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The impact of reduction of doublet well spacing on the Net Present Value and the life time of fluvial Hot Sedimentary Aquifer doublets

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ABSTRACT

This paper evaluates the impact of reduction of doublet well spacing, below the current West Netherlands Basin standard of 1000–1500 m, on the Net Present Value (NPV) and the life time of fluvial Hot Sedimentary Aquifer (HSA) doublets. First, a sensitivity analysis is used to show the possible advantage of such reduction on the NPV. The parameter value ranges are derived from West Netherlands Basin HSA doublet examples. The results indicate that a reduction of well spacing from 1400 to 1000 m could already improve NPV by up to 15%. This effect would be larger in more marginally economic HSA doublets compared to the West Netherlands Basin base case scenario. The possibility to reduce well spacing is supported by finite element production simulations, utilizing detailed facies architecture models. Furthermore, our results underline the necessity of detailed facies architecture models to assess the potential and risks of HSA doublets. This factor significantly affects doublet life time and net energy production of the doublet.

1. Introduction

Large potential resources of heat are stored in sedimentary rocks. In the Netherlands alone, the Dutch geological survey estimated the total recoverable heat from this type of resource to be approximately 55 times larger than the annual heat consumption (Kramers et al., 2012; CBS). Hot Sedimentary Aquifers (HSA) are especially suitable for 'direct use' or heat production, because they are often found in areas with average thermal gradient (Boxem et al., 2011; Pluymaekers et al., 2012). In these areas temperatures for commercial electricity production (e.g., Shengjun et al., 2011) are found at depths where pore space is generally diminished. However, heating accounts for half of the total energy consumption in, for example, the European Union (European Commission, 2016). Therefore, HSA should be considered as important energy resources. Unfortunately, a large gap currently exists between HSA potential and exploitation. This gap is a result of a combination of high initial investment costs and large uncertainties in both doublet life time and capacity. The height of the initial investment is mainly influenced by a combination of high drilling costs and the replacement of existing fossil fuel based heating networks. These two factors decrease the competitiveness of HSA exploitation with other energy sources and thereby limit its growth. In the Netherlands, for example, two new geothermal projects are realised in HSA each year, while more than 100 exploration licences have been granted since 2007. A reduction of the initial investment costs would reduce the risks for developers and hence stimulate the growth of HSA exploitation. In this paper, we evaluate the effect of well spacing reduction on the Net Present Value (NPV) of a HSA doublet. Also, we discuss the effect such a reduction would have on the life time of a doublet. The current well spacing standard in the West Netherlands Basin (WNB) and Paris Basin (Mijnlieff and Van Wees, 2009; Lopez et al., 2010; Mottaghy et al., 2011; Daniilidis et al., 2016), is 1000–1500 m. Partially, the large distance is used to prevent early cold water breakthrough. Overdesign, however, could lead to unnecessarily long thermal breakthrough time. For example, no thermal breakthrough has yet been reported in the past 40 years of exploitation in the Paris Basin. A well spacing reduction could still result in sufficient life time, while improving the financial situation of a doublet in two ways. First, it may reduce the drilling costs by making the overall well length shorter, at least for the current standard doublet layout with two deviated wells from the same surface location. Second, it could reduce the required pump energy due to shorter flow paths between the wells. Another advantage is the decrease of chance on geological flow baffles between the wells, such as sealed sub-seismic faults (e.g.,

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Bailey et al., 2002) or poor sandstone body connectivity (Larue and Hovadik, 2006; Pranter and Sommer, 2011). Finally, more doublets could be realised in the same aquifer which increases the amount of produced geothermal heat (Mijnlieff and Van Wees, 2009). The number of studies on optimisation of geothermal systems is limited and often focus on maximizing energy production (e.g., Sauty et al., 1980; Ekneligoda and Min, 2014; Adams, 2015). Both the possible financial advantage of well spacing reduction and its impact on doublet life time is evaluated in this paper. In the first part, the effect of a variation in well spacing on the Net Present Value (NPV) for a typical WNB doublet is determined. This is derived from a sensitivity analysis in which both production and financial parameters are varied. Parameter ranges are derived from a West Netherlands Basin case study. The analysis is based on finite-element production simulations in ho permeable and impermeable facies bodies in the aquifer could significantly affect doublet life time and capacity (e.g., Pranter et al., 2007; Hamm and Lopez, 2012; Poulsen et al., 2015; Crooijmans et al., 2016). Homogeneous aquifer models do not capture this uncertainty. In our study, detailed fluvial facies architecture realisations are generated utilizing a process-based facies modelling approach (Cojan et al., 2004; Grappe et al., 2012; Hamm and Lopez, 2012) based on a WNB geological dataset. Minimum well spacing is analysed in terms of life time and NPV. The results of this study could be used as an incentive for re-evaluation of HSA well spacing standards. Utilizing detailed facies architecture models, more profound estimates of doublet life time and capacity can be made. This should prevent overdesign and thereby improve the competitiveness of HSA exploitation.

