GEOTHERMAL ENERGY FROM ABANDONED PETROLEUM WELLS IN NEW ZEALAND

Agnes G. REYES
Institute of Geological and Nuclear Sciences, 1 Fairway Drive, Avalon, Lower Hutt 5013, New Zealand
e-mail: a.reyes@gns.cri.nz

ABSTRACT

There are >400 abandoned petroleum wells in onshore New Zealand that can potentially be harnessed for geothermal energy for direct heat applications, geothermal power production and cogeneration and development as pseudo hot spring systems for use in tourism and health spas. Well depths range from 17 to 5065m. Bottom hole temperatures (BHT) vary from 17ºC to 175ºC. The minimum estimated accessible heat from these wells at BHT>20ºC is 8.6 PJ/a, with recoverable heat energy of 0.86 PJ/a. About 0.3 PJ/a of this is recoverable from wells with BHT>95ºC, suitable for power production using a binary cycle or hybrid system. Taranaki, the only producing oil, gas and condensate region in the country, accounts for 40% of all abandoned petroleum wells and 76% of potential heat energy. Taranaki has large energy-intensive dairy, horticultural and food-producing/processing industries that could benefit from geothermal energy production using abandoned infrastructures, as the hydrocarbon reservoirs decline. Although the temperatures and fluid flow rates of abandoned wells in Taranaki and other regions may be geothermally viable, there are still many geoscientific, technical and non-technical problems to overcome before the first well can be converted for geothermal use and a pilot plant set up.

Keywords: New Zealand, abandoned petroleum wells, Taranaki

1. INTRODUCTION

Heat is an intrinsic property of the earth but geothermal resources, by definition, will only occur where heat energy is technologically and economically recoverable. With technological advances such as the use of ground source heat pumps (GSHP), borehole heat exchangers (BHE) and technology associated with Enhanced Geothermal Systems (EGS), geothermal energy can be harnessed now from temperatures <0ºC to >350ºC and from rock with limited or no fluids to formations with high fluid throughput (Sanner et al, 2003; Majer et al, 2007; Scott et al, 2015; Reyes, 2015; Luo et al, 2016; Gagne-Boisvert and Bernier, 2017).

Since about 1982, there has been interest in harnessing abandoned petroleum wells for geothermal energy in the USA (e.g., Bebout et al, 1982; Blackwell et al, 2010), Europe (Gerard et al, 2006), Middle East (e.g., Sanyal and Butler, 2010; Noorollahi et al, 2015) and Asia-Pacific (e.g., Reyes, 2007; Wang et al, 2016). Although geothermal pilot plants have been installed in petroleum-producing sedimentary basins as early 1987 in Soultz-sous-Forets in France (Gerard et al, 2006) and 1989-1991 in Pleasant Bayou Texas (Blackwell et al, 2010), these used wells specifically drilled for testing. It is only recently that abandoned petroleum wells have been exploited as a source of geothermal energy for power production and direct heat applications in China since 2011 and in North Dakota USA since 2016 (Wang et al, 2016).

There is recent interest in the possible extraction of geothermal energy from abandoned petroleum wells in New Zealand spurred on by (1) the government's initiative, under the Paris Agreement, to reduce greenhouse gas emissions by 30% below 2005 levels by 2030 and to attain carbon neutrality by 2050 (www.mfe.govt.nz) and (2) the decline and nearing end of life of reserves in Taranaki, the only oil, gas and condensate producing region in the country (www.mbie.govt.nz) where more than 175 abandoned wells are extant and another 75 available when petroleum production ceases.

Using abandoned petroleum wells will cut geothermal development costs not only because of the ready-made infrastructures but also because of (1) the large amount of publicly-available data such as seismic surveys of the regions and subsurface data from well drilling e.g., geology including lithology, stratigraphy and structures; formation properties such as porosity and permeability; reservoir pressures; fluid salinity and gas compositions; gas and water flow rates; well temperatures during drilling and BHT; and drilling history including mud losses and the state of the well (www.nzpam.govt.nz) and (2) availability of cuttings and sidewall cores from wells.

