Geothermics 64 (2016) 300–313

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Assessment of complex well architecture performance for geothermal exploitation of the Paris basin: A modeling and economic analysis

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ARTICLE INFO

Article history:
Received 5 November 2015
Received in revised form 3 June 2016
Accepted 13 June 2016

Keywords:
Paris basin
Geothermal well architectures
Doublet performance
Modeling analysis
Cost performance analysis

ABSTRACT

The deep geothermal resource of the center of the Paris basin (Ile-de-France region, France) has been exploited since the mid-1980s, the main target being the Dogger aquifer (1500–2000 m deep, 55–80 °C). Currently, the Triassic sandstone units below the Dogger aquifer are envisaged as new targets. This paper presents a modeling and economic analysis used to assess new well architectures (sub-horizontal, horizontal or multilateral wells) in comparison with standard geothermal operation, with a view to increasing doublet hydraulic performance. The reservoir modeling covers the Dogger carbonate aquifer, which can be described by a relatively homogeneous permeability distribution, and the Trias fluviatile sandstones, with higher temperature but lower permeability and far more heterogeneous petrophysical properties. The results of the modeling analysis are expressed in terms of a doublet performance index (DPI, in $m^3/(h\,bar)$), which is the average between the productivity and injectivity indices. Economic analysis results are given in terms of a doublet cost-performance index (CPI, in k€/year/DPI). The results suggest that both DPI and CPI are better for complex well architectures compared to standard deviated wells. Moreover, better doublet performances are achieved in the Dogger reservoir for which DPI is 4–5.5 times that of the Trias reservoir, depending on well architecture. The extra costs of complex well architectures compared to the cost of standard wells are largely offset by the relative benefits of increasing doublet hydraulic performance. The economic analysis also demonstrates that the cost of any additional unit of DPI in the Trias reservoir is 5–7 times that of the same unit in the Dogger reservoir. However, improvements in drilling technologies and further experience from new operations will lead to substantial cost reductions in the future.

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1. Introduction

1.1. Geothermal exploitation in the Paris basin: background and current challenges

In France, development of the exploitation of deep aquifers for extraction of geothermal heat dates back to the early 1980s, in the aftermath of the second oil crisis. At that time, two main sedimentary basins were targeted, in the Aquitaine and Paris regions (Fig. 1). In the Paris basin, geothermal exploitation to supply district heating networks was particularly successful as a result of the conjunction of three factors: (i) a huge demand for heat, due to high population density; (ii) incentive-raising governmental policies and subsidies for renewable energies; (iii) the presence of a hot limestone aquifer, known as the Dogger aquifer, exploitable because of its geological age and its favorable transmissivities, which usually exceed 10 Darcy m at depths of more than 1500 m. High levels of salinity in the Dogger brines preclude their surface disposal and this has led to use of the doublet with pairs of production and reinjection wells as the standard exploitation technique. Initial technical difficulties – mainly well corrosion, scaling problems arising from high dissolved sulfide concentrations in the production brine, and bacteria proliferation (Fouillac et al., 1990; Lopez et al., 2010; Hamm et al., 2011, 2012) – were overcome in the early 1990s when protection treatments (corrosion inhibitors) were developed. Since then, 36 active doublets have been providing heat daily to the equivalent of 180,000 dwellings.

Reinjection of cooled brine into the aquifer led to gradual depletion of the resource at the doublet level, calling into question the validity of doublet lifetimes and sustainable exploitation of the resource. Most of the existing work has therefore focused on quantifying the evolution over time of the “cold plume” around injections wells, and on predicting operational lifetime and the onset of “thermal breakthrough”. After many years without new

