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Combined use of geothermal energy and oil or gas production

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ABSTRACT

Investigation of the combined systems is essential for enhancing production and sustainable energy recovery from deep geological formations. Two synergy solutions for oil and gas development projects by the utilization of geothermal energy in the Netherlands are considered here to improve energy recovery from the subsurface: I) In the Moerkapelle viscous oil field we studied the synergy potential between the production of oil and geothermal energy by utilization of hot geothermal fluids for enhanced recovery of the heavy oil. II) In the low-pressure Oude Leede gas field the synergy potential under study was for marginally economic natural gas production from gas fields within the proximity of a geothermal doublet project. The study focus is the development of strategies for injecting cooled geothermal water for water flooding as a viable alternative to compression of the low-pressure gas reservoir. We investigated these strategies for various conditions. We found that: a) for the first synergy case, the extra amount of oil produced by utilizing the geothermal energy could make the geothermal business case independent of subsidies and may be a viable option to reduce the overall project cost, b) and for the second case under certain conditions produced water from geothermal reservoir can be partially utilized for water injection in the gas field to maintain the gas reservoir pressure above the abandonment pressure, or slow down the pressure depletion. Injecting water could also increase the ultimate recovery factor for higher abandonment pressure in a gas field. Here we give an overview about our work.

1. INTRODUCTION

Production of oil and gas in the Netherlands is in a mature stage. Many hydrocarbon fields reach their end-of-field-life when production from such fields is no longer commercially or technically feasible, or the fields were previously abandoned when - after drilling of exploration wells - field development is non-profitable (so-called stranded fields). Production decrease coincides with an increased interest in geothermal energy production as an alternative source of energy in the Netherlands. Deep geothermal projects target the same reservoir space as the oil and gas industry, with aquifers between 1500 and 4000 meters depth and a temperature range from 50°C to 120°C. To date, a limited number of deep geothermal projects are operational in the Netherlands (Willems and Nick, 2019). More geothermal resources can be exploited by combining geothermal field developments with other energy harvesting projects from the subsurface.

The aim of the present study is to demonstrate that geothermal energy production can be more profitable once it is combined with oil and gas production, for example, from stranded fields. Focus of the study is on the synergy potential of thermally-enhanced oil recovery, and the coproduction of oil/gas and geothermal energy. In addition to the economic effects, the synergy potential may contribute an innovative low carbon-emission technology. In this study the following key questions are addressed:

- What are the relevant geological features and flow processes that need to be included in studying coproduction of oil/gas and geothermal energy?
- Are the reservoir conditions of the selected stranded fields suitable for synergetic exploitation?
- What are the minimum conditions that need to be met in order to find synergy for oil, gas and geothermal energy recovery?
- How can we optimize production? What recovery techniques and strategies should be used?
- How significant is the recovery improvement by utilizing geothermal energy for enhancing energy recovery in a given field?

2. METHODOLOGY

Many fields in the Netherlands are either abandoned or are not developed due to being non-profitable, e.g., Oude Leede, Moerkapelle, Nieuweschans, and Kerkwijk (EBN, 2013). It is possible to find cost-effective solutions by integrating geothermal energy with oil and gas productions. Depending on the geological setting and the operational strategies, some of the stranded wells if not all can be reconsidered for energy production. We examined how stranded fields can be reconsidered for production through finding synergy between the hydrocarbon and geothermal energy production.

Two synergy types are considered:

I) Utilizing geothermal hot fluid for enhanced oil recovery of heavy oil provides a feasible synergy between oil and geothermal energy production. Hot-water flooding, known as thermal oil recovery, is one method of heating the reservoir to decrease the oil viscosity and thus improve the displacement efficiency compared to that achievable from conventional water flooding schemes. This would also help to reduce the amount of water that needs to be re-injected into the geothermal reservoir. The Moerkapelle oil field is considered for this type of synergy since a geothermal reservoir with a temperature above 100 ^{o}C can be developed under the oil field (Figure 1). We examined different thermal enhanced recovery strategies by utilizing the developed reservoir model for the selected field. For this task, a non-isothermal multiphase flow modeling is utilized to handle the combined heat and multiphase flow and transport.