2. UNCONVENTIONAL AND CONVENTIONAL GEOTHERMAL RESOURCES

In unconventional heat resources of New Zealand, the mode of heat transfer is dominated by conduction with lower heat output, thermal gradients, relative permeability and volume of circulating fluids compared to conventional ones associated with thermal springs. The volumetric stored heat in low-temperature regions in the country, from surface to 3.5km, is 6.5x that of the high-temperature regions in the Taupo Volcanic Zone and Ngawha at 3.6 x 10^{15}PJ/a, due to a much larger volume. However most of this heat energy is locked in the rock. Heat from unconventional geothermal resources can be accessed by drilling new wells and using hundreds of available abandoned deep petroleum wells, thousands of shallow domestic, industrial and mine exploration drill holes, and hundreds of abandoned underground mineral and coal mines. These infrastructures can hold conductively-heated fluids, act as a focus for advecting hot thermal aqueous solutions from depth (Reyes, 2015) or, in the absence of fluid flow, be used as ready-made deep pipes for EGS and deep BHE geothermal energy extraction (e.g., Caulk and Tomac, 2017).

3. LOCATION OF ABANDONED PETROLEUM WELLS

There are >400 abandoned petroleum wells in 17 of the 18 regions shown in Fig. 1 except in region 14, the North Alpine Fault Zone. In this region two sites were drilled by the Deep Fault Drilling Project (DFDP) under the auspices of the International Continental Scientific Drilling Program, with one research well attaining a depth of about 815m (Townend et al, 2017).

About 40% of all abandoned petroleum wells are located in Taranaki. These are located within or near populated areas where access to geothermal energy (or cogeneration of geothermal and gas), for power and direct heat use, would benefit the large energy-intensive dairy, food-processing and horticultural industries in the region. Other regions with a significant number of abandoned wells are the Hikurangi Accretionary Prism in the East Coast of the North Island (region 1) where nearly 25% of the wells occur, Whanganui-Taumarunui (region 10), and the West Coast of the South Island (regions 12, 14 and 15).

Most of the abandoned onshore wells were drilled between 1866 and 2005. Of those with known drilling dates, nearly 35% were drilled post-1980 (Reyes, 2007). However one well drilled in 1908, Bonithon-1, is still being used for direct heat applications in Taranaki, in a spa (Reyes et al, 2010).

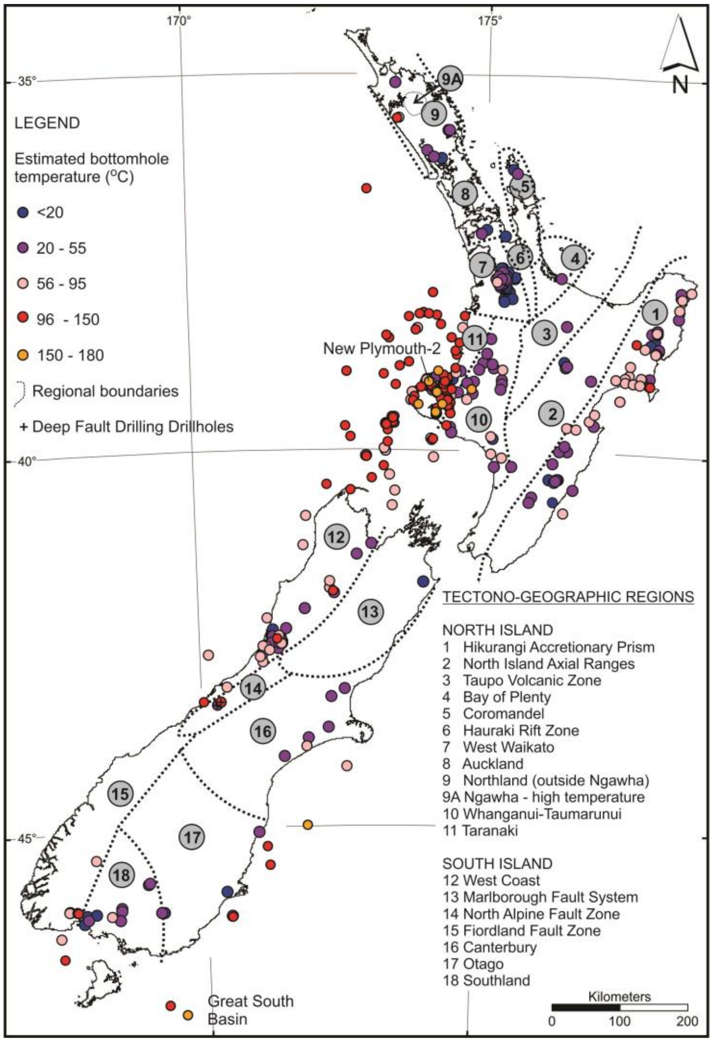

Fig. 1 Location of abandoned wells and estimated bottomhole temperatures (BHT) modified from Reyes (2007; 2015). Deep Fault Drilling drillhole BHTs in region 14 are based on a geothermal gradient of 120°C/km (Sutherland et al 2017; Townend et al, 2017).

