Analysis of the impact of the reinjection of gases on the mass flow rate from production wells at varying reservoir conditions

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ABSTRACT

Greenhouse gas emissions from geothermal power plants are a barrier to the growth of geothermal energy at present and in the future. The discharge of the gases associated with the electricity generation process from geothermal fluids to the atmosphere contradicts New Zealand's target to achieve net-zero emissions by 2050. These gases are dominated by carbon dioxide. Reinjecting the gases back into the reservoir by dissolving them in the separated brine could be one way of reducing emissions from the geothermal electricity generation process. Besides reducing greenhouse gas emissions, reinjection may help in mitigating silica scaling problems by making the reservoir fluids more acidic. This helps in the dissolution of minerals, which further helps in improving the permeability of the reservoir and contributes to variation in output from the production well.

This paper discusses an analysis of the impact of the concentration of gases present in the reservoir on the mass flow rate from the production well. This is a result of changes in the thermodynamic properties of the fluid present in the reservoir. The analysis of the main parameters that contribute to the predicted mass flows will be presented. Well flows are estimated from production wells over the range of conditions found in New Zealand's geothermal production fields. It demonstrates the impact of reinjection of gases on different types of geothermal reservoirs through changes in mass flow rate from the production well.

1. INTRODUCTION

Geothermal energy is one of New Zealand's cheapest energy sources for electricity generation (Barbier, 2002). Besides cost-effectiveness, geothermal energy has many other benefits because it is reliable, sustainable, and relatively environmentally friendly (Rybach, 2003). Geothermal energy is extracted from the heat deep inside the earth's crust, where the earth's crust is thinner, and the hot mantle is close to the surface. Although thought a relatively clean source of energy, some greenhouse gases are emitted during extraction and processing. The extracted geothermal fluid contains greenhouse gases such as carbon dioxide, hydrogen sulphide, and methane (Fridriksson et al., 2016) which are dispersed into the atmosphere after the electricity generation process (Burnell et al., 2016). The geothermal powerplant emits greenhouse gases during the power generation process (McLean et al., 2020; McLean & Richardson, 2016). Emissions also occur in the natural state in flux forms through the soil, hot pools, steaming ground and fumaroles (McLean & Richardson, 2016).

The greenhouse gases in the geothermal fluid coming out of the reservoir do not condense at the same conditions as the water vapour. Hence, they are referred to as non-condensable gases. Their presence affects the efficiency of the turbine in generating electricity by continuously collecting in the condenser. In the last decade, many studies have aimed to identify strategies to successfully compress and reinject the gases back into the reservoir through the injection well of geothermal power plants (Kamila et al., 2021; Kaya et al., 2011; Rivera Diaz et al., 2016). The compelling case for gas reinjection was also discussed in some recently published research (Kaya & Zarrouk, 2017), (Bonafin et al., 2019).

Our research investigates the impact of gas reinjection on the mass flow rate from production wells at varying reservoir conditions.

2. BACKGROUND

The geothermal power plants in New Zealand have different emission intensities for each power plant. Some geothermal power plants emit a high quantity of gases as they contain more gas in the geothermal fluid extracted from the earth. The gases content in the geothermal fluid depends on the interaction of the fluid under the ground with the magma chamber that contains various gases.

Under the climate change regulations, greenhouse gas emissions from geothermal power plants in New Zealand are reported every year. The 2019 report on New Zealand's geothermal power plants contains emissions data from 12 major geothermal installations in New Zealand (Mclean et al., 2020; McLean & Richardson, 2016). Emissions can change due to degassing the fluid before reinjecting it and operational changes aimed at reducing emissions. The emissions vary in different power plants (Figure 1).

Rotokawa, Ngatamariki, and Ngawha geothermal power plants show a decline in CO_2 emissions due to degassing. Wairakei, Te Mihi, Pohipihi and Ohaaki geothermal power plants showing both increased and decreased CO_2 emissions due to operational changes in these power plants. While degassing and reinjecting the fluid back to the reservoir decreases gas content, a decline in flow rate at the same pressure is seen (Peter & Acuna, 2010). However, the reduction in flow rate is not generalized for all the reservoir conditions. Hence, this study seeks to understand the behavior of reinjected gases into the reservoir dominated by carbon dioxide.

