A practical method to calculate the productivity of a horizontal well for a geothermal project in The Netherlands.

Introduction

The greenhouse project Erica in the southeastern part of Drenthe the Netherlands, wants to use geothermal energy for greenhouse heating. Erica is located on the rim of the northeastern part of the Lower Saxony Basin. The subsurface consists of different types of sediments with several unconformities and NW-SE oriented faults. Previous research showed that the Lower Volpriehausen Sandstone Member has the most promising hydraulic properties and temperature for geothermal application (Heijnen et al, 2010). However, the thickness of the Lower Volpriehausen Sandstone Member is limited to approximately 30m. Given the limited thickness and related low flow rate a vertical well is not economical feasible in this case. To increase the production rate in the Erica project a choice was made for a horizontal well with a length of 500m, as such a well is several times more productive than a vertical well. For horizontal wells the value of the vertical permeability is of great influence on the flow rate. This paper describes how a realistic vertical permeability has been determined and the effect on the production of geothermal energy.

In the literature several equations for calculating the productivity of horizontal wells are mentioned (i.e. Badu and Odeh, 1989; Joshi, 1991; Giger, 1984; Renard and Dupuy, 1990). In general these equations require two important input parameters; (i) a geometric factor that accounts for the effect of vertical anisotropy (ratio between horizontal and vertical permeability), well location and the relative dimensions of the drainage volume and (ii) the skin caused by the restricted entry. The latter accounts for the effect of the well length. Besides well length also the vertical permeability has a significant influence on production rate. It is therefore important to determine the vertical permeability of the reservoir as close as possible.

Vertical anisotropy

Core data of the Lower Volpriehausen Sandstone in the area of Erica has been analysed to predict the vertical anisotropy (K_H/K_V). Figure 1 (left hand side) shows the wells which have been used for the approximation of the vertical anisotropy.

To obtain an indication of the vertical anisotropy the data has been plotted and a regression line has been applied resulting in a most common vertical anisotropy of around 2 (Figure 1, right hand side). This means that the vertical permeability is about half the horizontal permeability. The analysis has been performed for three cases; (i) the Lower Volpriehausen Sandstone Member, (ii) both the Lower and the Upper Volpriehausen Sandstone members and (iii) the Upper Volpriehausen Sandstone Member. The results show comparable values for the most common vertical anisotropy. However, the data points are widely spread round the regression line, which indicates that the vertical anisotropy has a large variation. Therefore a probability density curve has been made. The curve in figure 2 shows that the chance is 90% that the vertical anisotropy is less than 20.