Most wells are abandoned because of low or lack of hydrocarbon shows. The wells may be dry or saturated with fresh or saline aqueous solutions, a boon to geothermal energy production. Others are abandoned because of drilling problems e.g., swelling clays and sand bursts.

4. TEMPERATURES, DEPTHS AND HEAT ENERGY

As shown in Figs. 1 and 2, most of the regions with the most number of abandoned wells have estimated subsurface temperatures varying from 100-200°C with Coromandel (region 5) with 250°C and Otago (region 17) at <100°C. Taranaki (region 11) is one of the regions with the highest geothermal prospectivity based on the number of wells that can be converted for harnessing geothermal energy, subsurface temperatures and available heat energy (Reyes, 2015, 2017).

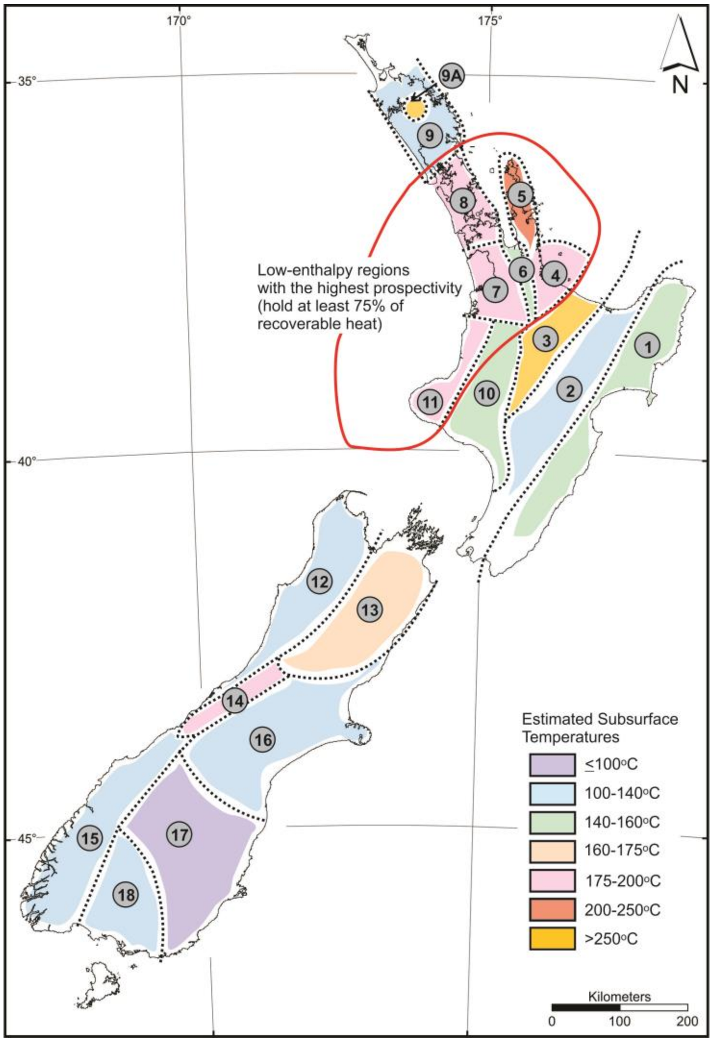

Fig. 2 Estimated subsurface temperatures per region, based on fluid chemical geothermometers where fluids are available and BHTs of abandoned wells and underground mines (Reyes et al, 2010, Reyes, 2015, Reyes 2017).

Vertical depths of abandoned wells range from 17 to 5065m (Fig. 3) with the majority drilled below 3000m. Twelve of the 13 wells drilled to >4000m are located in Taranaki with one, Rere-1, found in the