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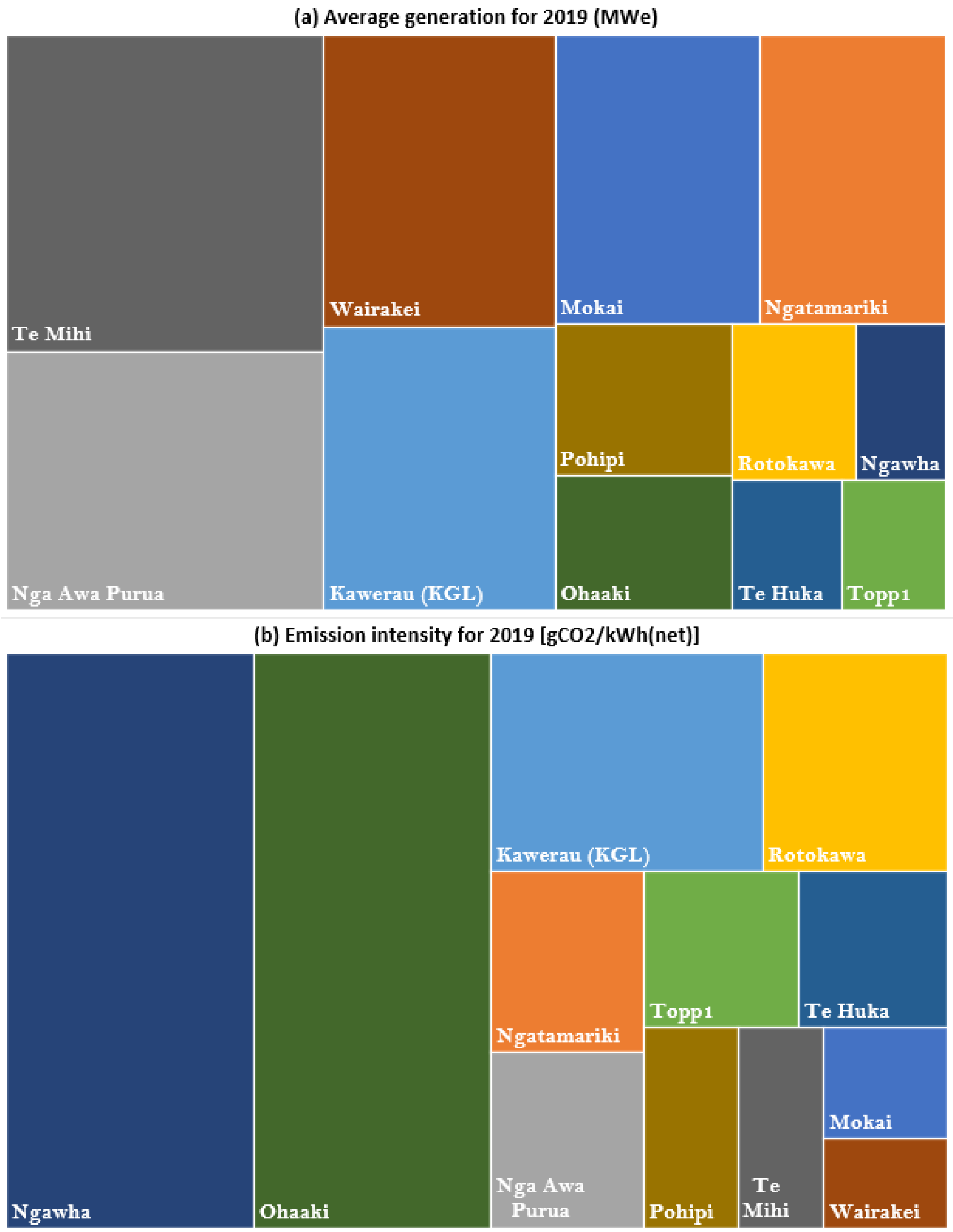

Figure 1: Annual generation and emission intensity of the geothermal power plants in New Zealand.

