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Synergy potential for oil and geothermal energy exploitation

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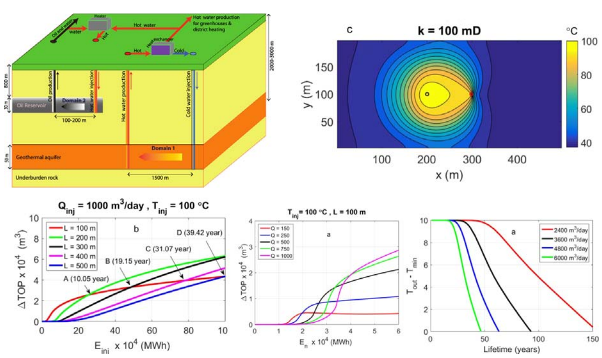
HIGHLIGHTS

- Detailed study on combining geothermal energy and thermally enhanced oil recovery.
- Combining these projects can reduce the required subsidy for geothermal projects.
- Wellbore spacing plays a key role in oil recovery and geothermal energy performance.
- Effectiveness of enhanced oil production strongly depends on the heat plume shape.

GRAPHICAL ABSTRACT



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ABSTRACT

A new solution for harvesting energy simultaneously from two different sources of energy by combining geothermal energy production and thermal enhanced heavy oil recovery is introduced. Numerical simulations are employed to evaluate the feasibility of generating energy from geothermal resources, both for thermally enhanced oil recovery from a heavy oil reservoir and for direct heating purposes. A single phase non-isothermal fluid flow modeling for geothermal doublet system and a two-phase non-isothermal fluid flow modelling for water flooding in an oil reservoir are utilised. Sensitivity and feasibility analyses of the synergy potential of thermally-enhanced oil recovery and geothermal energy production are performed. A series of simulations are carried out to examine the effects of reservoir properties on energy consumption and oil recovery for different injection rates and injection temperature. Our results show that total oil production strongly depends on the shape of heat plume which can be affected by porosity, permeability, injection temperature, well spacing and injection rate in the oil reservoir. The favourable oil recovery obtains at high amount of (a) injection rate, (b) injection temperature, (c) porosity and (d) low amount of oil reservoir permeability respectively. Furthermore, our study indicates the wellbore spacing plays an important role in oil recovery and an optimum wellbore spacing can be established. The analyses suggest that the extra amount of oil produced by utilising the geothermal energy could make the geothermal business case independent and may be a viable option to reduce the overall project cost. Furthermore, the results display that the enhance oil productions are able to reduce the required subsidy for a single doublet geothermal project up to 50%.

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Nomenclature

$\Delta\dot{E}_i$	annual thermal energy extracted
$\dot{m}_i$	mass production of hot water
c_p	specific heat
ΔT_i	temperature difference between the produced and injected
ρC	volumetric heat capacity
q'	external sinks and sources
T'	temperature at sources
P	pressure
$\boldsymbol{u}$	Darcy velocity vector
k	permeability
k_{ro}	oil relative permeability
k_{rw}	water relative permeability
S_{orw}	residual oil saturation
S_{wir}	initial water saturation
ΔTOP	total oil production variable (TOP for elevated Temperature injection – TOP for T_{inj} = 37 °C)
S	salinity of geothermal fluid
Q	injection rate in oil reservoir
L	distance between injection and production wells in oil reservoir domain
GWh	gigawatt hour
E_{inj}	energy injection in oil reservoir domain
E_n	net cumulative energy consumption in oil reservoir
Q_{inj}^{w}	water injection rate in oil reservoir domain
Q_{pro}^{w}	water production rate in oil reservoir domain
T_{init}	initial temperature in oil reservoir domain
T_{inj}	injection temperature in oil reservoir domain
T_{pro}	production temperature of oil reservoir
T_s	surface temperature
NPV	net present value
S_a	brine salinity (M)
MWh	megawatt hour
γ	dynamic viscosity
μ	viscosity
ρ	density
λ	thermal conductivity
ϕ	porosity

1. Introduction

In the Netherlands geothermal energy production from deep geological formations has a great potential as environmentally benign heat source, and its usage has been growing since the first well doublets were realised in 2007 [1]. The main geothermal targets are hot sedimentary aquifers at depths between 2 and 3 km with approximately a temperature of 70–100 °C (e.g., [2]). A doublet system consisting of a hot-water production and a cold-water reinjection well can be utilised to harvest energy from the hot sedimentary aquifers (e.g., [3]). Despite recent developments and a growing number of projects in the Netherlands, however, geothermal energy is not yet cost-competitive without subsidies.