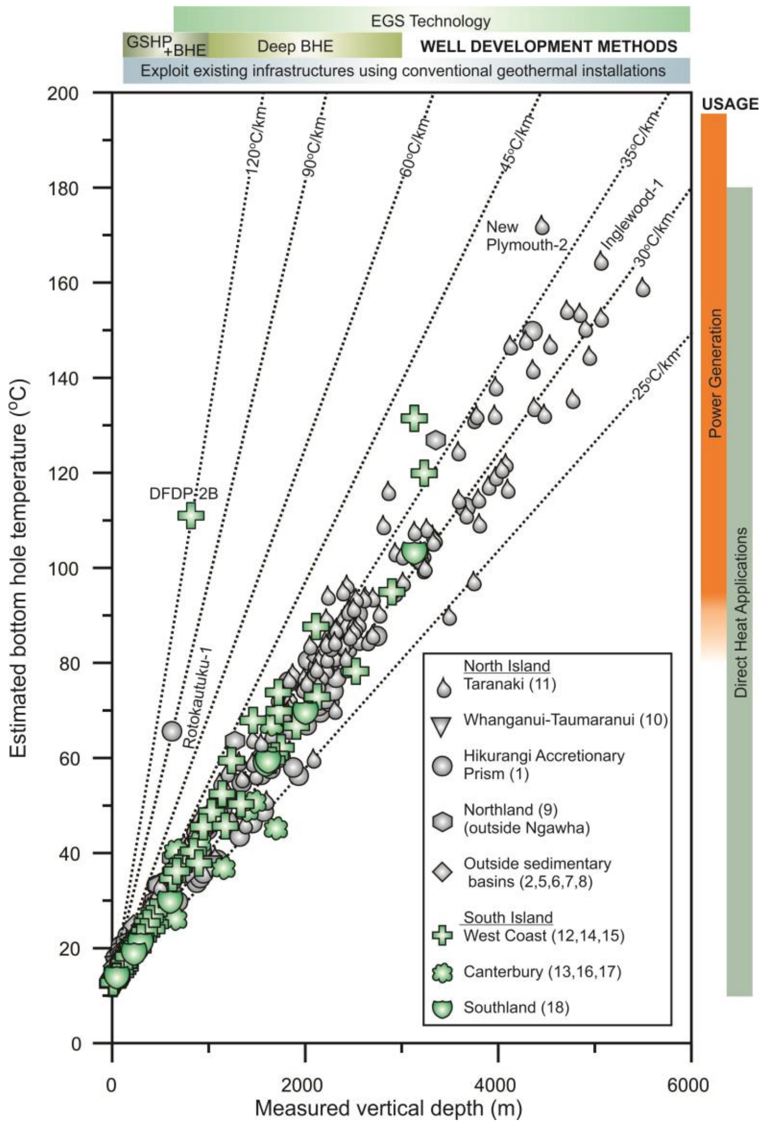

Fig. 3 Cross plot of measured depth vs estimated bottomhole temperature of abandoned wells with geothermal gradients based on 12°C and 15°C surface temperature. Numbers in parenthesis correspond to regions in Fig. 1. Bars on the right show general usage of heat at a given temperature. On top are general well development methods based on depth and temperatures. EGS: Enhanced Geothermal System, BHE: Borehole Heat Exchanger, GSHP: Ground Source Heat Pump. Well data are from www.nzpam.govt.nz except for DFDP-2B (Sutherland et al, 2017).

Hikurangi Accretionary Prism (region 1). Stabilized downhole temperatures are rarely measured in petroleum wells although temperatures during or just a few hours after drilling are available. In the absence of stable downhole temperatures, bottomhole temperatures (BHT) are roughly estimated using surface conductive heat flow data (Funnell et al, 1996; King and Trasher, 1996; Funnell and Allis, 1997; Field et al, 1997; Allis et al, 1998; Cook et al, 1999) and converted to thermal gradient using a factor of

2.1 (Funnell, pers. comm., 2003) and an average surface temperature of 12ºC for the South Island and 15ºC for the North Island. A comparison of BHT with measured downhole temperatures, aqueous solution chemical geothermometry and homogenization temperatures of the latest aqueous fluid inclusions (Reyes, 2015) suggest that values are probably within ±20ºC of stable well conditions.

The estimated BHTs of abandoned wells vary from near ambient to 175ºC, with the latter occurring at 4450m in New Plymouth-2 in Taranaki. Most of the wells plot between thermal gradients of 25º-45ºC/km with Rotokautuku-1 in the East Coast at 90ºC/km and the deep DFDP well in region 14 in the South Island at 120ºC/km (Fig. 3).

About 22% of the wells have BHT>95ºC suitable for power generation using a binary cycle or hybrid system and the rest can be used for direct heat applications. Nearly 80% of wells with BHT>95ºC are located in Taranaki. The rest occur in the Hikurangi Accretionary Prism (region 1), Northland (region 9), Whanganui-Taumarunui (region 10), West Coast (region 12) and the Fiordland Fault Zone (region 15).

