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Research paper

Geothermal energy from abandoned oil and gas wells using water in combination with a closed wellbore

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HIGHLIGHTS

- We evaluate potential electricity generation using abandoned oil and gas wells.
- A method involving a closed wellbore and water as the working fluid is proposed.
- This method generates power in line with approaches using coproduced fluids.
- Flow rates up to 15 kg/s are shown using various wellbore depths.
- Net power figures of 109 kW–630 kW are obtained.

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ABSTRACT

Binary cycle power plants have been used successfully for electricity generation utilizing co-produced fluids from active onshore oil wells. Adapting this process for use on abandoned wells by circulating the binary working fluid down the wellbore has been previously proposed and a selection of fluids evaluated.

This work proposes and evaluates an approach using water as the wellbore fluid in combination with abandoned wells and a closed wellbore. The wellbore is therefore used as a heat exchanger. The aim is to enable electricity generation via a binary cycle plant while mitigating contamination risks associated with the circulation of conventional organic working fluids. Well log data for over 2500 wells in Texas are used to assess the use of wellbores in this way and for calculation of geothermal gradient and surface temperature. Wellbore heat transfer and wellbore thermal resistance are calculated.

With a geothermal gradient of 0.0311 °C/m, a fluid temperature of 130 °C is achieved using a wellbore depth of 4200 m and a mass flow rate of 2.5 kg/s. Flow rates up to 15 kg/s are shown using greater wellbore depth. Head loss and pumping requirements are calculated relative to wellbore depth with results finding maximum head loss and corresponding pump requirements remain small for the mass flow rates evaluated.

Net power figures of 109 kW–630 kW are obtained utilizing a binary cycle power plant with a multistage heat exchanger. The use of abandoned wells as a means of generating electricity with water as the wellbore circulating fluid, utilising a method with no reliance on naturally occurring geothermal fluid is shown, offering a potential use for a global resource that is as yet unused.

1. Background

The global energy sector faces increasing challenges in a world where energy demand continues to grow yet energy policy increasingly pursues a rebalance away from conventional fossil fuel based generation.

Renewable energy offers just one component in a set of tools that are increasingly being deployed in order to meet these challenges.

The International Energy Agency (IEA) 2014 World Energy Outlook suggests at least half of total growth in global generation should be met by renewable energy sources for the period leading to 2040 [1] though achieving this is not without difficulties. Current energy markets are not necessarily designed to suitably integrate renewable energy as part of a mix with fossil fuel generation while

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Nomenclature

A_p	cross sectional area of pipe (m^2)
a	relaxation distance (m)
C_p	heat capacity at constant pressure (m^2/s^2 °C)
d	pipe diameter (m)
g	gravitational constant (m/s^2)
g_e	geothermal gradient (°C/m)
H_{loss}	head loss (m)
h_i	specific enthalpy of fluid at inlet (m^2/s^2)
h_o	specific enthalpy of fluid at outlet (m^2/s^2)
$\dot{m}$	mass flow rate (kg/s)
P	power (kg m^2/s^3)
p	pressure (kg/m s^2)
T	temperature (°C)
T_{ei}	temperature of environment at inlet (°C)
T_{es}	temperature of environment at surface (°C)
T_i	fluid temperature at inlet (°C)
U	overall heat transfer coefficient (kg/s^3 °C)
v	velocity (m/s)
x	thickness of cement (m)
Z	drilled depth (m)
ε	surface roughness (m)
η	efficiency
θ	wellbore inclination angle
κ	thermal conductivity (kg m/s^3 °C)
λ	friction coefficient
ν	kinematic viscosity (m^2/s)
ρ	fluid density (kg/m^3)
τ	shear stress at pipe wall (kg/m s^2)
Φ	correction parameter

networks themselves face technical issues as the penetration of renewable energy increases [1,2].

While the more conventional technologies of wind, solar photovoltaic (PV) and hydropower are expected to take a leading role in this energy future – indeed wind and solar PV are expected to quadruple their contribution to the global energy mix in the renewable picture provided by the IEA [1] – a continued development of innovative solutions that can contribute to this mix will be needed if increasing penetration is to be achieved. Focus on renewable energy generation that can provide a complimentary balance to the intermittent generation provided by wind and solar PV will equally be needed if these sectors are expected to make up an increasingly large share of the market.

The ability of geothermal systems to provide continuous base load type generation, complimenting the more variable output produced by wind and solar PV makes it a potentially important component of any future energy mix, particularly considering its suitability for both developed and developing countries energy needs [3].

Traditionally geothermal energy has sought to exploit the presence of either hot steam or very hot water within the earths crust in order to generate energy. Non-conventional geothermal generation, with its focus on the finding of alternative access to hot fluids for geothermal electricity generation offers an exiting area of research; one with the potential to expand the geothermal resource base and thus the contribution of geothermal energy.

One such area of research has centred around co-production – that is the utilisation of hot geothermal fluid collocated with oil or gas reserves. Geothermally heated water produced at the surface as a by product of active hydrocarbon production presented a resource that one could tap into for the purposes of electricity generation [4–7].

Despite the positive potential associated with geothermal generation using co-produced fluids, this approach is not without drawbacks. A reliance on co-produced fluids to drive such a process directly ties any energy generation to active oil production. Further more, with such a dependency any well shut down will see a corresponding shut down in co-produced energy generation.

The aim of this research is to look at an alternative approach in which binary cycle power plants may be used to generate geothermal energy away from traditional or co-production based routes; suggesting a method of using abandoned oil and gas wells without any reliance on co-production or naturally occurring geothermal liquids. The use of abandoned wells enabling the Earths geothermal potential to be utilised without a requirement to drill fresh wellbores for the purpose, while the stand alone nature of this approach would allow generation of geothermal energy in locations with existing wellbores but an absence of naturally occurring geothermal fluid.

2. Concept

The process of utilising binary cycle power plants as a means of generating electricity from conventional geothermal fluids in the low (70 °C–100 °C) and medium (100 °C–150 °C) temperature range is well established [8]. The Chena binary cycle plant in Alaska operates with an inlet fluid temp of 73.33 °C and a mass flow rate of 33.39 kg/s however water cooling is required in order to be effective at this temperature. A cooling water temperature of 4.44 °C with a mass flow rate of 101.68 kg/s is used [8]. Using medium temperature range geothermal fluid in combination with air cooling, this process has seen use on active onshore oil wells with success. Using co-produced fluids as the source of geothermal heat, a 280 kW air-cooled binary cycle power plant at the Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming, USA [4,5] and a 310 kW air cooled binary cycle power plant at the Huabei Oilfield in China [6] have both enjoyed successful operation. The plant at RMOTC was operational from 2008 until 2014, the plant at Huabei was installed in 2011 and remains operational.

It is expected that this approach can be further adapted for use on abandoned oil and gas wells removing any reliance on co-production for electricity generation. The concept of using abandoned oil and gas wells as a source of geothermal energy centres on the use of the wellbore as a heat exchanger; removing any reliance on naturally occurring geothermal fluid for operation while decoupling generation from active hydrocarbon production.

Employing a novel approach, our design intends to circulate water down the annulus of a wellbore, between the production tubing and the casing before returning this water to the surface via a centrally located, thermally insulated production tubing. At the surface this heated water is circulated through a binary cycle power plant enabling the generation of electricity before being returned to the wellbore. By closing the wellbore at a specified depth, utilising conventional completion equipment, this water flow circuit operates as a closed loop system. No contact with the geological formation occurs and no naturally occurring geothermal fluids can enter the system. This minimises risk of environmental contamination by leakage from the system while protecting both equipment and environment from performance or safety risks caused by