Modelling of Completion Tests in Two Wells of the Wairakei–Tauhara Geothermal System, New Zealand

Sylvania Marchellina S.1, Mike O’Sullivan1, John O’Sullivan1, Kerin Brockbank2

1The University of Auckland, New Zealand
2Contact Energy Limited, Wairakei

Email: ssuh572@aucklanduni.ac.nz

Abstract. A completion test in a geothermal well, usually conducted soon after drilling is completed, consists of pumping water at various rates into the well and carrying out pressure, temperature and spinner (PTS) runs. Then after injection is stopped pressure and temperature runs are carried out while the well warms up. The spinner test helps to identify the permeable zones (feed-zones) in the well especially the reservoir characteristics. The warming-up temperature profiles also help to identify feed-zones. The analysis of the completion tests at present is mainly qualitative and the aim of the present study is to make it more quantitative by using the geothermal reservoir simulator TOUGH2 to simulate completion tests. In this study, modelling is conducted for two completion tests carried out in the Wairakei – Tauhara geothermal field, New Zealand. The tests were for WK242 (Wairakei) and THM15 (Tauhara). The simulations were carried out using AUTOUGH2, the University of Auckland’s version of TOUGH2. For both wells, manual calibration was used to improve the match of the model results to the measured data and additionally, for THM15 some inverse modelling was undertaken with iTough2. For both wells, a reasonable match to the data was obtained. It was found that WK242 has two inflows (around depth 450 m and 750 m) and one loss zone (below 950 m). However, THM15 has only one inflow (around depth 135 m) and a minor loss (around 112 m). The inflows and losses indicate the location of potential feed-zones.

1. Introduction

1.1. Completion Test
Completion tests are performed on most geothermal wells immediately after drilling when the slotted liner has been set. The test consists of injecting water into the well at three or four different rates and allowing the pressure to correct at each stage, typically requiring 1-2 hours. The injection phase is often followed by a pressure fall-off test and then the well is allowed to heat up.

During injection and heating-up a pressure-temperature-spinner (PTS) tool is run up and down the well. For heating up the PTS runs are carried out at increasing time intervals, e.g., 1 hour, 1 day, 1 week and 1 month. The spinner data and the temperature data can be used to deduce the location and importance of the feed-zones [7][6]. The injectivity of the well can be determined by plotting pressure at some representative depth, preferably a major feed-zone, versus injection rate. These pressures can be obtained from the PTS runs or by setting the tool at the selected depth during part of the injection phase [2]. Injectivity is a useful indicator of the expected performance of the well.

During heating-up the temperature profiles can be used to infer the locations and strengths of the feed-zones. As the well heat up the pressure gradient in the well changes, pivoting about a particular
point (sometimes called the pressure control point or PCP), indicating the location of either a single major permeable zone or the mean position between two or more feed-zones [7, 1]. The standard completion test uses a stepwise increasing injection rate that for vapour-dominated reservoirs the stepwise increasing phase should be followed by a second stepwise decreasing phase [3].

1.2. Wairakei – Tauhara Geothermal System

The Wairakei – Tauhara geothermal field, at the southern end of the Taupo Volcanic Zone, is a liquid-dominated reservoir in commercial operation since 1958 and currently operated by Contact Energy Limited (see Figure 1). It is probably the most investigated geothermal system in the world [1][5][8][15].

![Figure 1. Map of Wairakei – Tauhara Geothermal System [15].](image)

There is a combination of matrix permeability and fracture permeability in the Wairakei – Tauhara geothermal system. Ignimbrites and intrusive lava domes are located in the deeper part, with intraformational (matrix) pathways, while lava domes, sedimentary and pyroclastic aquifers are found in the shallow part, and control fluid flow through the geothermal system [1][15].

The Wairakei – Tauhara geothermal system has been of interest as a modelling test case for a number of years [9][11]. These studies have helped in understanding the large-scale permeability structure of the system. The objective of the research reported here is to use small-scale numerical models of completion tests in the Wairakei – Tauhara geothermal system, to develop a better understanding of the local, near-well, and reservoir characteristics.

1.3. Modelling a Completion Test

Usually completion test data is used to provide qualitative information about the reservoir permeability structure near the well. The aim of this study is to use numerical modelling of completion tests to make the analysis more quantitative.

This study focuses on numerical models of two wells: WK242, on the Wairakei side of the geothermal system and THM15, on the Tauhara side of the geothermal system. Both wells are vertical, however WK242 is deeper and hotter than THM15.