Many of the geothermal reservoirs identified and currently used in the hot sedimentary aquifers of the Netherlands are in close proximity and often from the same reservoir rocks as the well-characterised hydrocarbon resources of the country. And even though these oil and gas reservoirs have been exploited successfully for many decades, not all of the known resources have been produced, some reservoirs have even been abandoned for various reasons. An example of an abandoned oil reservoir is the Moerkapelle field in the West Netherlands Basin, which contains highly viscous heavy oil at approximate 850 m depth. The viscosity of the oil was simply too high to be produced economically.

One way to produce heavy oil is by hot water or steam injection. While this method of enhanced oil recovery (EOR) is routinely applied all over the world it is not always energetically or economically viable. In the case of the Moerkapelle field, operations were stopped because the viscosity of the oil in the reservoir was so high and the reservoir is relatively small such that standard EOR approaches available at the time did not help to produce enough of the available oil. For this reason, the field was abandoned in1986.

In this paper, the synergy potential of a combined energy production from a geothermal reservoir and the heavy oil from the Moerkapelle field is investigated employing numerical simulations. The geothermal reservoir will provide the hot water for flooding of the oil reservoir as well as for the heating of greenhouses or other buildings nearby. The oil produced could make the overall project economically feasible: the hot water makes oil production possible and the co-produced oil could make the geothermal business case independent of subsidies. To perform such a study, both parameters that control the efficiency and productivity of a geothermal reservoir and those making heavy oil production feasible and profitable are examined.

Hot water flooding as a key method for thermal enhanced heavy oil recovery, is utilised routinely in the oil and gas industries [4]. Many authors [5–7] suggested that the most effective methods are steam flooding or hot water flooding resulting in an enhanced recovery factor of about 20–30%. Numerous laboratory experiments and numerical simulation studies have shown that the oil viscosity and mobility ratio can be reduced by hot water injection, resulting in ultimately resulting in improved oil recovery (e.g., [8–12]). Martin et al. [13], considering a case study of a hot water flood pilot test in the Loco field in southern Oklahoma which contains crude oil with 600 cp viscosity, showed the hot water flooding yield oil recovery increasing. In another case study, Cassinat et al. [14] showed hot water injection may significantly increase pool recoveries as much as 25% in the Senex oil field located in Northern Alberta, Canada, which contains a 12 cp (37° API) crude with high paraffin content. Yu [15] showed that when injecting cold water to displace oil, the injected cold water cools down the oil layer which increases the oil viscosity and changes the oil-water phase permeability. These changes result in an oil displacement efficiency reduction of 2–8%. Pederson and Sitorus [16], Wang and Wang [17], and Chen et al. [18] indicated that thermal water flooding is superior to conventional water flooding, and can improve oil recovery by 4–10%.

While in most cases the hot water for thermal water flooding is produced by burning fossil fuels, a geothermal reservoir could provide an economically and environmentally promising alternative to provide steam or hot water. Abandoned deep-hydrocarbon reservoirs and dry wells also have been considered as geothermal energy source [19]. Simulation studies of hot water injection in heavy oil reservoirs (and its effects on oil reservoir behaviour) and of geothermal doublet performances are individually well developed [3,20–27]. Investigations combining the geothermal energy sources and heavy oil reservoirs, however, are still limited.

To our knowledge, this option has only been tested once so far by Wys et al. [28], who conducted an economic feasibility study on recovering heavy oil using a geopressured geothermal resource in an oilfield of south Texas. The study showed that the breakeven price for oil is less than 14 dollars per barrel and for gas less than 2 dollars per thousand cubic feet and the payback is less than 2 years after injection [29]. They suggested that such an application is profitable for heavy oil recovery enhancement. However, they did not consider some controlling parameters such as wellbore distance, injection rate and injection temperature on the oil recovery.

In this study, the feasibility of generating energy from geothermal resources, both for EOR from a heavy oil reservoir and for heating purposes is addressed through a numerical study. The parameters of a