3. CASE STUDIES

The three case studies considered for analysis were three production wells with fluid and/or steam in the production wellbore. All three cases are discussed individually, and the impact of reinjection carbon dioxide is assessed. The simulated results of all three cases were different to each other. Case 1 is a study of a production well from Ngawha geothermal fields in New Zealand (*1981 DSIR Ngawha - Sect 4 (Grant) & Summary.Pdf*, n.d.), while case 2 is a case study of a production well from geothermal field in Indonesia (Peter & Acuna, 2010) and case study 3 is on a production well at Hatchobaru geothermal field in Japan (Tokita & Itoi, 2004).

For each well, we need to prescribe the characteristics of the well and the feed zones. The wellbore characteristics are given as sections with a constant diameter and inclination to the vertical. The well specification and reservoir properties for each case are given in the tables below (Table 1 to Table 6).

Calibrated Models

For each case study, a wellbore model was developed. A wellbore simulator named “WELLFLOW” was used to solve for the flow from the well. The wellbore simulator is a proprietary simulator that solves the equations for conservation of mass, momentum, and energy (Hasan et al., 2010), (Hasan & Kabir, 2010). We have estimated the wellbore model productivity indices as follows:

- For case 1 and case 2, we have matched the total flow rate from the well and the wellhead pressure.
- For case 3, we have matched the flowing pressure profile and the velocity profile.

Figure 2 and 3 show the calibrated model for case 3, with measured pressure and flow speed values, respectively. The calibration against flow data was only performed for one case (case 3) due to unvailabilty of sufficient data for case 1 and case 2. For these cases the calibration matched measured output curves. Matches for velocities and pressures fore case 3 seem acceptable, given we did not have access to the full details of the test performed on the well. We have taken these wellbore models and used them to simulate the effects of changing gas concentrations for the three case studies.

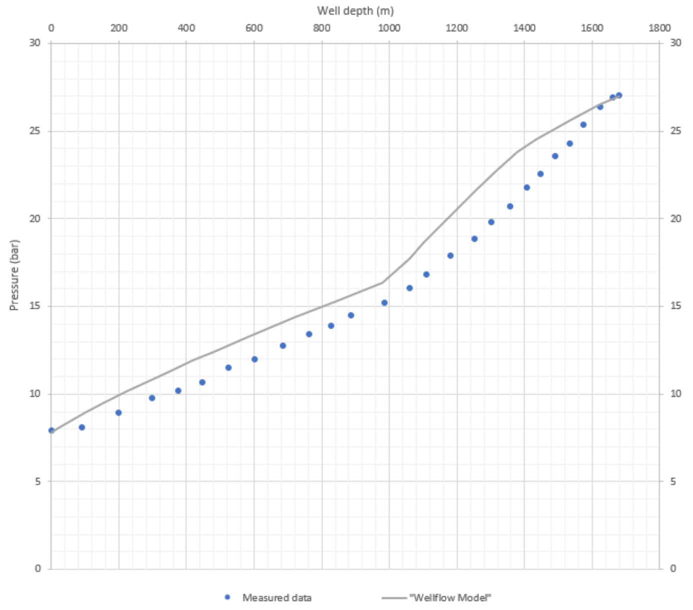

Figure 2: Pressure profile of the measured data and calibrated model for case 3.

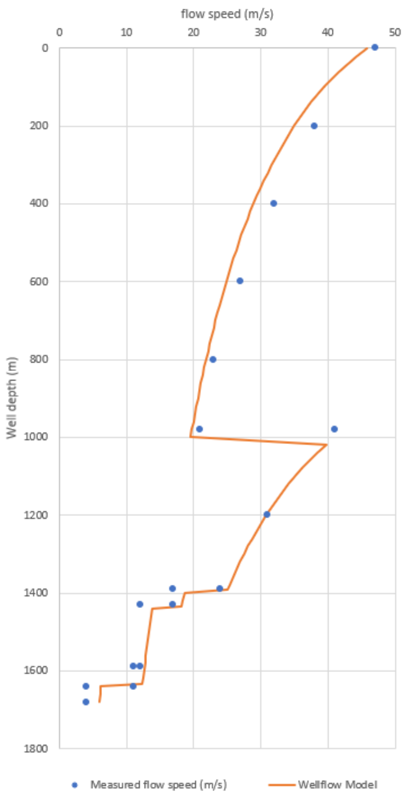

Figure 3: Velocity profile of the measured data and calibrated model for case 3.

