### Heat Transport

 should this include C?!





v = advective flow velocity in i direction (m/s)

D = effective heat diffusion dispersion coefficient in i direction (J/Kms)

(SM5.2)

#### Estimation of cooling

Geothermal reservoirs are likely to cool down with time, as a result of induced natural recharge of cold fluid or reinjection. According to Ali *et al*. (2016), the energy lost by the reservoir rock is equal to the energy gained by the fluid , with

(SM5.4)

(SM5.5)

where and are the mass of rock and fluid, respectively, the volume of rock, the heat capacity, the temperature change of the rock and the difference of temperature between the produced and inflowing fluid. The subscript *p* refers to the produced fluid (generally two-phase) and *i* to the injected/recharge liquid water.

When boiling conditions are reached in a system as a result of pressure drop, steam can be formed. The release of latent heat necessary to vaporize the steam can be at the origin of cooling of the host rock. These conditions can be found in the uppermost part of the central region of the reservoir, where the pressure and temperature follow the boiling point curve. The fluid vaporized gains temperature through a transfer of heat from the rock to the fluid and expands to replace the fluid withdrawn (Grant & Bixley, 2011).

This process results in a cooling of rock by an amount (Drouin *et al*., 2017), where *X* is the steam fraction and *L* the latent heat of vaporization. Thus, the total energy lost by the rock under reinjection and steam vaporization is resulting in a cooling of rock equal to:

(SM5.6)

* Cooling due to conduction through a cap rock

We first want to estimate the total time necessary to cools down by 30 °C the upper part of the reservoir from an initial uniform temperature to , if cooling occurs from above or below. We consider a 1-dimensional (1D) layer where a 10°C cold layer is present at y = 0. We assume that the change in temperatures in each 50 m long elements in the vertical direction are only due to conduction of heat between the elements, with the amount of energy transferred between the elements *i* and *j* at the time step *t* is

(SM5.7)

The heat flow out of the element *j* becomes the heat flow in the element (G. Gunnarsson, Orkuveita Reykjavíkur, personal communication, 2017). Based on the heat diffusion equation,

(SM5.8)

where is the volumetric heat capacity of the wet rock (J/m3°C) and *V* the volume of each element, the temperature decrease in the element at time is (Axelsson, 2012a):

(SM5.9)

*With the and the density and heat capacity of the “wet” rock respectively, the reservoir area A = 1.9 km², the thickness of each element d = 50 m, k = 2.5 W/(K.m) the conductive heat coefficient and the time step (assumed to be 1 year)*

* Cooling due to cold inflow

We therefore try to estimate the rate of temperature change of the reservoir rockthat would be due to the replacement of a fraction of the mass extracted by cold inflowing water. Here we consider two special situations: i) the heating of groundwater by mining heat from the host reservoir rock without steam generation and ii) all the energy comes from cooling steam in the steam cap. We combine these two results to estimate the proportion of steam that would need to condense to prevent the reservoir below 1500 m from cooling.

We use the average production rate during the period 2009-2016 (Table SM5.2) and the properties in Table SM5.3 to estimate the cooling due to cold recharge. As mentioned earlier, no vaporization of steam is expected to take place in the reservoir during this period of time, as indicated by the decrease in the discharged enthalpy and the partial re-saturation of shallow feed zones (O. Sigurdsson, HS-Orka, personal communication, 2018). Equation SM5.6 is therefore simplified to (see also Im *et al.*, 2017):

(SM5.10)

Here is the expected rate of cooling of the reservoir rock due to production, the average mass extraction rate (Table SM5.2), = 340 kg/s the rate of mass recharge (considering both natural and injected mass) and 3.8 km3, the reservoir volume. *T*, and refer to the temperature, density and heat capacity of the produced fluid (*p*), inflowing fluid (*i*) and rock (*r*), respectively (Table SM5.3). The heat capacity of the produced two-phased fluid is determined using the steam and water properties at an average temperature 240°C (Table C1) and Equation SM5.11 (Axelsson, 2012a), for a steam fraction X = 14% (Appendix C)

(SM5.11)