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Reinjection at Wairakei Tauhara Geothermal Field

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Abstract

A 3D numerical model of the Wairakei-Tauhara field is used to investigate the effect of reinjection on liquid-dominated two-phase geothermal systems. Wairakei-Tauhara is an interesting case study as it has been operated with no reinjection for most of its lifetime. Several scenarios are run with the model to test what would have happened if a different reinjection strategy had been followed. The impacts of different rates of outfield and infield reinjection on production enthalpy, reservoir pressure and temperature, recharge conditions and surface features are investigated. Our modelling results show that infield reinjection suppresses boiling and therefore decreases energy production as a result of the decrease in production enthalpy. Since pressure is maintained by cold reinjection, natural hot water recharge to the system is also suppressed by infield reinjection. A low level of infield reinjection (25% of the separated water) results in a low level of thermal degradation and does not cause a significant pressure drawdown. Therefore this scenario appears to be a good infield reinjection strategy.

If production is carried out without reinjection, the flow of chloride water from the deep aquifers to the surface features decreases with time and some areas of the ground surface tend to become steam heated. Reinjection supports the flow of chloride water to the surface features, but at a lower temperature than in the natural state. However if the reinjection zone is close to the steam-heated surface features they may significantly decline or totally disappear.

Introduction

Liquid dominated two-phase geothermal systems contain all, or mostly, very hot water in their natural state. However, when production commences, boiling occurs near the feed zones of the wells, caused by large pressure drops. The permeability in the rock surrounding the hot reservoir in such systems may be similar to that inside the reservoir. Therefore recharge from the sides of the reservoir can easily flow into it. In the Wairakei-Tauhara geothermal system, in general permeabilities are high. There are a number of NE–SW trending faults. These faults provide enhanced permeability in the field [1]. Hence there is substantial recharge that provides natural pressure support to the system [2].

In liquid-dominated two-phase systems, injecting cold water into the production zone will cause faster cooling of the production wells. In some cases, it may even suppress boiling and cause the production enthalpy to drop to that of hot water. Systems of this type do not run out of water, and also they do not suffer from excessive pressure drawdown because the pressure declines until it reaches the boiling point and then the boiling process “buffers” any further decline. Thus this type of system does not require pressure maintenance. Therefore, from a reservoir engineering perspective there is no reason to inject infield in two-phase liquid-dominated geothermal systems. In fact injection in such systems has often resulted in adverse thermal breakthrough and a consequent move of injection outfield, e.g. at Cerro Prieto [3] and Tiwi [4].

At Wairakei, production has caused widespread pressure drawdown. The drawdown has stabilized at approximately 25 bar in the deep liquid zone of the Wairakei field. The large pressure drawdown has caused the formation of extensive two-phase zones [1], and there is a shallow vapour-dominated zone in a predominantly low enthalpy liquid-dominated system.

The large pressure drop in the reservoir has also caused a reduction in surface flows at liquid-fed features and an increased heat flow, mainly from steam, through the surface at some locations. For example in the pre-exploitation state of the Wairakei-Tauhara geothermal system there was a chloride water up-flow from the deep reservoir that mixed with groundwater, and discharged to the surface, mainly at Geyser Valley [5]. Production decreased the vertical pressure gradient in shallow part of the reservoir and prevented up-flow from the deeper high-temperature reservoir. Additionally a large area of steam discharge was present at the Karapiti thermal area before production start. After production commenced, due to the pressure drop in reservoir and expansion of the boiling zone, the steam flow to the surface increased. Now the area contains hot ground, numerous fumaroles and steaming craters [6].

In this paper the effect of reinjection at the Wairakei-Tauhara geothermal field is discussed. Since reinjection was carried out only over the last 10 years of production, experiences from this field allow us to observe some of the effect of reinjection on the production performance and field characteristics as well as allowing us to observe the results of production without reinjection.

Model Description

An existing computer model of the Wairakei-Tauhara field [7] is used. The areal and vertical grid structures of the model are shown in Figure 1. The top few layers of the model follow the topography of the Wairakei-Tauhara region.