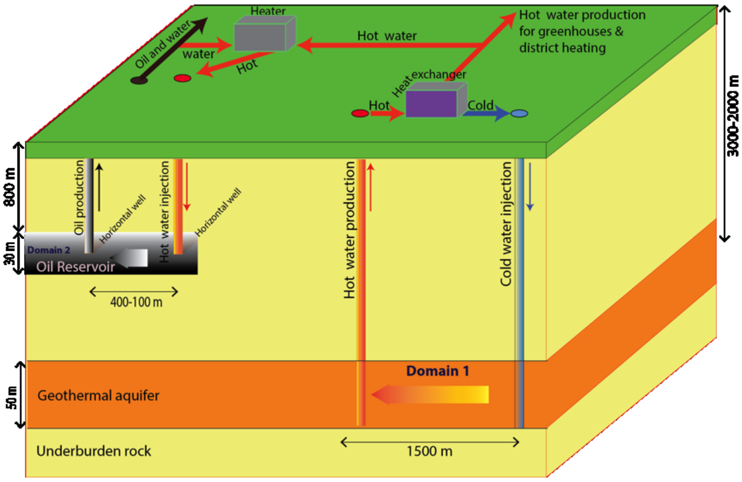

Figure 1: Schematic of the conceptual model for Moerkapelle oil field for integration of geothermal energy production and enhanced oil recovery.

II) This synergy type can be considered for marginally economic natural gas production from gas fields in the proximity of a geothermal doublet project. Injection of the cooled geothermal water for water flooding of low-pressure gas reservoirs is a viable alternative to compression (Figure 2). One major impediments for geothermal energy development is the risk of a low injectivity. Therefore, injection of cooled geothermal fluid into nearby gas fields would be a major additional economic incentive. The amount of water that can be injected would be high because of the high gas compressibility. Oude Leede field is an excellent choice for this synergy type as a nearby geothermal system composed of a doublet is planned on the campus of the TU Delft (Vardon et al., 2020). To this end, two-phase flow and heat transport simulations were conducted utilizing the upscaled geological model. This allows for the assessment of the relative contribution of reservoir geology, well placement, reservoir conditions, and options for production scenarios in the overall performance of the site selected for the demonstration cases. Finally, strategies to maximize the energy production from such fields were identified.

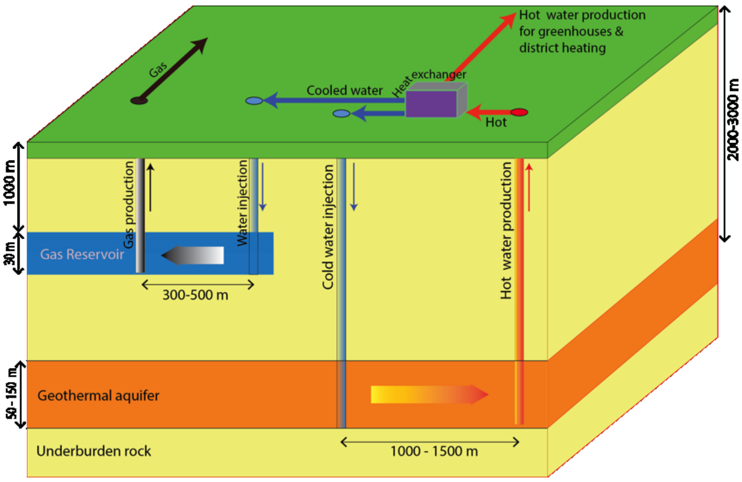

Figure 2: The conceptual model for integration of geothermal energy with gas production in the Oude Leede gas field in the Netherlands by disposing part or all of the cooled geothermal water into the gas field to improve gas production and reduce the cost of injection of the cooled geothermal water.

2. SYNERGY TYPE I: VERTICAL WELLS

A single phase non-isothermal fluid flow model for a geothermal doublet system and a two-phase non-isothermal fluid flow conceptual model for water flooding were employed to study the feasibility of the synergy potential of thermally-enhanced oil recovery, and geothermal energy production. Different simulations were considered to cover a large range of initial and operational conditions. The simulation results suggest that total oil production strongly depends on the shape of the heat plume which can be affected by porosity, permeability, injection temperature, well spacing, and injection rate in the oil reservoir. The positive conditions for oil recovery were found to be: high injection rate, high injection temperature, high porosity, and low oil reservoir permeability respectively. Not surprisingly, the wellbore spacing plays an important role in oil recovery, and optimum wellbore spacing can be established. Ziabakhsh-Ganji et al., (2018) illustrated that, after 20 years of continuous hot water injection, about 7% of the energy extracted from a geothermal doublet can be consumed to gain an additional 10% oil recovery. The low consumption of geothermal energy can be attributed to the relatively fast breakthrough of hot water in an oil production well that can be reused for waterflooding. We also examined heterogeneous oil reservoirs for this synergy type. We found, irrespective of the degree of reservoir heterogeneity, better performance of displacing heavy oil by the geothermal fluid compared to the conventional waterflooding (Ziabakhsh-Ganji et al., 2016). Based on the numerical simulation results, it indicates that the extra amount of oil produced by using the geothermal energy could make the geothermal business case independent. This can be a practical solution to reduce the overall project cost and subsequently reduce the required subsidy for a single doublet geothermal project up to 50% (Ziabakhsh-Ganji et al., 2018).