There are several methods for developing abandoned petroleum wells to produce geothermal energy (Fig. 3). However, in an initial estimate of heat energy available in these wells, it is assumed that a conventional geothermal well configuration and surface installation will be employed, using heated standing water in a well. The assumptions for the calculation of stored heat are enumerated in Reyes (2015). Thus the estimated stored heat from the onshore abandoned wells with BHT>20ºC is 194 x 10^3PJ/a, of which 76% occurs in Taranaki. Assuming a flowrate of 3L/s, the total accessible heat available is 8.6PJ/a. Because heat recoverability in low-grade low-enthalpy geothermal systems is not only dependent on the efficiency of the technological infrastructures that convert heat energy to a usable form but also to other technical and non-technical factors (Reyes, 2015), a conservative recoverability factor of 10% is used to convert accessible to recoverable energy to 0.86PJ/a.

5. HURDLES IN CONVERTING PETROLEUM WELLS FOR GEOTHERMAL USE

Aside from the difficulty of locating some old wells due to the obliteration of surface traces (Funnell, pers. comm., 2007) there are other factors that may make abandoned wells unusable without expensive remediation. e.g., (1) unknown state of the casing, such as corrosion, and unsatisfactory grouting jobs especially of wells drilled before 1980 (65% of wells), (2) practice of filling and plugging abandoned wells will require drilling-out fills and cement before use, (3) liner tubings, normally used for petroleum wells will need to be converted to slotted liners or the tubings perforated, (4) absence of liners in some wells may cause formation cave-ins and (5) aqueous fluids may cause fouling, scaling and/or corrosion of geothermal installations. Apart from these, access to the wells may be limited by oil companies, Maori tribes and private owners.

The requisite subsurface temperatures for geothermal development using abandoned wells are available (Fig. 2). One of the key parameters necessary for developing a well using a conventional geothermal configuration is water flow rates. There has been minimal study of water flow rates in these wells using available data at www.nzpam.govt.nz although Reyes (2015) has given a range of 0.02 to 9.12 L/s for nine wells. Through the years permeability can change in a well due to scaling or formation cave-ins and/or failure of liners and casings. However there are evidences for permeability in some wells such as mud losses encountered during drilling (e.g., Ian Brown Associates, 1998) and measured flow rates post-drilling (e.g., Carter et al, 1984). Furthermore, overpressuring at depth in Taranaki (King and Trasher, 1996), Hikurangi Accretionary Prism (Field et al, 1997) and Northland (Isaac et al, 1994) indicate artesian conditions. Thus a number of wells can flow without the need for well stimulation and/or hydrofracturing.

With the employment of BHE (Borehole heat Exchanger) and/or EGS (Enhanced Geothermal Systems) technologies, well development becomes an engineering, numerical simulation and economic assessment endeavor with less input from basic geoscientific studies.

6. FUTURE WORK

The study of abandoned petroleum wells for adaptation for geothermal energy production is in its infancy in New Zealand, although there are now government-led directives that encourage further study. It was recommended in 2007 (Reyes) that any development of abandoned wells for geothermal use, such as the installation of a pilot geothermal plant, be focused on Taranaki. But various studies need to be done before any wells are converted e.g., (1) review of available data at www.nzpam.govt.nz and other literature on wells regarding fluid reservoirs, fluid chemistry, permeability and fluid flow rates, fault and stratigraphic permeability, well connectivities, geology, and downhole pressures and temperatures and other well parameters; (2) determine the state of the casings, tubings and cementing jobs of selected wells; (3) determine fluid pathways and temperatures using petrological, geochemical and numerical modeling; analyse fluid discharge chemistry to find out if hybrid plants can be used to harness both gas and geothermal energy; to predict fouling, scaling and corroding propensities of the fluids; and to determine ways of disposing spent well fluids; (4) analyze the economic viability of using EGS and BHE instead of, or in tandem with conventional geothermal well development methods; (5) numerically simulate various scenarios on how to best adapt the wells for geothermal energy use and also how to optimize the use of geothermal energy e.g., cascade schemes from power production to heating applications of spent heat energy.

7. CONCLUSIONS

Subsurface temperatures necessary for geothermal energy development are present in all regions in New Zealand with abandoned petroleum wells. But there are still numerous geoscientific, technical and non-technical problems to be considered before petroleum wells can be adapted for geothermal energy production or cogeneration. However New Zealand has the available expertise in the geothermal and petroleum industries, access to the requisite technologies and an enormous dataset on the wells, and recently, the support of the government; thus making this scheme for converting abandoned petroleum wells for geothermal use viable.

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