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Study of geothermal power generation from a very deep oil well with a wellbore heat exchanger

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ABSTRACT

The present study analyses the possibility to implement a WellBore Heat eXchanger (WBHX) on one of the largest European oil fields: the Villafortuna Trecate oilfield. The research is focused on the optimization of the WBHX to maximize the extracted heat. Hence, a numerical model of a WBHX has been setup. The simulations have considered the use of two different heat transfer fluids: water and diathermic oil. It was also tried different internal diameters of the pipes in order to optimize the geometrical configuration for the specific case study.

To assess the energy conversion by an ORC plant a model has been build. The goal was to evaluate the possible working fluid as well as validate the MIT correlation. The R-C318 has been selected and a good agreement between MIT correlation and the ORC plant model has been highlighted.

The simulations demonstrated the importance to consider the change of fluid properties inside the exchanger. With a water flowrate of 15 m^3/h the optimum condition is obtained; under such condition, the thermal power is 1.5 MW and the net electrical power is 134 kW for single well. The results lead also to conclude that the water is the best heat transfer fluid.

1. Introduction

One of the more complex technical issues in the geothermal plants is the re-injection of the fluids. The geothermal fluids have physicochemical properties not suitable to the terrestrial ecosystems. Therefore, they should be treated and re-injected underground. These operations entail high economic costs since they require the drilling and maintenance of additional wells, the treatment and the pumping of the fluids.

A possible alternative is the use of an indirect system to extract heat, the WellBore Heat eXchanger (WBHX). This kind of well completion allows to extract heat using an heat carrier fluid circulating in a closed loop. Thus, no geothermal fluids production take place and the environmental impact as well as the required energy for reinjection are strongly reduced. Corrosion and scaling problems are also avoided. Disadvantages could be envisaged in the reduction of the heat recovery efficiency.

From the current studies, the reliance of feasibility of the WBHX power plants by the flowrates and the thermal insulation has been demonstrated [19]. Other main parameters to be considered are the local geothermal gradient, the depth of the wells and the heat carrier fluid [6,10,13].

Several studies have presented numerical models to analyze the use of the WBHX concept either in existing geothermal wells [24] and in oil wells revamping [6,10,13,19,29,34].

The use of oil wells for the application of the WBHX is justified by the reduction of the abandonment costs of the oil fields and by the improvement of the economic feasibility of the geothermal plant since drilling costs are avoided (generally corresponding to the 50% of total costs of the project).

Starting from these considerations, this paper evaluate the implementation of the WBHX on one of the largest European oil fields: the Villafortuna Trecate oilfield, active since 1984 [3]. The reservoir has been identified between 5800 and 6100 m depth with a temperature of about 160–170 °C, so the asset can be classified as a medium enthalpy geothermal resource. The Villafortuna-Trecate field is still producing but it is strongly depleted. About 50 wells have been drilled and only 8 are in production.

In order to evaluate the possible application of the WBHX a numerical model was developed. The research has been focused on the optimization of the WBHX to maximize the extracted heat. The simulations have considered the use of two heat transfer fluids: water and diathermic oil, which has never been considered for this type of applications. It was also modified the internal diameter

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Nomenclature

Variable

A	cross-section [m^2]
c_p	specific heat capacity [J/kg K]
D	diameter [m]
h	convective heat transfer coefficient [W/m^2 K]
k_t	total heat transfer coefficient [W/m^2 K]
k_o	overall heat transfer coefficient [W/m^2 K]
R	linear thermal resistance coefficient [K m/W]
H	heat flux [W]
L	length [m]
N_u	Nusselt number
P_r	Prandtl number
Q	flowrate [m^3/s]
r	radius [m]
R_e	Reynolds number
t′	time [s]
T	temperature [C]
V	volume [m^3]
v	flow velocity of the fluid [m/s]
t	thickness of pipe
a_s	thermal diffusivity [m^2/s]
λ	thermal conductivity [W/m K]
λ_t	thermal conductivity of the material of the pipe [W/m K]
μ	dynamic viscosity [P_a s]
ν	kinematic viscosity [m^2/s]
ρ	density [kg/m^3]
η_x	efficiency of the ORC machine

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f	fluid property
s	rock property
w	wellbore radius
c	casing radius
o	outer radius (of pipe)
i	inner radius (of pipe)
r	radial component (in pipe)
t	total
up	upwards
down	downwards

Acronyms

WBHX	WellBore Heat eXchanger
HPHT	high pressure high temperature
ORC	Organic Ranking Cycle

of the pipes until you find the configuration that ensures greater efficiency in the extraction of heat.

Fig. 1 illustrates a schematic layout of the WBHX as well as a cross-section. The well bottom will be closed and a dual shell co-axial tube is inserted into the well too. The heat carrier fluid enters the wellbore heat exchanger in the annular space between the well casing and the external shell. During the downward flow, the fluid acquires heat from the surrounding ground. At the bottom end, the fluid is upward diverted and flows into the internal pipe up to wellhead. The gap between the two pipes is filled with insulating material in order to reduce the heat exchange between upward flow and downward flow.

The produced thermal energy can be used in district heating plants or can be converted into electricity using an Organic Ranking Cycle (ORC) plant (Fig. 2) as discussed in previous works [1]. Other researchers [6,10,13] have focused on a direct power generation system to convert the thermal energy into electricity. Instead the proposed system is a binary cycle plant: there are two steps of heat exchange: in the first step a working fluid is circulated in the double-pipe exchanger and it acquires heat from the rock; in the second step the working fluid exchanges the heat with the low-boiling point fluid of the ORC machine. In order to evaluate the conversion capacity of the ORC plant a thermodynamic model has been build. Having selected the working fluid, the produced electrical power has been compared to that one evaluated using the relationship, based on data from actual ORC plants, between thermal efficiency and fluid temperature [31].

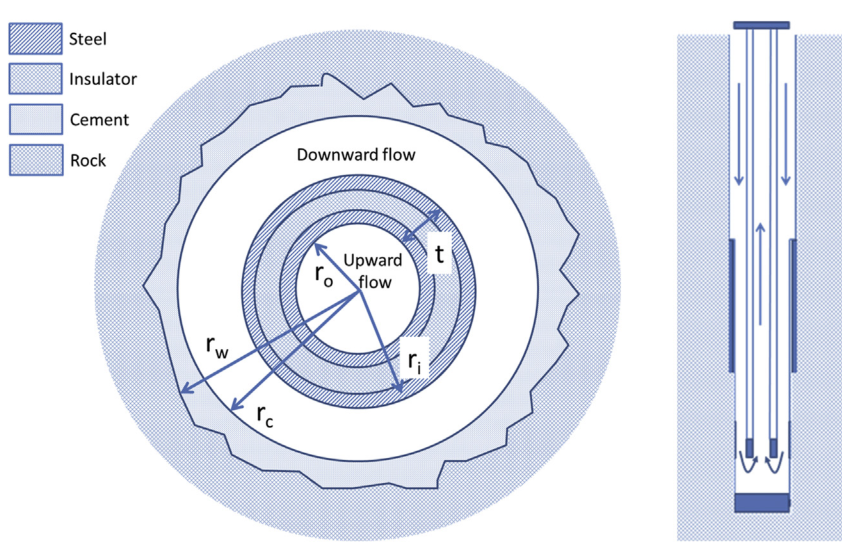

Fig. 1. Wellbore heat exchanger. Cross section and schematic.