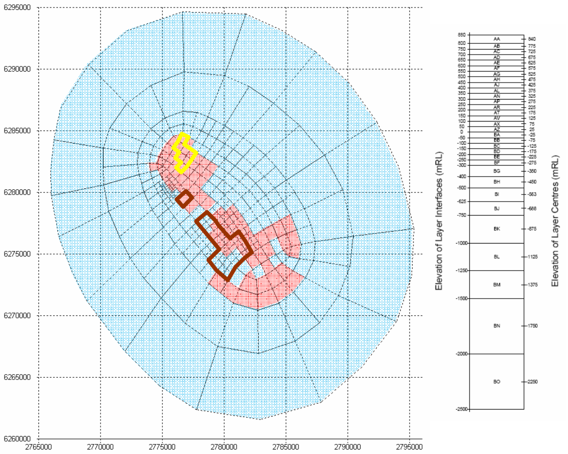


Figure 1. Areal and vertical structure of the Wairakei–Tauhara model

In order to obtain an accurate representation of the shallow zone, the unsaturated zone is included in the model and thus the model considers the flow of energy, water and air within the geothermal system [8].

Natural State Model

Pre-exploitation conditions of the Wairakei-Tauhara system are simulated in the natural state model. Atmospheric conditions are maintained at the ground surface with 1bar pressure and 20°C temperature. To implement the infiltration of rainwater, a proportion of the average rainfall into the surface blocks is injected into the surface blocks at a temperature of 20°C. To represent the lake at the south west of the system, a wet atmosphere and a cold temperature (5 °C) is assigned to the blocks representing the lake area.

At the base of the model, for the boundary conditions, mass inputs (red area in Figure 1) and heat inputs (blue area in Figure 1) are applied.

The cap-rock is mainly located in the AP layer (+275masl) and nearby. Surface outflows to hot springs (the grid-blocks bounded with yellow and brown lines in Figure 1) are represented in the model by mass flows from beneath the cap rock.

The Wairakei geothermal reservoir is characterised by high horizontal permeabilities, low vertical permeabilities, and low permeabilities in the basement and cap-rock [1].

To improve the fit of the natural state model results to the field data, calibration is carried out. Simulation results are compared with pre-production measurements (e.g. reservoir temperatures, surface outflow locations and vapour saturations). The main parameters adjusted are the permeabilities and the deep inflows [1].

Production history

The historical data for production and reinjection at the Wairakei field are included as input in the model used for simulating the production history. The initial conditions for the production history model are taken from the natural state model. Further calibration is carried out to obtain a match of the model behaviour to the measured changes in pressures, production enthalpies, surface heat flows, temperatures and vapour saturations [1].

The production wells are grouped according to their locations in one of five production areas: Eastern Borefield, Western Borefield, Poihipi, Te Mihi and Waist.

Almost all of the production at Wairakei has been taken from between +100 to -500masl. The major part of the production has been from the Western Borefield but at a decreasing mass flow rate throughout the past 40 years. The total production from the Eastern Borefield area has decreased gradually and this area has produced only about 30kg/s for the last 15 years.

Reinjection experience at Wairakei-Tauhara

In the Wairakei-Tauhara field until after about 40 years of production, the bulk of the cooled geothermal fluid (both condensed steam from the direct-contact condensers and the separated brine) was discharged into the Waikato River [2]. After 40 years of production, a small amount of the separated geothermal water was reinjected close to the Eastern Borefield.

As a result of this strategy of no-reinjection for long time followed by a small amount of reinjection, the following effects have been observed:

(a) A large two-phase zone, with a high vapour saturation in some locations (steam zones), has formed and the enthalpy of some of the production wells has increased [1].

(b) An increase in steam heated surface features has been observed [1], but most of the surface features that were fed by hot chloride water have disappeared [9].

(c) There has been a large drawdown in the reservoir pressure. This has induced an increase in cool recharge from the top and sides of the reservoir and an increase in deep hot recharge. After 30 years of production, the pressure in the deep liquid zone stabilized at about 25 bar [1].

Reinjection Scenarios

In this study our particular interest is to decide if the best reinjection strategy should involve infield reinjection, outfield reinjection or a mixture of both. Therefore alternative reinjection strategies for Wairakei-Tauhara are investigated. The impact of different rates of outfield and infield reinjection on production enthalpy, reservoir pressure and temperature, recharge conditions and surface features is investigated.

The reinjection scenarios examined in this paper are summarized in Table 1. SGW (separated geothermal water) represents the total amount of water produced from the separators. The enthalpy of the reinjection fluid was taken as 564.4kJ/kg corresponding to the average temperature of the fluid from the separators of about 134°C.

