Reinjection of thermal waters into sandstone reservoirs in the North German Basin

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Abstract

Intensive investigations into the utilisation of the geothermal potential in the North German Basin began already in the early 1980s. The firsts tests of production and reinjection of thermal water from / into sandstone reservoirs were started in 1982. As a result, these led to the commissioning of the first geothermal heating plant for heat supply of a residential area in the town of Waren (Müritz) in 1984. More plants were put into operation in Neubrandenburg, Neustadt-Glewe and Berlin. The use of the sandstone reservoirs for heat storage produced new technical solutions. The exact knowledge of the geological and geochemical conditions forms the essential prerequisite for the successful planning, construction and operation of the geothermal plant. In the following, technical solutions and practical experience are presented along with the geological and geochemical conditions.

Keywords: reinjection, thermal waters, sandstone reservoirs.

1 Hydrogeothermal energy use and storage

For the utilisation of hydrogeothermal energy, the thermal water is produced via a well from deep formations up to the surface (production well) and after heat absorption reinjected into the host formation via a second well (injection well).

On one hand, the normally required reinjection of the waters into the underground is to maintain the hydraulic regime, and on the other hand, especially highly mineralised waters must not be disposed off into surface water bodies for reasons of environmental protection. The thermal water is circulated between production and injection wells in a primary closed loop. Via heat exchangers, the heat is absorbed from the thermal water and supplied to the consumers via a secondary loop. As a rule, a geothermal storage system consists also of two wells or two groups of wells developing the same aquifer. Both wells are equipped with pumps and an injection casing allowing the unit to be flown through in either direction. Heat exchangers, which are integrated in the surface pipe system connecting both wells, allow charging and discharging of energy. The conditions described here refer to the North German-Polish Depression, exclusively. The North German-Polish Depression forms the core of the Central European Depression, which includes also the Danish-Polish and the North Sea Depression (Rockel, W. and Schneider, H., 1992).

2 Hydrogeological and geochemical conditions

2.1 Reservoir characteristics

The economically efficient use of low-enthalpy (40-100°C) hydrogeothermal reservoirs requires large thermal water resources and flowrates (50-100 m³/h/well). Therefore, use is tied to several geological conditions (Seibt, P., 1991):

- the existence of a productive water-bearing rock formation (productive horizon)
- a sufficient vertical and lateral extension of this rock formation in order to guarantee longevity (productive reservoir)
- an economically interesting temperature level in the productive reservoir
- the principle 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, the high flowrates and the granting of long-term stable production and reinjection require above all certain minimum values as regards porosity, permeability and net thickness, thus resulting in considerable requirements on a pore reservoir usable for hydrogeothermal purposes. There are required sufficiently thick, high-porous and low-matrix sandstones whose primary pore space and grain structures are little changed diagenetically. However, definite *limits* can just be given for concrete, site-specific conditions. But the following orienting values for sandstones result from the experience gathered in projects implemented hitherto (Rockel,W. et al.,1997):

- effective porosity > 20 %
- permeability > 0.5×10^{-12} m²
- thickness > 20 m.

Such sandstones are found in the North German Basin down to depths of approx. 3,000 m.

2.2   Thermal water characteristics

The Mesozoic deep waters developed in NE Germany are classified as high-saline Na-(Ca-Mg)-Cl waters. The depth-depending salt concentration can amount to more than 300 g/l. The main components are chloride ions with almost 50 mmol(eq) % and sodium ions with 43… 47 mmol(eq) %. As secondary and trace components magnesium, calcium, potassium, iron, strontium, manganese, barium as well as sulphate, bromide and iodide ions are dissolved in the thermal water. Silicic acid and borate ions play a minor role only.

The thermal waters contain small shares of solute gases, so called "formation gases". Predominantly, they consist of nitrogen and carbon dioxide. Methane may occur as a secondary component. Ethane, hydrogen and helium are to be detected in traces only.

The Mesozoic deep waters show a reduced condition; the identified pH values indicate an acid character of the waters (Rockel,W. et al.,1997), (Seibt, P. and Kellner, T., 2002).

2.3   Reinjection of the thermal water

The operator of a geothermal plant has to pay special attention to the reinjection of the cooled-down thermal water into the respective 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 blockings occur in the injection horizon. Any reductions of the permeability are mainly due to solids. These may originate from (Rockel, W. and Schneider, H., 1992), (Rockel,W. et al.,1997):

- mobilisations of particles (erosion) due to too high injection and production flowrates

- chemical incompatibility of the cooled-down injected fluid with the formation fluid
- entry of oxidation or corrosion products from the thermal water loop
- bacterial activities
- technical insufficiencies of installation and equipment.

The zone endangered mainly is the near-well area.

The reinjection of the cooled-down thermal water (i.e., the flowing-off of the thermal water via the well completion, the near-well zone, and the flowing 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.

3 Technical concept of the thermal water loop

3.1 Underground installation

Completion

Once the well is drilled properly, it has to be completed. The final installation of a geothermal well in the immediate reservoir section can be done according to the variants "open-hole" and "cased-hole" completion. In case of open-hole completion, the last set casing ends above the reservoir layer, thus leaving it open (i.e., the reservoir layer is not cased).

Providing sufficient stability of the rock, this variant surely represents the most favourable option in terms of cost, in particular when re-using old wells where the later liner installation may restrict the usability. In addition, this variant of installation offers better hydraulic conditions. However, the work in the open section of the well can be implemented only at high technical risk.

In case of low stability of the reservoir rock (e.g., sandstone reservoirs tending to desanding when under hydraulic load), special additional completion measures need to be carried out. Gravel-pack – the typical variant of completion of geothermal wells in sandstone reservoirs down to a depth of 2,500 m - implies the filling of the annular space remaining after extension of the well in the reservoir section and installation of a wire-wrapped screen with filter gravel adapted to the grain size of the reservoir sand.