Case 1: In this case, a production well from a single-phase liquid-dominated geothermal reservoir field (*1981 DSIR Ngawha - Sect 4 (Grant) & Summary.Pdf*, n.d.) was used to analyze the effect of reinjection of carbon dioxide into the system. In this well, both the feeds were in liquid conditions, and the wellhead pressure of 12 bar was used. Table 1 and Table 2 given below shows the well characteristics and reservoir properties for case study 1. Figure 4 below displays the two models developed with two different conditions: one when there is no carbon dioxide present while the other is in the presence of 1.5% of carbon dioxide. An increase in mass flow rate of about 30% occurred when the carbon dioxide was present.

Table 1: Well specifications for case 1

Measured lengths (m)	Diameter (m)	Inclination to vertical (degree)
745	0.22	90
205	0.168	85
270	0.168	80

Table 2: Reservoir properties for case 1

Feed zone	Reservoir properties		
	Measured Depth (m)	Pressure (bar)	Enthalpy (kJ/kg)
Feed 1	745	73	990
Feed 2	1220	111.2	973

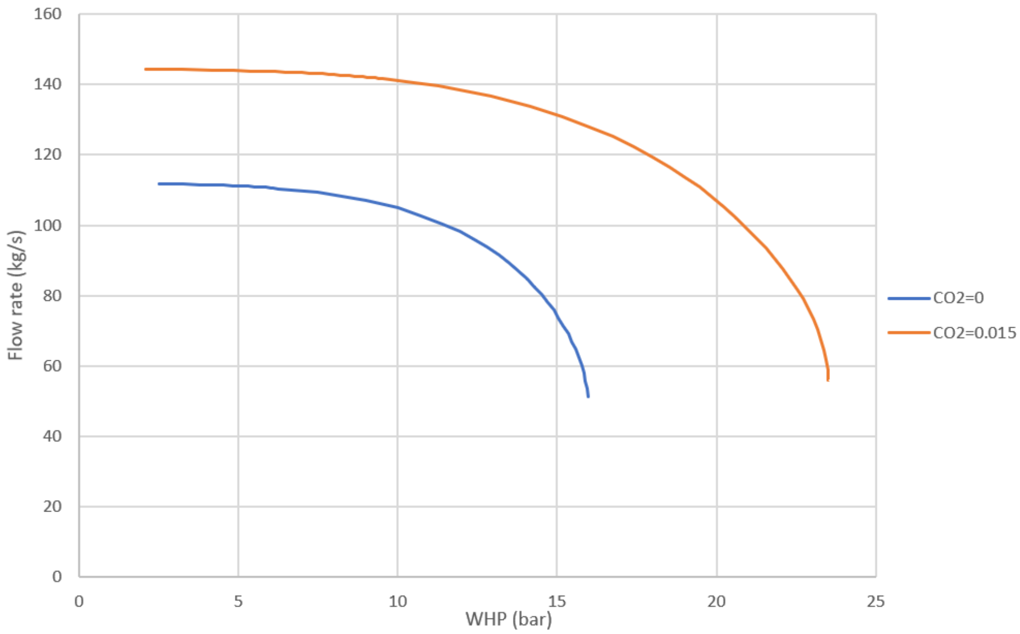

Figure 4: Simulated output for a well taken as case study 1

Case 2. In this case, the data of a production well in a single-phase liquid dominated geothermal reservoir field was used to analyze the effect of reinjection of carbon dioxide into the system. In this well, the top feed was steam, the bottom three were liquid (Peter & Acuna, 2010), and the wellhead pressure for this well of 10 bar was used. Table 3 and Table 4 given below shows the well characteristics and reservoir properties for case study 2. This well produced almost 25% more flow with the addition of 2% carbon dioxide than it made when no carbon dioxide was present (Figure 5).