2. Data and aquifer modelling

The aquifer models in this paper were based on a geological dataset of the fluvial Lower Cretaceous Nieuwerkerk Formation in the West Netherlands Basin (DeVault and Jeremiah, 2002; Jeremiah et al., 2010; Donselaar et al., 2015). This dataset was chosen, because most of the approximately 40 exploration licences target this HSA interval in the WNB. Parameter values, which were used in aquifer modelling and production simulations, were derived from this dataset. Furthermore, production rates and reinjection temperatures were derived from WNB doublet examples. By using this dataset a realistic range of heterogeneities was derived to constraint the set of facies realisations. Two types of aquifer models were created: (1) detailed facies architecture realisations and (2) homogeneous models. The first type of realisations were generated with a process-based approach. The following sections describe the geological data and the modelling approach.

2.1. Geological dataset

A subsurface dataset of the fluvial Nieuwerkerk Formation in the WNB formed the basis for the geological modelling in this study. The same dataset and modelling approach as described in Crooijmans et al. (2016) and Willems et al. (2017) was used. The dataset comprised of cores and Gamma-ray (GR) logs of geothermal wells In the WNB. The core study provided thickness ranges of facies bodies which were used as input parameters to generate process-based facies realisations. In approximately 75 m of core in MKP-11 and 25 m in Q13-09, five different types of facies bodies were recognized: floodplain fines, crevasse splays, single-storey channel bodies and amalgamated sandstone complexes. The maximum fining upward sequence that was recognized in the cores was 4 m (Fig. 1). Therefore it was assumed that the paleo bank-full flow depth of the fluvial system that formed the Nieuwerkerk Formation was 4 m. Based on flow depth, the paleo bank-full flow width was estimated at 40 m (Williams, 1986) (Fig. 1). Furthermore, cores provided porosity-permeability relations for the aquifer property modelling. The gamma ray logs were used to derive N/G ranges of the Nieuwerkerk Formation. GR logs in the WNB showed that the Nieuwerkerk Formation significantly varies in thickness and N/G. The thickness varies from 50 to almost 200 m and the N/G the approximately 15–70% in different sections of the aquifer (Fig. 1).

2.2. Process-based detailed facies architecture realisations

To generate the detailed facies architecture realisations, a similar approach as in Crooijmans et al. (2016) and Willems et al. (2017) was used. Input parameters for the process-based facies modelling (Fig. 2) were (1) channel width and depth, (2) maximum overbank flood deposit thickness (H_{th}), (3) avulsion frequency, (4) flood frequency, and (5) floodplain topography parameter (henceforth: FT-parameter) (Fig. 2). In fluvial systems, the thickness of floodplain deposit decreases away from the channel. The distance at which the thickness decreased exponentially is the FT-parameter (Fig. 2). A high FT-parameter means that the flood deposit is wide and thick, which increases the sediment aggradation rate and decreases the N/G of the realisation. The paleo bank-full flow depth was derived from the core analysis and analogues, respectively. As it was not straightforward derive values of the other parameter from cores such as the flood plain deposit thickness (e.g., Bridge, 2006), values ranges were assumed to capture the uncertainty of the parameter values and to obtain realisations that range in N/G. Flood frequency, maximum flood deposit thickness (H_{th}) and the FT factor were the primary controls on N/G. To obtain realisations with a wide range of N/G values between 15 and 70%, overbank flood frequency was varied between 20 and 120 years, H_{th} between 0.2 and 0.6 m and the FT-factor between 300 and 600 m. Avulsion frequency is varied from 600 to 1600 years (Törnqvist and Bridge, 2002). During every simulated fluvial flood, sediments were deposited on the floodplain with a maximum thickness H_{th} near the channel (Fig. 2). In the simulations, sedimentary processes distribute and shape different facies bodies such as channel lags, point-bars, crevasse splays, mud plugs and floodplain fines. Realisations have dimensions of 1 km × 2 km × 50 m and the paleo flow direction is parallel to the long edge of the realisations. The process-based Flumy software method was explained in more detail in Cojan et al. (2004), Grappe et al. (2012) and Lopez et al. (2009).

2.3. Heterogeneous aquifer models

Facies grid blocks in the realisations were divided into two classes, aquifer and non-aquifer. The non-aquifer class included fine grained facies such as crevasse splays, overbank alluvium and mud plugs. These bodies were all assumed to be relatively impermeable. Their assumed permeability was 5 mD and porosity 10%. Sandy facies bodies such as point-bars and channel lags were all assumed to be aquifer grid blocks. Porosity values were assigned to these blocks based on the core plug porosity data. From this data, a beta distribution correlation function was derived. The distribution characteristics including: mean, standard deviation, skew and kurtosis were equal to 0.28, 0.075, 0.35 and 2.3, respectively. Secondly, the permeability of each grid block was determined by a porosity-permeability relation obtained from petrophysical data of well MKP-11 (TNO, 1977): $k = 0.0633e^{29.5}\phi$. In this equation, k is the permeability [mD] and ϕ is the porosity [–].

2.4. Homogeneous aquifer models

For the NPV sensitivity analysis, homogeneous aquifer models were created based on the same geological dataset. These models had an average porosity of 28% and permeability between 250 and 2000 mD. This permeability range was derived from WNB HSA well