Scenario	Reinjection Strategy
BASE	Historical situation - no reinjection for a long time, followed by a small amount of reinjection for about the last 10 years
OUT	Outfield reinjection of 100% of total produced mass
IN100	Infield reinjection of 100% of SGW
IN50	Infield reinjection of 50% of SGW
IN25	Infield reinjection of 25% of SGW

Table 1 Reinjection scenarios

Outfield reinjection

The outfield reinjection scenario (OUT) involves reinjecting the waste fluid outside the known reservoir boundaries. It was assumed that the amount of steam loss is negligible and the total mass produced from all of the wells is reinjected.

The locations of the main outfield injection zones were at first based on those used in previous modeling studies of the Wairakei-Tauhara model [10]. However the blocks used in the previous study can accept only a limited amount of reinjection and the amount of liquid to be injected for the OUT scenario is large. Therefore we extended the outfield reinjection areas by including large grid blocks next to the reinjection blocks used in [10]. These areas have the largest permeability of all the outfield blocks and thus they have a relatively high injectivity. There are very low permeability regions between the reservoir and some outfield reinjection zones, indicating a weak connection to the reservoir. The total mass produced from the different production areas is injected into the outfield reinjection zones in proportion to the volume of these grid-blocks. The depths of the reinjection zones vary between -25 and -225masl.

Comparison of the pressure and enthalpy histories of the BASE and OUT scenarios shows that outfield reinjection does not affect the pressure behaviour and the thermal state of the reservoir. This is to be expected as there is no strong hydraulic communication between the outfield reinjection zones and production areas. Hence outfield reinjection can be considered as a waste water disposal method rather than a technique for maintaining reservoir pressure.

Infield reinjection

Infield reinjection involves reinjecting fluid inside the reservoir boundaries and thus into the zones that have a permeable connection with the production area. With infield reinjection, because of the permeability connection between the production and the reinjection zones, the possibility of the rapid movement of cool injected water along preferred flow paths between the injection and production wells is a major concern.

As can be seen from Table 1, three different scenarios are tried for infield reinjection: IN100, IN50 and IN25 representing injection of 100%, 50% and 25% of the SGW, respectively. The amount of SGW is calculated by subtracting the steam production from the separators from the total produced mass. Hence the steam condensate produced from the field is not reinjected. The total reinjection is distributed into the infield reinjection grid-blocks in proportion to their volumes.

To decide on the location of infield reinjection blocks, previous work on the Wairakei-Tauhara model was reviewed. The areal and vertical locations for infield reinjection used in previous studies [7], are as shown in Figure 2. They are convenient locations in the higher permeability regions of the infield zone, and as far as possible from the Wairakei production wells and the future Tauhara production zone. Since the horizontal and vertical permeabilities are high in the area between the production and infield reinjection zones there is a strong hydraulic connection between them.

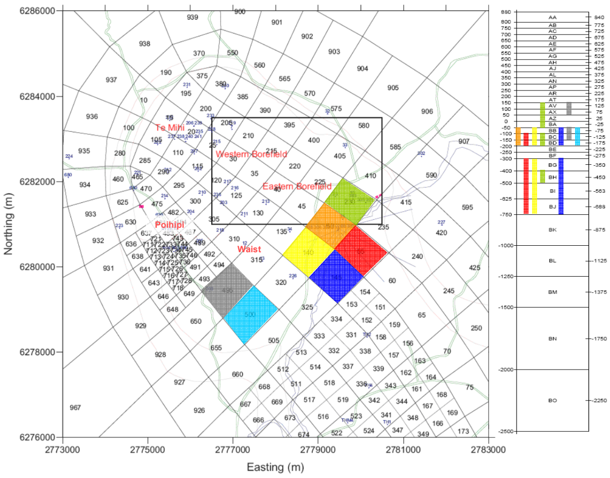
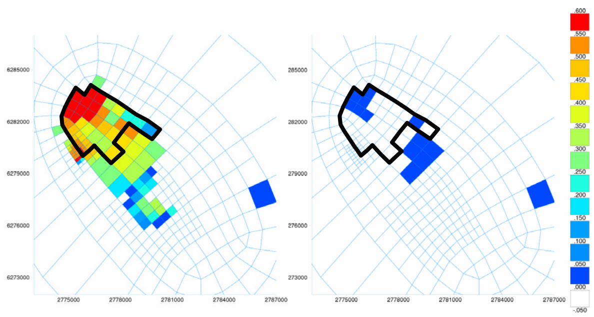


Figure 2. Areal and vertical location of infield reinjection.

