Chapter 1
Introduction

1.1 Geothermal Systems

> Geothermal energy is a promising alternative energy source as it is suited for base-load energy supply, can replace fossil fuel power generation, can be combined with other renewable energy sources such as solar thermal energy, and can stimulate the regional economy.

The above text is quoted from an editorial of a new open-access journal Geothermal Energy (Kolditz et al. 2013), which advocates the potential of this renewable energy resource for both heat supply and electricity production. Indeed, *Geothermal energy* has recently became an essential part in many research programmes worldwide. The current status of research on geoenergy (including both geological energy resources and concepts for energy waste deposition) in Germany and other countries has been compiled in a thematic issue on "Geoenergy: new concepts for utilization of geo-reservoirs as potential energy sources" (Scheck-Wenderoth et al. 2013). The Helmholtz Association dedicated a topic on geothermal energy systems into its next 5-year-program from 2015 to 2019 (Huenges et al. 2013).

When looking at different types of geothermal systems, it can be distinguished between shallow, medium, and deep systems in general (cf. Fig. 1.1). Installations of shallow systems are allowed down to 100–150 m of subsurface, which includes soil and shallow aquifers. If going further down, the medium systems are associated with hydrothermal resources and may be suited for underground thermal storage (Bauer et al. 2013). Deep systems are connected to petrothermal sources and need to be stimulated, in order to increase the hydraulic conductivity for heat extraction by fluid circulation (Enhanced Geothermal Systems—EGS).

H. Shao et al., *Geoenergy Modeling II*, SpringerBriefs in Energy,
DOI 10.1007/978-3-319-45057-5_1

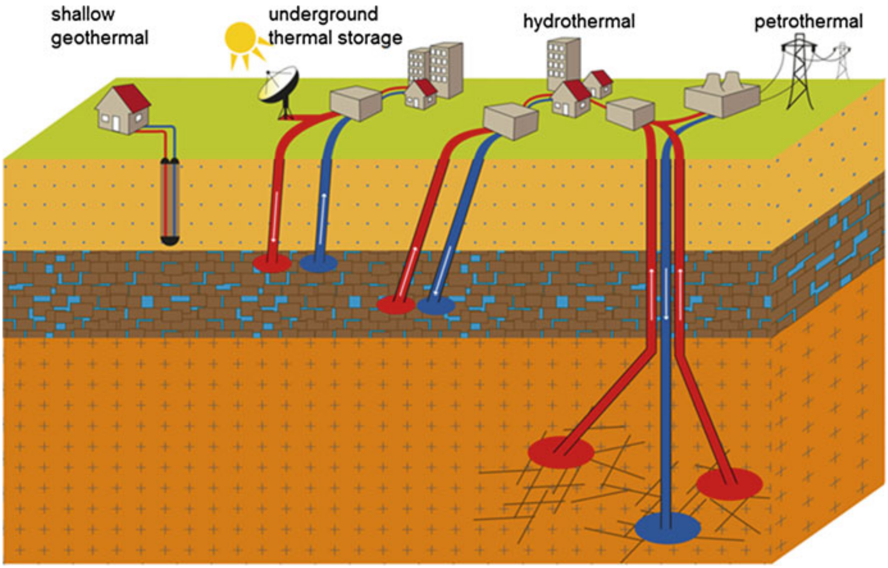

Fig. 1.1 Overview of different types of geothermal systems: shallow, medium and deep systems (Huenges et al. 2013)

1.2 Geothermal Resources

In general, the corresponding temperature regimes at different depths depend on the geothermal gradient (Clauser 1999). Some areas benefit from favourable geothermal conditions with amplified heat fluxes, e.g., in the North German Basin, Upper Rhine Valley, and the Molasse Basin of Germany (Cacace et al. 2013). Conventional geothermal systems mainly rely on heated water (hydrothermal systems) that approaches the near-surface. Therefore they are regionally limited to near continental plate boundaries and volcanoes. Nevertheless, this book will focus on the numerical modelling of extracting shallow geothermal resources. In particular, this book will explain in details how to numerically simulate the evolving soil temperature in response to heat extraction from borehole heat exchangers.

Before diving down into the numerical world, let's have an overview on how much energy is stored in the subsurface that we are standing on. First, here are some interesting numbers about the solid earth:

- The mean surface temperature is abut 15 °C.
- Despite of strong fluctuations of the surface temperature, the soil or rock temperature beneath 15–20 m of depth is largely constant.
- The geothermal gradient in the upper part is about 30 K per kilometer depth (0.03 $\mathrm{K m^{-1}}$). In another word, from the surface downwards, the average soil temperature will increase 3° by every 100 m.

So how much energy can we extract from the shallow subsurface?

When looking into the shallow geothermal systems, it is rather unlikely to have a 20–30 K temperature drop as in the deep geothermal reservoirs. However, if the temperature of the shallow subsurface is decreased by only 0.5–2 °C, it will still generate large amount of energy. For example, Zhu et al. (2010) evaluated the geothermal potential of the city Cologne, and they found that a temperature decrease of 2 °C in the 20 m thick aquifer will yield enough energy that is more than the city's annual space heating demand. Using a similar approach, Arola and Korkka-Niemi (2014) assessed the effect of urban heat islands on the geothermal potential in three cities in southern Finland. It turns out that, because of the urban heat island effect, 50–60 % more heat can be supplied from shallow subsurface in the urban area, in comparison to rural areas.

1.3 Utilizing Shallow Geothermal Resources

Now the energy embedded in the shallow subsurface is more than plenty. How can it be utilized? Currently, the most widely applied technology is the so-called Ground Source Heat Pump (GSHP) system. Such system is typically composed of three inter-connected parts (cf. Fig. 1.2), namely (1) the ground loop, (2) the heat pump, and (3) the in-door loop.