Table 3: Well specifications for case 2

Measured lengths (m)	Diameter (m)	Inclination to vertical (degree)
393.2	0.384	90
831.2	0.315	78
199	0.255	69
228.6	0.206	70
588.3	0.164	70

Table 4: Reservoir properties for case 2

Feed zone	Reservoir properties		
	Measured Depth (m)	**Pressure (bar)**	**Enthalpy (kJ/kg)**
Feed 1	1264.9	47.3	2765.5
Feed 2	1639.8	71.1	1122.5
Feed 3	1697.7	75.4	1122.5
Feed 4	2203.7	113.7	1115.5

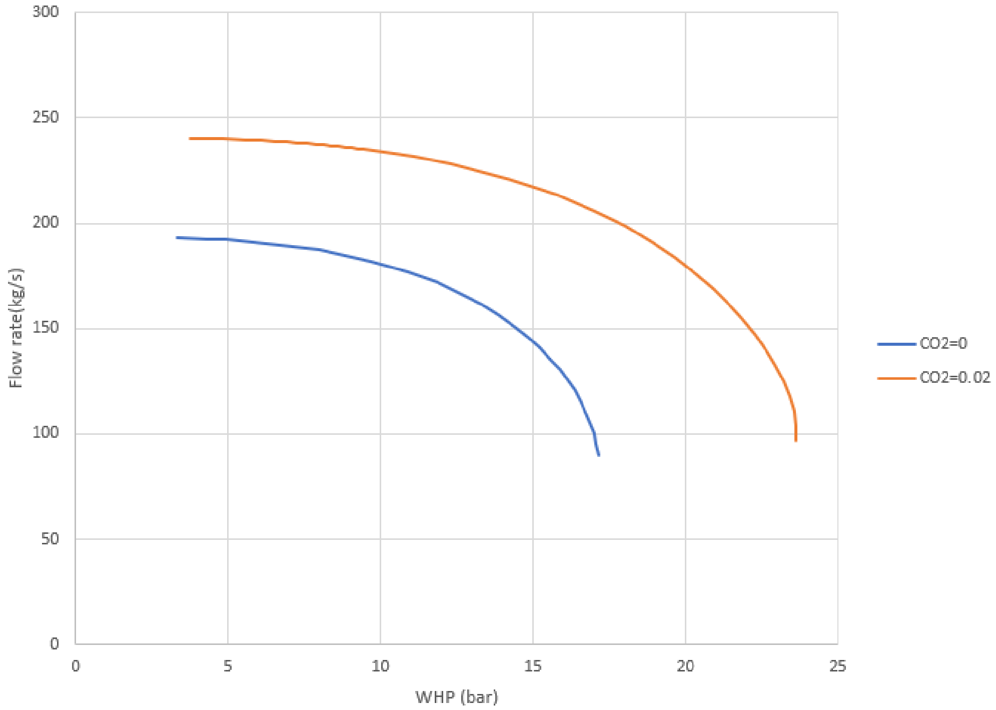

Figure 5: Simulated output for a well taken as case study 2

Case 3. In this case, the data of a production well from a two-phase liquid dominated geothermal reservoir field (Tokita & Itoi, 2004) was used to analyze the impact of reinjection of carbon dioxide into the system. The top well feeds were steam in this well, the bottom two were liquid, and the wellhead pressure of 8 bar was used. Table 5 and Table 6 given below shows the well characteristics and reservoir properties for case study 3. In this case, a decline in flow rate from the well is seen due to the presence of 2% carbon dioxide, while more fluid is produced while the gas was absent (figure 6).

Table 5: Case 3 well specifications Well specifications for case 3

Measured lengths (m)	Diameter (m)	Inclination to vertical (degree)
1000	0.22	90
678	0.152	90

Table 6: Reservoir properties for case 3

Feed zone	Reservoir properties		
	Measured Depth (m)	**Pressure (bar)**	**Enthalpy (kJ/kg)**
Feed 1	1392	52	1411
Feed 2	1433	54.9	1377
Feed 3	1634	56.9	1323
Feed 4	1678	61.8	1302