3. SYNERGY TYPE I: HORIZONTAL WELLS

Another scenario considered for synergy type I was replacing the vertical wells with horizontal wells in the oil reservoirs. Here, we focused on whether or not the synergy between thermal enhanced oil recovery and geothermal energy production is a viable solution in the fluvial sedimentary system of the West Netherlands Basin. A series of heterogeneous porosity and permeability fields utilizing a process based facies modeling (e.g. Crooijmans et al., 2016; Willems et al., 2017) were generated for the dynamic simulations. The simulation results suggest that the geological heterogeneity considerably impacts the enhanced oil recovery from a heavy oil reservoir. The enhanced oil recovery was observed with a delay as the oil viscosity reduction mainly happens near the injector. Initially, no significant oil saturation alteration in the reservoir and near the producer was observed. As the hot temperature front moves gradually in the reservoir oil viscosity was reduced which then leads to increased production rates at a later time. This highlights the controlling role of the well spacing for the efficiency and economics of the project. Long horizontal wellbore length and high value of the injection pressure are favorable for improving recovery in highly heterogeneous reservoirs. In contrast, increasing the wellbore distance and oil viscosity showed inverse effects on the thermal oil recovery in this study. Considering a heterogeneous field with two horizontal wells in the oil field, after 40 years of continuous hot water injection, less than 10% of the energy extracted from a geothermal doublet, with a discharge rate of 150 m^3/hr, is needed to improve the oil recovery by about 12%. The simulation results suggest that in a heterogeneous reservoir, the synergy between geothermal and stranded oil fields may compensate the required subsidy for a single doublet geothermal project, this can make the synergy project economically attractive.

4. SYNERGY TYPE II

A different strategy for integration of geothermal energy with gas production in the Oude Leede gas field in the Netherlands was considered: the injection of cooled geothermal water into the gas field located just a couple of kilometers from the geothermal reservoir in Delft. Similar to the previous synergy type, 3D numerical simulations which consider the gas trapping mechanism was utilized for this part. In this strategy water flooding in the gas field can compensate pressure loss by reducing the pore space but it may trigger gas trapping which is not favorable for the gas production. The impact of injection rate, permeability, initial saturation and reservoir pressure on the ultimate gas recovery and the residual trapped gas saturation were studied. As expected, we found that injecting water will increase the ultimate gas recovery factor for higher abandonment pressure, but higher water injection rates will keep the reservoir pressure up, resulting in increased trapped gas saturation. The exergy recovery factor of a gas compression process due to the large amounts of energy required for compression is higher than a water injection process. The net present value analysis indicated that water injection is economically preferable for a higher abandonment pressure but not feasible. In contrast, natural gas depletion performs better than the water injection scenario due to the higher costs of water injection and drilling in the gas reservoir with a lower abandonment pressure. Therefore, the abandonment pressure is a major factor in determining the recovery efficiency, and whether or not this synergy type is an attractive solution. In summary, water injection into a gas reservoir is technically promising but it may not be an economically viable solution for the studied field (Khoshnevis et al., 2019).

5. CONCLUSIONS AND FINAL REMARKS

This study dealt with different aspects of combining geothermal energy production and oil and gas production. Different numerical simulations and analyses including exergy and NPV calculations were considered in the entire work. We highlighted the minimum conditions that need to be met in order to find synergy for oil/gas and geothermal energy recovery.

While the project addressed the synergy potential of oil or gas with geothermal energy, it has to be borne in mind that the focus of the work presented here was the technical feasibility to recover oil and/or gas from stranded fields by using water flooding with either hot (for oil) or cold water. For the properties and recovery of the hydrocarbons investigated here, the source of the water was not relevant. The geothermal reservoirs assumed for our calculations were either hypothetical (for the Moerkapelle case) or not yet developed, such that performance availability can only be estimated. The primary focus for the geothermal development was not so much on the generation and provision of heat for greenhouses or residential buildings, but on the added economic value for the geothermal business case if the hydrocarbons can be produced as well as the heat.

To investigate the complete synergy potential, the performance data of the geothermal reservoir would need to be known, requiring a detailed geological model as well as the layout of the geothermal wells and the potential heat consumers. Similarly, for proper field development of the Moerkapelle field, better knowledge of the reservoir geometry and a detailed geological model is needed. In general, real data such as PVT, SCAL and the exact reservoir conditions need to be known. Before the realization of such projects is seriously considered, these points must be addressed by future studies.

ACKNOWLEDGEMENTS

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