Cased-hole completion is the casing of the reservoir layer and cementing of the annulus between casing and reservoir. Subsequently, this sealing between reservoir layer and borehole must be removed by perforation of the casing wall and the grouting behind it.

This variant of completion does not restrict the technical options of stimulation measures and implies little technical risk.

Testing of geothermal horizons

In this context, a test means the investigation of the hydrodynamic characteristics of geothermal reservoirs. In order to be able to identify the suitability of the reservoirs for geothermal energy supply by targetted tests in the drilling phase already, flowrate, drawdown, formation temperature and pressure, chemism and gas content of the water as well as the stability of the rock are determined.

Investigations into clastic sediments show that the potential injectivity index (i.e., the thermal water injection flowrate which is possible at a certain pressure) can be concluded from the results of the geoscientific investigations and the production tests. Thus, injection tests can be obsolete – which always imply the risk of reservoir

damaging due to the potentials for chemical precepitations exisisting during production, storage an reinjection.

As a rule, a casing lift test is carried out as a cumulative test upon development of the reservoir, allowing temperature and pressure to be measured in different production regimes as well as recording of the influx throughout the reservoir section.

Based on the data obtained during the drilling process and available from regional geological investigations as well as of the parameters obtained from the tests, the hydro- and thermodynamic behaviour of the geothermal reservoir can be modelled during the operation of a Geothermal Heating Plant. The most important findings are the maximum water head changes to be expected (with the aim to prove the technical feasibility of the production and injection flowrate) and the time of the beginning of the temperature drop as the proof of the required service life of the plant or the temperature development in the production well.

3.2 Surface installation

The technical concept of the surface installation must consider the problems presented above. Important details are highlighted in the following (Seibt, A. et al., 1997).

Thermal water production
Due to the high salt content of the thermal water, special submersible motor pumps are applied for the production.

The pump itself is made of corrosion-resistent materials (e.g. red bronze for the running wheels). Also the rising pipes of the pumps and the finishing pipes have to be made of coated or inert material in order to prevent corrosion and, thus, leakage into other aquifers, in particular groundwater-bearing beds with usable freshwater resources.

Avoidance of the entry of oxygen
While in operation and idle, the system is kept under permanent overpressure in order to possibly exclude the entry of oxygen and any relevant consequences (cf. 2.3). For that, extensive protective gas systems are installed. The surface tank systems and the annular spaces in the wells are charged with nitrogen.

Materials
Up to the early 1990s, the geothermal heating plants in Waren and Neubrandenburg were operated with unprotected metallic pipes. Corrosion damages indicated that the entry of small amounts of oxygen into the system could not be avoided absolutely, thus making the process of corrosion uncontrollable, in particular of unalloyed and low-alloy steels.

However, a wide range of suitable materials is available for the 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 compound materials (plastic/glass fiber), specially and rubber coated metals as well as high-alloy steels are applied in different combinations.

Thermal water filtration
Along with technological measures aiming to reduce or avoid potential precipitations as described under 2.4, the thermal water has to be filtered in order to protect the geological reservoir from blockings. Moreover, filtration prevents the entry of traces

of oils and greases – partly coming from the submersible water pump – into the injection well and, thus, into the reservoir horizon.

4 Implemented projects

Waren

Since 1985, i.e. for 17 years, cooled-down 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 / Federal Land of Mecklenburg-West Pomerania. The aquifer is formed by Hettangian sandstones in a depth of 1,470 m providing flowrates around 60 m³/h. When produced, the thermal water temperature is 62 °C, when injected, it ranges from 20 to 40°C. The salt content of this NaCl brine is 158 g/l, iron content is 12 mg/l (Seibt, P. and Kellner, T., 2002), (Seibt, P. et al., 1994).

Neustadt-Glewe

The site was explored in 1989. It was found to be characterised by extreme conditions. With a thermal water temperature of 100°C, a salt content of 220 g/l, iron about 80 mg/l, and high gas contents in the fluid the heating plant is in basically smooth operation since 1995. The thermal water is produced from and injected into a sandstone layer in a depth of 2,200 m at flowrates of max. 125 m³/h.
Via a defective regulating valve, oxygen entered the otherwise closed system over a short period of time in 1998, resulting in iron precipitation which caused an increase of the injection pressure. Upon inspection of the injection well and intensification, the injectivity could be restored by 100 % (Seibt, P. et al., 1994); (Seibt, P. et al., 1994); (Menzel, H. et al., 2000).

Berlin

The aquifer thermal energy store forming an essential part of the integrated energy supply system of the buildings of the German Parliament in Berlin (Reichstag plus new buildings) is installed in a weakly consolidated sandstone in a depth of about 300 m. The thermal water has an initial temperature of 19°C and a salt content of 29 g/l (Poppei, J. et al., 1998), (Seibt, P. et al., 1996), (Seibt, P. and Kabus, F., 1997). For two years now, waste heat coming from the vegetable oil driven cogeneration plant is stored and recovered without any technical problem (Zenke, J. et al., 2000).

Neubrandenburg

The Geothermal Heating Plant was commissioned in 1989. The thermal water is produced from two fine sandstone horizons in depths of 1,150 and 1,250 m, with temperatures of 52 and 54°C, salt contents of 113 and 133 g/l, respectively, at flowrates of up to 100 m³/h, and reinjected into the host aquifers. In the early 1990s, the surface plant was rehabilitated, however, without installation of a nitrogen charging system. Consequently, the injectivity deteriorated continuously. The GHP is being reactivated at present and retrofitted for the 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.

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