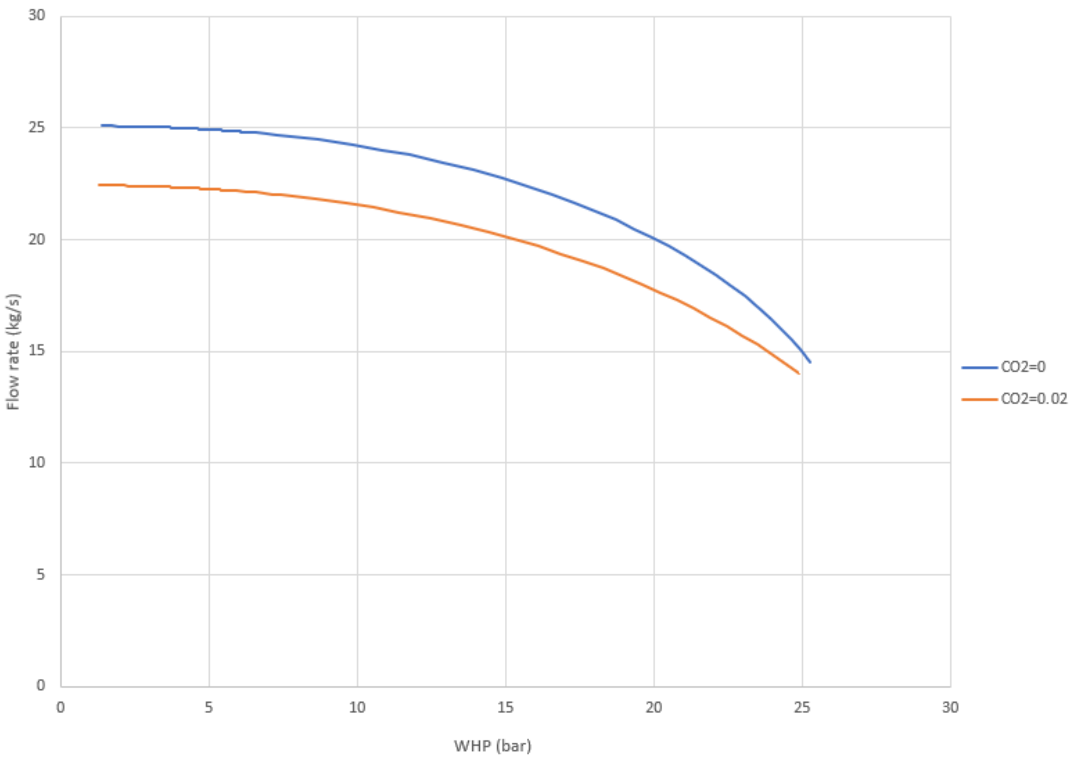

Figure 6: Simulated output for a well taken as case study 3

4. RESULTS AND DISCUSSION

The simulation models developed for three different case studies show the impacts of reinjecting gases are complex and vary with the reservoir conditions. Many processes take place, which impacts the thermodynamic properties of the reservoir and the properties of the production fluid.

For cases 1 and 2, which are liquid-dominated reservoirs, there was an increase in flow rate from the well. This finding results from boiling occurring at the deeper level in the wellbore when the gas was present. As the flashing occurs in the deeper depth, we have a larger column of less dense fluid. Consequently, for a given well head pressure a lower bottom hole pressure obtained, resulting in a higher flow rate.

Case 3 shows a different behavior. As the conditions in the reservoir are two-phase so there is no effect on the boiling depth, we can conjecture that the presence of CO_2 changes the mixture viscosity in the wellbore (compared to the case with no CO_2) resulting in a decreased flow rate. More cases with similar conditions need to be studied using wellbore modelling to test this behavior.

5. CONCLUSION

- The impact of CO_2 on flow in a wellbore is complicated because multiple processes contribute to output from a well.
- From our case studies, it appears that wells in liquid dominated reservoirs will exhibit reduced output if the gas concentration reduces.
- The presence of gases can change the depth at which boiling occurs in the wellbore, promoting a greater flow rate. However, if the fluid had already flashed when entering the wellbore, that effect might be nullified by the gases contribute to the fluid's viscosity.
- Individual reservoirs need to be tested for carbon dioxide impacts on production as our three test cases behaved differently.
- Our study suggests different types of reservoirs may display other behavior. More studies using wellbore modelling are needed to extensively understand the impact of carbon dioxide on flow rate and predict the production for any reservoir of interest.

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