The vapour saturation in the AT layer (+175masl) after 53 years of production for the IN100 is shown in Figure 3b. Comparison of this figure with BASE scenario result (Figure 3a) shows that when 100% of the SGW is reinjected into the system boiling does not occur and the vapour-dominated shallow steam zone does not develop.

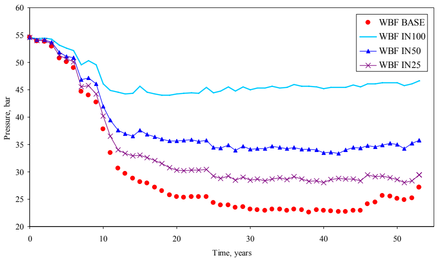


(a) BASE (b) IN100

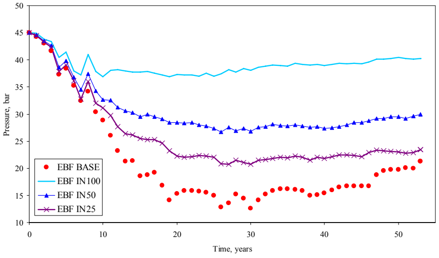
Figure 3. Vapour saturation distribution in the AT layer at year 53 for: (a) the BASE scenario and (b) the IN100 scenario.

Comparison recharge histories for the BASE and IN100 scenarios shows that reinjection of 100% of the produced liquid significantly decreases the natural recharge from the base and sides of the system.

The pressure histories for the BASE scenario, are compared with the pressure histories for the three infield reinjection scenarios (IN100, IN50, IN25) for the Western Borefield and Eastern Borefield in Figure 4a and 4b respectively. For the pressure histories, the grid-blocks in the middle of each production area (e.g. BC 35 for the Western Borefield) are used.



(a) Western Borefield

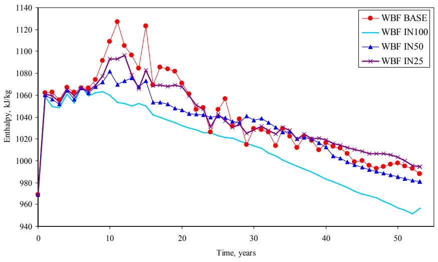


(b) Eastern Borefield

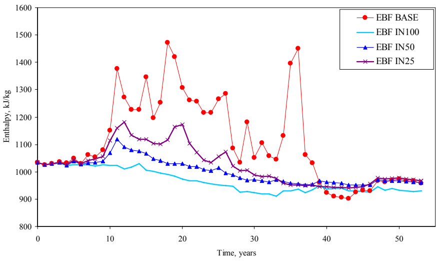
Figure 4. Pressure histories for the BASE, IN25, IN50 and IN100 scenarios for: (a) Western Borefield, (b) Eastern Borefield.

The consequences of strong hydraulic communication between the reinjection and production zones can be seen in Figure 4. Because of this communication, infield reinjection supports the reservoir pressure. The highest pressure increase from infield injection occurs for the IN100 scenario which has the highest rate of reinjection. Decreasing the reinjection flow rate decreases the pressure support.

The impact of infield reinjection on reservoir enthalpies is shown in Figure 5. According to Figure 5a and 5b, for the BASE scenario, after about 5 years of production, the production enthalpy for both production areas increases due to the formation of high saturation two-phase zones. However for IN100, the production enthalpy decreases considerably. The main reason for this enthalpy drop is that the high rate of infield reinjection suppresses boiling (see Figure 3b). Additionally infield reinjection increases the reservoir pressure and prevents the recharge of hot fluid into to reservoir.



(a) Western Borefield



(b) Eastern Borefield

Figure 5. Production enthalpy histories for the BASE, IN25, IN50 and IN100 scenarios for: (a) Western Borefield, (b) Eastern Borefield.

When the amount of reinjection is decreased, the effect on the enthalpy is also decreased. For the Eastern Borefield (Figure 5b), even with the 50% reinjection of SGW, the detrimental effect of reinjection is still significant.

