation, which caused an increase of the injection pressure. Moreover, carbonates were found. After inspection of the injection and intensification, the injectivity could be restored by 100 % (Figure 16).

In 2007, a re-increase of the injection pressure could be observed which was steady, however. Video inspection and downhole sampling were done for investigation of the reason. It was stated that the deterioration of the injectivity was caused, among others, by underground precipitations of carbonates, iron compounds and lead compounds in the screen section of the well.

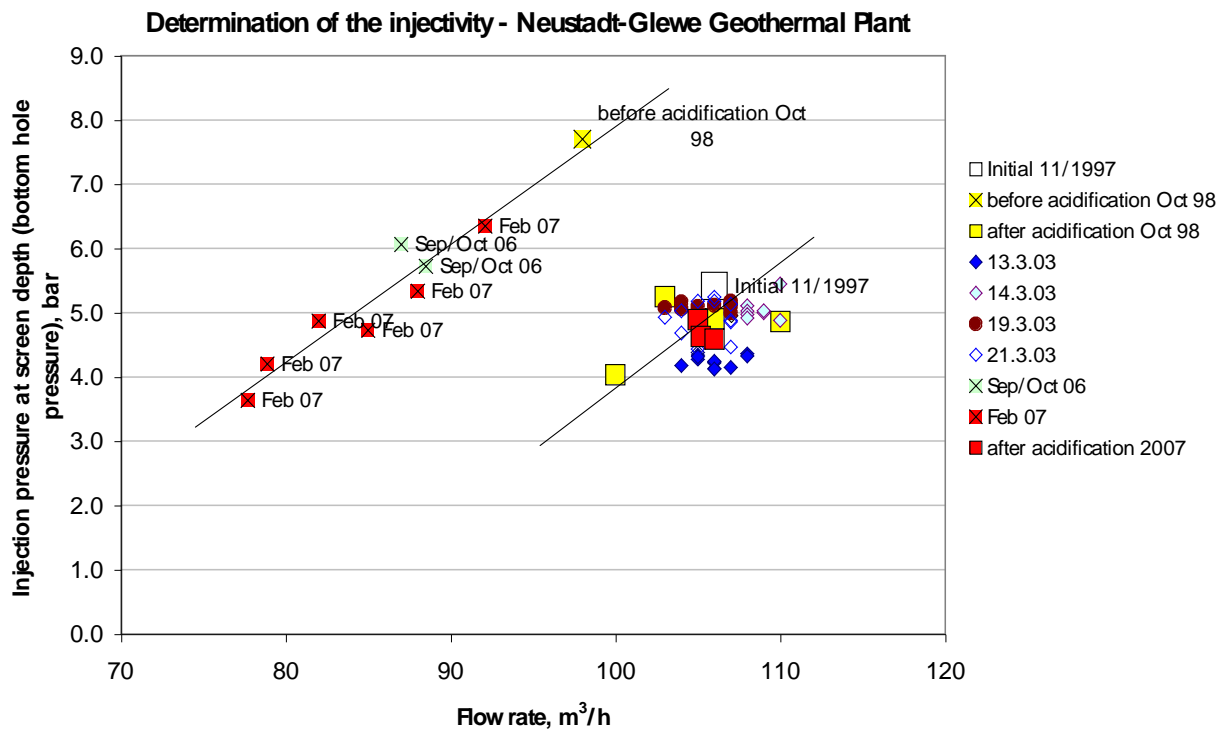
For re-establishment of the injectivity of the injection well, these solids were to be removed. Again, the pH value of the injection fluid was decreased by feeding HCl into the surface system (soft acidizing).

For acidification in 2007, three times more acid was needed compared to 1998. This may be due to deeper penetration of the carbonates into the reservoir.

Before acidification in 1998, carbonate formations could be observed in the screen section. The video inspection in 2006 showed that the screen was almost completely free from precipitations.

As also the pressure maintenance in the plant was improved in the recent years, and long-lasting and heavy under-pressures did not occur anymore in the injection well zone, such high amounts of carbonate cannot precipitate anymore within a relatively short period of time. The effect is that the now formed lower amounts of carbonate can penetrate deeper into the reservoir than before. Thus, a larger zone around the well is affected by carbonate precipitations which results in an increased consumption of acid for acidification.

Through both acidification measures the injectivity could be improved essentially or re-established completely (cf. Figure 16).



The soft acidizing method gives good results in sedimentary geothermal environs, both for rehabilitation of well casings, and the reservoir rock formation itself. It is most important, however, that it can be applied during the geothermal doublet exploitation (uninterrupted operation), and does not require heavy equipment and rigs. Soft acidizing is done using light equipment and coiled tubing when there shall be treated specifically reservoir sections with primarily worse features. This economically profitable method gives more permanent results than other well and reservoir rehabilitation and maintenance methods.