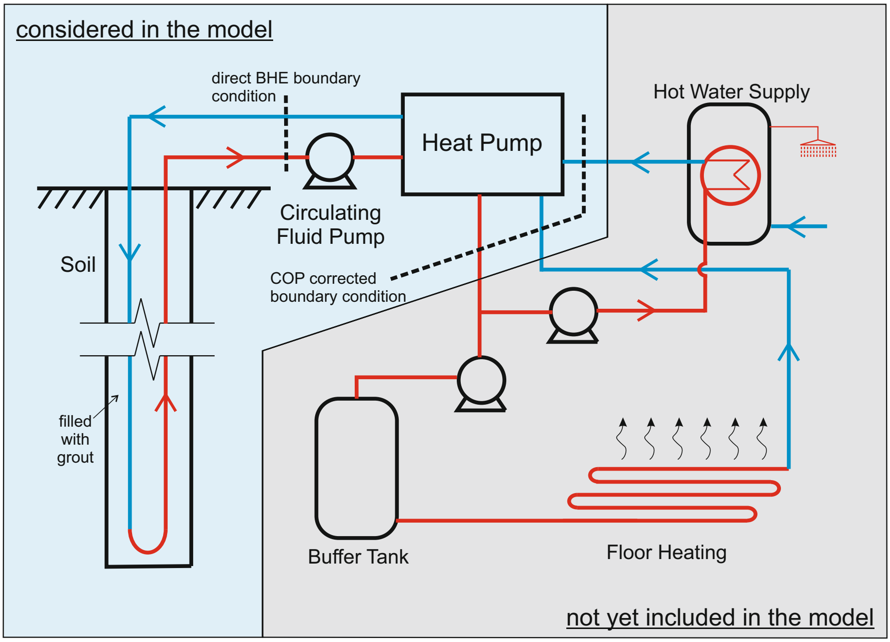

Fig. 1.2 Overview of the Ground Source Heat Pump (GSHP) system, reproduced after Zheng et al. (2016)

- The ground loop is composed of one or multiple borehole heat exchangers (BHE). Their main function is to extract heat from the shallow subsurface for building heating, or injecting heat while providing cooling. This is typically achieved by installing closed loop tubes, buried vertically or horizontally in the ground, and circulating refrigerant through the pipes.
- The function of the heat pump, is to elevate the low-grade heat from the ground loop, to high-grade heat that can directly be applied for room heating or hot water supply.
- As for the in-door loop, it is designed to transport and dissipate high-grade heat or code through the building.

In this book, the numerical modelling software OpenGeoSys (OGS) will be employed to model the borehole heat exchanger and heat pump part, more specifically to simulate the dynamics behaviour of soil temperature due to GSHP operation (Fig. 1.3).

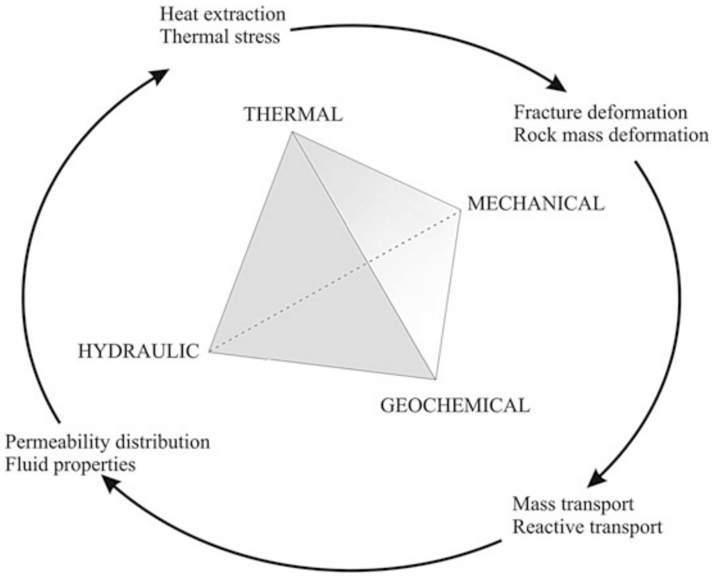

Fig. 1.3 THMC coupling concept. OGS is a scientific open-source initiative for numerical simulation of thermo-hydro-mechanical/chemical (THMC) processes in porous and fractured media, continuously developed since the mid-eighties. The OGS code is targeting primarily applications in environmental geoscience, e.g. in the fields of contaminant hydrology, water resources management, waste deposits, or geothermal systems, but it has also been applied to new topics in energy storage recently

1.4 Tutorial and Course Structure

This tutorial “Computational Energy Systems II: Shallow Geothermal System” contains several parts. In Chap. 2, the governing equations of the numerical model will be defined. Chapter 3 shows the user how to set up a project to simulate heat transport processes induced by a BHE operation. To construct the mesh used in Chap. 3, a meshing tool will be needed, which is introduced in Chap. 4. The developed OGS model will be verified in Chap. 5, with three different benchmarks. A realistic application is presented in Chap. 6, and the knowledge from the modelling study will be further discussed. This tutorial can also be used in combination with the following material

- OGS training course on geoenergy aspects held by Norihiro Watanabe in November 2013 in Guangzhou,
- OGS training course on CO_2-reduction modelling held by Norbert Böttcher in 2012 in Daejon, South Korea,
- OGS benchmarking chapter on heat transport processes by Norbert Böttcher,
- University lecture material (TU Dresden) and presentations by Olaf Kolditz.

By visiting the OGS webpage at https://docs.opengeosys.org/books/shallow-geothermal-systems, interested readers can obtain the dataset used in this book, to conduct their own simulations for the ground source heat pump system.