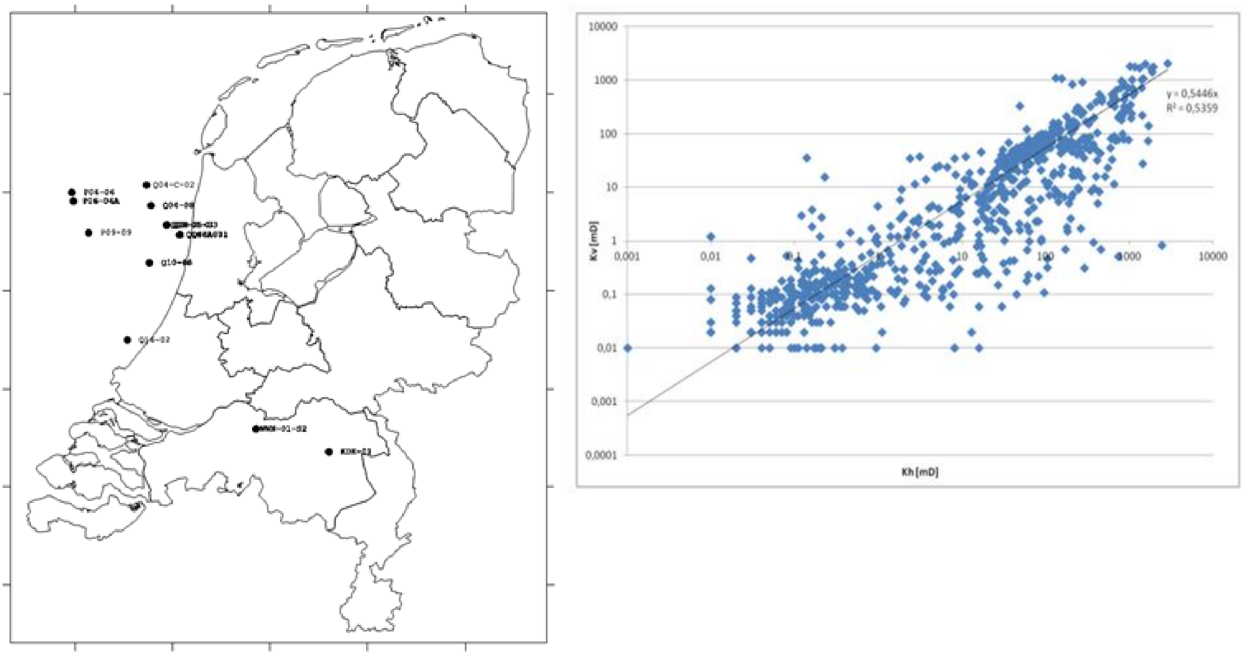

Figure 1*: Overview of used wells with core data (left), Measured core data and regression line (right). Horizontal axis gives the horizontal permeability in [mD];Vertical axis gives the vertical permeability in [mD].*

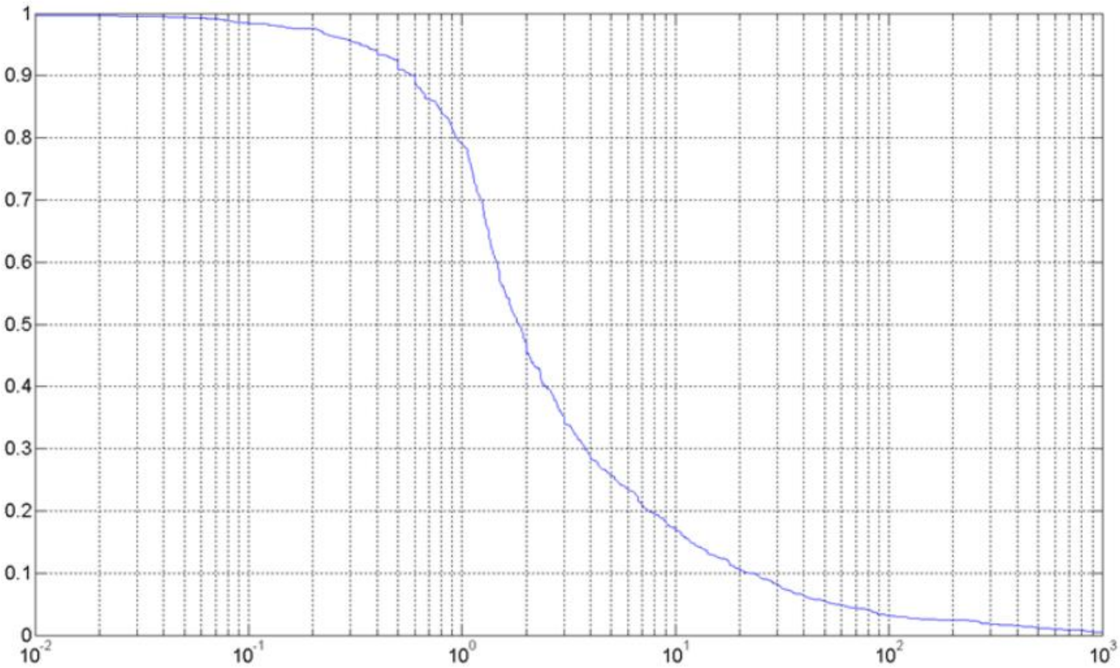

Figure 2: *Data plot vertical anisotropy / probability density function. Horizontal axis gives the vertical anisotropy; Vertical axis gives the probability.*

As the vertical anisotropy strongly depends on the observed scale, using core data for determining the vertical anisotropy leaves us with a scaling problem. This is mainly due to the presence of flow resistance barriers within a reservoir. These barriers are formed by grain orientation, difference in permeability per layer and sedimentary structures. There are methods to take these factors into account and scale-up the measured vertical anisotropy (i.e. Begg et al, 1985a; Begg and King, 1985b; Elliott, 1994). For this study the method of Begg et al.(19985a) has been used. Part of the required data for applying this method can directly be derived from well log data and core measurements. Other data require assumptions which are based on literature and typical values for the type of deposition. The used method is principally derived for the situation in which intersections of clay layers are present. The consequence of this is that all disturbances in the reservoir are considered to be impermeable. This may lead to an overestimation of the vertical anisotropy when instead of clay layers more sandy flow barriers are present.

Wells in the surrounding of Erica show that there are no clay layers continuously present within the Lower Volpriehausen Sandstone. Log evaluations show that the net/gross ratio is high. Both observations are consistent with an aeolian deposition. The typical structure size within an aeolian deposition ranges from 10m to a maximum of 100m . The size has therefore been varied between 0, 10 and 100m. The vertical anisotropy of the plugs has been varied between 0.2, 1.8 and 168. Figure 3 shows the probability density function of the scaled vertical anisotropy. The plot shows that the expected vertical anisotropy for the Erica case is 5.7.