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http://dx.doi.org/10.1016/j.geothermics.2016.06.008
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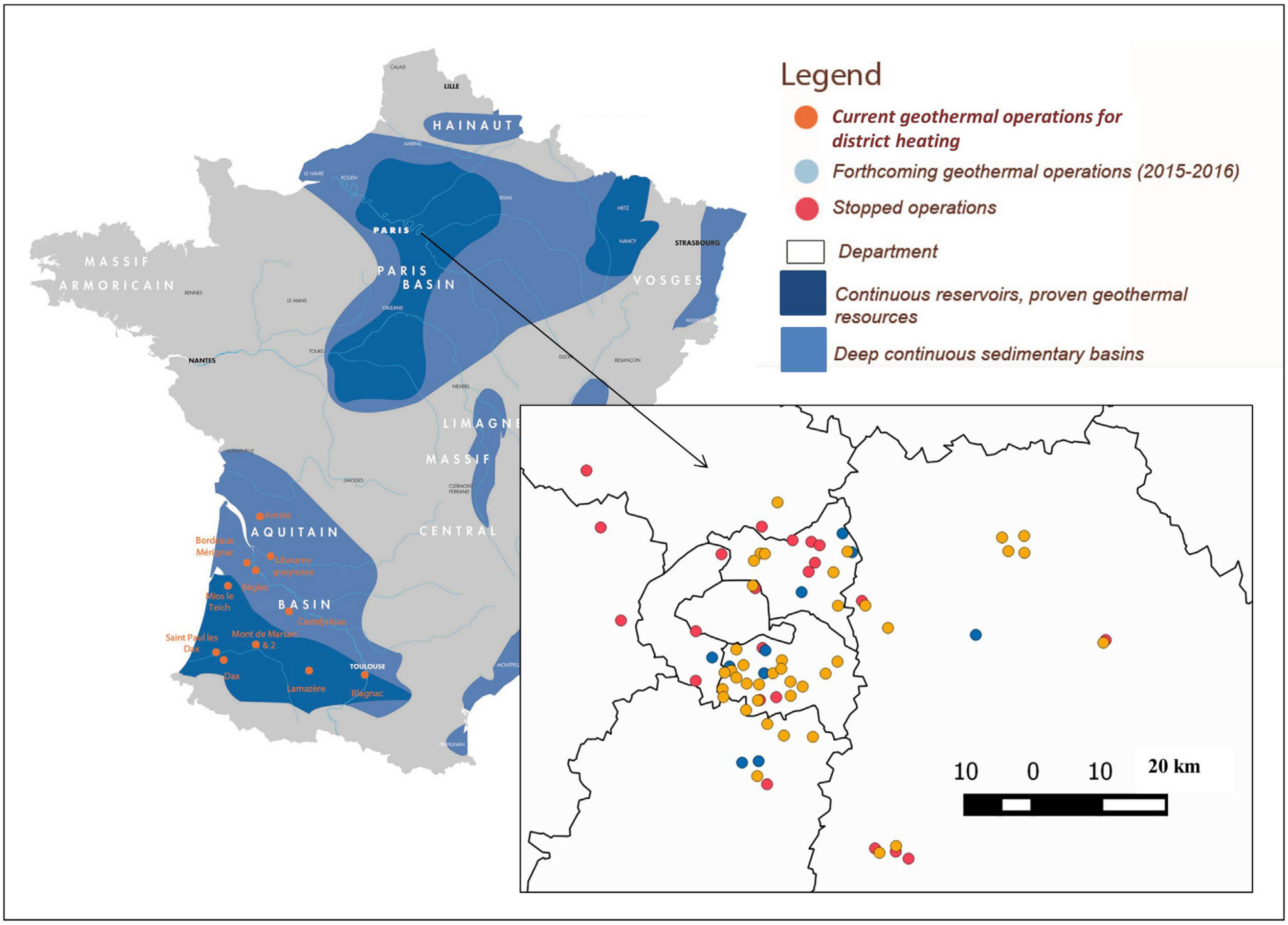

Fig. 1. The two main sedimentary basins exploited for district heating networks and localization of deep geothermal operations (zoom in Ile-de-France).

drilling, there has been a renewal of geothermal exploitation of the Dogger aquifer in Ile-de-France since 2007: 30 new wells have been drilled and many new or rehabilitation projects are currently under consideration. In this new context, challenges are emerging such as conflicts over the resource in densely exploited areas, as in the south-east of Paris (Hamm, 2014). Alternatives may be to: (i) continue harnessing the Dogger aquifer but with much more efficient geothermal wells (i.e. produce more heat with fewer wells); (ii) exploit deeper aquifers, which are expected to be hotter.

1.2. Triassic aquifers as new targets

The Triassic sandstone units underlying the Dogger aquifer have good reservoir properties and may constitute attractive geothermal targets for district heating. Attempts at their geothermal exploitation were made in the early 1980s (Boisdet et al., 1989; Lopez and Millot, 2008) but these proved unsuccessful: the deep layers proved hotter but less productive than the overlying Dogger aquifer. Out of the three projects targeting this formation, only one – the Melleray facility located in the south-western part of the sedimentary basin – was commissioned; it ran for no more than a year in the face of injection related problems.

However, deep Triassic aquifers in the Paris basin – at depths of between 2000 and 2500 m and with temperatures up to 120 °C in some areas – are now considered a possible target for power production and heat cogeneration. The main difficulties to be overcome in exploitation of the Triassic aquifer relate to the nature of the aquifer, which consists of fluvial deposits with permeable sand bodies that are relatively narrow and disconnected. Its properties (i.e. porosity and permeability) are thus more heterogeneous and discontinuous than those of the Dogger limestone aquifer. Permeability can vary by a factor of over one thousand between sandy facies and more impervious ones (Eschard et al., 1998). Recent work has allowed better characterizing of the Triassic geothermal reservoirs of the Paris basin (Bouchot et al., 2012) and of the impact of fluvial sedimentary heterogeneities on a geothermal doublet (Hamm and Lopez, 2012). Nevertheless, if exploitation failure is to be avoided, further investigations are required before drilling of new wells in the Triassic aquifer.

1.3. An overview of deep well architectures and their applications in the Paris basin

The majority of the geothermal wells in the Dogger aquifer were drilled between 1980 and 1986 (112 wells) using the “doublet technology” with either one vertical well and one deviated well or two deviated wells, depending on the context (Lopez et al., 2010). Around the same time (between 1950 and 2000), more than 800 wells were drilled in the basin for oil exploitation. These, primarily, targeted two reservoirs: the middle Jurassic (Dogger) limestone and the upper Trias fluviatile sandstones (Delmas et al., 2002). During that period, new exploitation techniques appeared, mainly in the oil or gas extraction industry, either enhancing reservoir contact and drainage surface or reducing near-wellbore velocity and thereby improving well productivity and/or injectivity. The drilling technologies for complex well architecture rely on advanced techniques such as Measurements While Drilling (MWD), Logging While Drilling (LWD) and geo-steering techniques (MIT, 2006).

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