Because the Eastern Borefield area is much closer to the infield reinjection zone, the difference in enthalpy between the BASE and IN100 scenarios is much higher for the Eastern Borefield wells than for the Western Borefield wells. For the Western Borefield area, the fluctuations in the production enthalpy between that of water and dry steam indicates boiling in the reservoir takes place for the IN25 scenario as well as for the BASE scenario (Figure 5a). In the long term (after 20 years) the reinjection of 25% SGW does not have any detrimental effect on the production enthalpies.

Effect of infield reinjection on surface manifestations

Two-phase geothermal systems may exhibit a wide range of surface geothermal phenomena including springs, geysers, fumaroles, steaming grounds etc. Reinjecting cold water back into the reservoir may cause a decline in surface manifestations since the reinjection fluid invades and condenses the steam zones that lie across the top of the reservoir. At Wairakei production resulted in the decline of hot springs and geysers and an increase in steaming ground [6].

The locations of surface features in the model are shown in Figure 1 (the grid-blocks bounded with yellow and brown lines). To investigate effect of infield reinjection on surface manifestations, the spring blocks in the model are divided into three groups: i) North (Te Mihi, Alum Lake and Waiora features [5]) ii) Middle (Karapiti thermal area [5]) iii) South (features in the Tauhara region [5]).

The effect of infield reinjection on the mass flow from the north spring blocks (the grid-blocks bounded with yellow line in Figure 1) for various reinjection scenarios is shown in Figure 6. This figure compares the mass flow history from the spring blocks for the BASE, IN100, IN50 and IN25 scenarios.

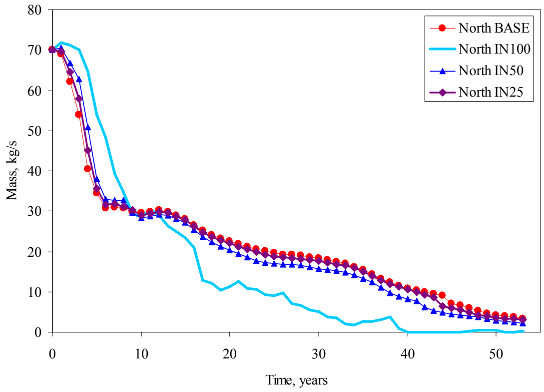


Figure 6. Mass flows at north spring blocks for the BASE, IN25, IN50 and IN100 scenarios.

As shown in Figure 6, a high amount of infield reinjection (IN100) increases the mass flow at the north spring wells for the first 9 years of the production due to the pressure support through reinjection. However after 9 years, a larger mass flow decline occurs for the IN100 scenario than for the BASE scenario.

The high hydraulic communication between the reinjection zone and the North spring blocks causes a breakthrough of injected fluid that cools the zone lying over the reservoir and prevents the formation of steam zones in this area. For the intermediate reinjection (IN50) scenario, the mass flow of the north spring wells is affected much less than for the IN100 scenario. For the IN25 scenario there is no apparent difference from the BASE scenario with regard to the mass flows from these wells.

Summary

Outfield reinjection: Since the permeable connection between the reinjection zones and production areas is weak, outfield reinjection does not have any effect on the reservoir pressure or production enthalpies. Therefore outfield reinjection is a safe method for disposing of water without risking the detrimental effects of cold reinjection.

Infield reinjection: Infield reinjection is effective in preventing a large pressure drop in the reservoir. However a large drop in the reservoir pressure causes boiling in the reservoir and hence results in the formation of high saturation boiling zones. Reinjecting into zones that are connected to the production area prevents the increase in the steam fraction and causes a drop in the production enthalpies. Since pressure is maintained by reinjection, natural hot water recharge to the system is also suppressed. Reinjecting 50% of the separated water causes considerably less thermal degradation than 100% reinjection, but still causes a decrease in energy production due to the decline in production enthalpy. A still lower rate of reinjection (25% of the separated water) does not cause a significant pressure drawdown or temperature decrease. This scenario appears to be a good infield reinjection strategy.

Surface features: Infield reinjection causes a significant decline or disappearance of steam-fed surface features, if the reinjection zone is close to the surface features. Reinjection supports the chloride water flow to surface features, but at a lower temperature than in the natural state.

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