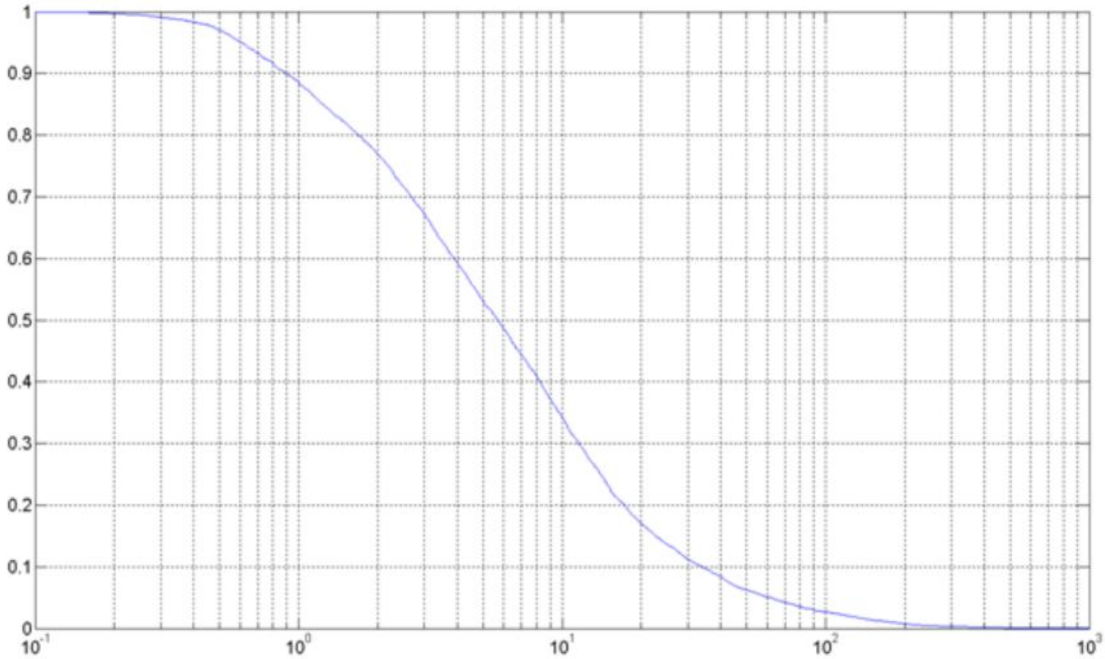

Figure 3: *Probability density function of scaled vertical anisotropy. Horizontal axis gives the vertical anisotropy; Vertical axis gives the probability.*

Productivity Improvement Factor (PIF)

The thermal capacity for geothermal projects are generally given in a standard uncertainty range; p90, p50 and p10. The p90 is the capacity that will be exceeded with 90% certainty, the p50 is the expected capacity and the p10 is the capacity that will be exceeded with 10% certainty.

According to literature, there are several methods to calculate the PIF (productivity improvement factor) of a horizontal well compared to a vertical well. To calculate the PIF for Erica, the equation for a pseudo steady state flow situation of Babu and Odeh (1989) has been applied. The PIF depends on the vertical anisotropy and the case for which it is being calculated. The higher the vertical anisotropy, the lower the PIF. The p90 case results in a higher PIF than the p10 case.

For the calculation of the geothermal capacity and its distribution, generally DoubletCalc is used (Mijnlieff et al, 2014). However, this program is unable to calculate the flow rate for horizontal wells. To enable the use of DoubletCalc, the PIF can be translated to a negative skin. To determine the skin the following steps have been taken:

- Calculation of the pressure drop using a vertical well in the expected situation.
- Increase of the flow rate by applying the calculated improvement factor.
- Adaptation of the skin until the pressure drop coincides with the initial pressure drop.

The results of this analysis show that the vertical anisotropy depends strongly on the dimensions of sedimentary structures. As the vertical anisotropy is an important input parameter in the flow rate calculations for a horizontal well, it is recommended to take its uncertainty into account. For the Erica project a Matlab program has been written which, contrary to DoubletCalc, also accounts for the uncertainty of the vertical anisotropy. A Monte-Carlo analysis is part of the program to obtain correct percentiles for the geothermal capacity.

Conclusions

The estimation of the geothermal capacity of horizontal geothermal wells depends strongly on the vertical anisotropy. As such, the vertical anisotropy should not be merely assumed but estimated by the method described above. The most likely vertical anisotropy for the Lower Volpriehausen Sandstone Member at Erica is 5.7. To obtain correct estimations of the thermal capacity and its uncertainty from a horizontal well, the range of vertical anisotropy should be taken into account within the Monte-Carlo analysis. In the case of Erica, a horizontal well in this reservoir has an expected PIF of 3.6 compared to a vertical well.

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