## 5.2 Klaipeda

The Klaipeda geothermal project started in 1996 and the production began in 2000. The aquifer is formed by Devonian sandstone located at a depth of approx. 1,150 m (top). The Na-Cl dominated deep water with temperatures of approx. 40 °C shows salinities of approximately 95 g/L and low gas contents. The injectivity of the wells has been deteriorating ever since this point. The countermeasures taken in 2002 and 2003 could not help this situation (Figure 17). In 2002, acidification was done by means of coiled tubing which resulted in a short-term 100 % improvement of the injectivity. Gypsum precipitated heavily in the surface part of the plant. These precipitations were removed in 2003 resulting in a drastic decrease of the injectivity of the injection well KGDP I4. By means of an inhibitor system, the scaling of gypsum in the surface installations could be eliminated. The causes of the deterioration of the injectivity are scale-dependent. So, the discontinuous deterioration during the cleaning work in the surface system in 2003 is assumed to be caused by technical problems. But, the continuous decrease of the injectivity may be due to several reasons such as the formation of sulphide scales resulting from microbial activity, precipitation of iron hydroxide due to the entry of oxygen, rearrangement of particles within a moderately sorted and fine-grained sandstone with a high fine percentage, precipitations of gypsum in the aquifer, corrosion of the casing and damage of the near-well area, formation of filter cakes, improper dimensioning of the surface filters or the bottom hole screen, etc.



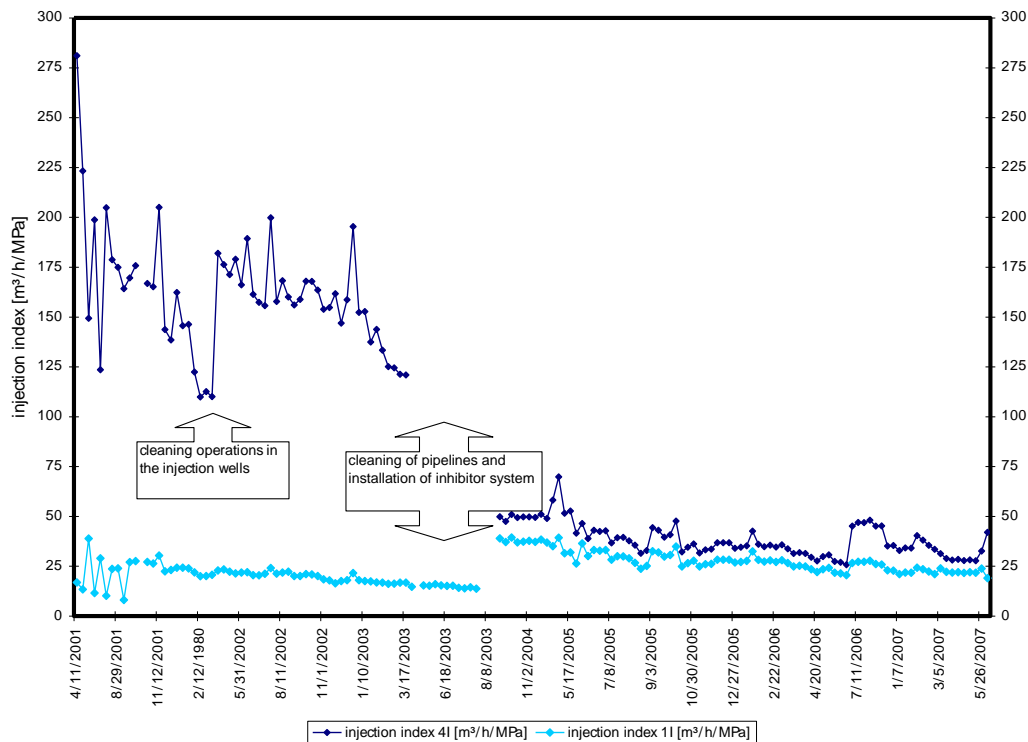


FIGURE 17: Injectivities of the wells KGDP 1I and KGDP 4I in Klaipeda geothermal plant throughout the entire period from 03/2001 – 06/2007

Investigations in the Klaipeda Geothermal Plant showed that the injectivity of the well should be re-established by soft acidizing. However, for the sustainable maintenance of the injectivity it is necessary to identify the main causes of the deterioration and to take adequate countermeasures. These are planned to be prepared based on, e.g., downhole sampling, microbial and fluid-chemical (liquid and gas) investigations, oxygen measurements in the surface system for the identification of leakages, geophysical logging to identify rearrangements of clay in the screen section, inquiry/review and evaluation of the installation design and well records to verify the dimensioning of filter systems, potential corrosion (e.g., use of different/incompatible casing materials), and many more.

Resulting from the investigations, there should be proposed technical measures in order to essentially improve the injection behaviour of the wells.

## 6. CONCLUSIONS

Injection of thermal waters into porous reservoirs is technically feasible but in order to select and assess a site for injection, a careful study has to be made of the geological and geohydraulic parameters of the underground; the design of the drilling installation, surface loop and the economic profitability of the entire plant have to be investigated properly as well.

Advancing studies confirm that the practical results obtained from the operation of the geothermal plants in Berlin, Waren (Müritz), Neubrandenburg and Neustadt-Glewe can well be transferred to many other sites in Europe with analogous geological conditions.



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