For both cases the reservoir simulator AUTOUGH2 is used to model the completion tests. AUTOUGH2 [17][12][13] is the University of Auckland’s version of TOUGH2 [14]. The whole system
of the well and the reservoir are considered in the model, but an approximation is made by treating the wellbore as a very high permeability and high porosity porous medium. Since most of the flow in the wellbore involves cold or hot water, and no two-phase flow of water and steam, this approximation is expected to be satisfactory.

Calibration of the models is carried out to match the model results to the completion test data and parameters from the best-fit models provide quantitative information about the reservoir permeabilities and porosities and thus identifies the feed-zones. The study uses manual calibration based on forward model runs with AUTOUGH2 and also some automatic calibration based on inverse modelling with iTOUGH2 [4].

The methodology for this study is summarised in Figure 2. It is started with the development of the numerical model based on the conceptual model, including setting up of the rock properties and heat source. The results from the TOUGH2 simulation are compared with the field data. If the results do not match the measured data very well, (i.e. temperature and pressure), the model parameters (i.e. permeability and porosity) need to be adjusted. The forward simulation with TOUGH2 needs to be re-run until a satisfactory fit between measured data and computed results is obtained.

Inverse modelling analysis is carried out once the manual calibration has achieved a reasonable fit. This analysis aims to determine the model parameter values more accurately. The rock properties, permeability and porosity, are better calibrated using iTOUGH2.

Some experimentation with iTOUGH2 was required to achieve good results. In particular some adjustments were made to the weights applied to various data points in calculating the objective function.
(the weighted sum of squares of errors between the model results and measured data) minimised by iTOUGH2. This process forces iTOUGH2 to give higher priority to fitting some of the data.

2. Numerical Models of WK242 and THM15

2.1. Grid System
The model of WK242 is two-dimensional radially symmetric (R-Z) with a very fine grid near the well. To avoid any boundary effects the model is extended a large distance (16,825 m) in the horizontal (radial) direction. In the vertical direction it extends to a depth of 1200 m, 100 m below the bottom of the well. The grid consists of 99 columns (increasing ΔR) and 96 layers (constant ΔZ=12.5 m), giving a total of 9,504 blocks. Figure 3 shows a part of the model grid, extending out to a radius of approximately 2 m. It shows the very fine grid near the well that enables the conductive heat flow to the well to be accurately represented. It also enables the well liner to be represented by a single column.

![Figure 3. Part of model grid for WK242 (out to a radius of ~2 m).](image)

![Figure 4. Vertical slice through the model grid for WK242 (out to a radius of ~1 m).](image)

Figure 4 shows part of a vertical slice through the model grid out to a radius of approximately 1 m. As with WK242, the THM15 model is a two-dimensional radially symmetric (R-Z) model. The horizontal grid structure for both models is almost identical but as THM15 is much shallower than WK242, for THM15 the model is divided into 40 layers in the vertical direction (with a constant ΔZ= 5 m). The total number of blocks in the THM15 model is 3,960.

2.2. Rock Properties
The initial rock-type distribution assigned to the elements in the model was based on the geological model used in the large-scale computer model of Wairakei–Tauhara developed at the University of Auckland. In the model, the physical properties associated with the rock-types are: density, porosity, xyz permeabilities, thermal conductivity and specific heat.

In addition to the rock formations, there are other materials also used in the model, namely the well, casing and liner. The properties of casing and liner are 7,900 kg/m³ for the material density, 45 W/m.K for the thermal conductivity, and 490 J/kg.K for the specific heat. The higher thermal conductivity of the casing and liner means that those materials conduct heat better than rocks. The casing is made impermeable and the liner is assigned a very high permeability. The “well” rock-type is assigned a porosity of 0.99 and a very high permeability of 1.0E-6 m².

The rock grain density used in the model is 2,200 kg/m³, and the thermal conductivity is 1.17 W/m°C. Most of the rocks in the WK242 model have a porosity of 0.18, except for Superficial formation (SF) and Rautehuia breccia (RBy) (see Table 1).
Table 1. Rock names and model abbreviations for both wells.

|岩层名称 | 缩写 | 岩层名称 | 缩写 |
|--------|------|--------|------|
| Superficial Formation | SF | Post Oruanui Tephra | TPHRA |
| Oruanui Formation | OF | Oruanui Formation | ORUAN |
| Huka Falls | HF | Alluvium | ALLUV |
| Rautuhaia Breccia | RBy | Upper Huka Falls | UHUKA, UHUKB, UHUKC, UHULD |
| Waiora Formation | WO8, WO4, WOs | Mid Huka Falls | MHUKA, MHUKB, MHUKC, MHUKD |
| Karapiti Rhyolite | Kbs, Kb5 | Lower Huka Falls | LHUKA, LHUKB, LHUKC, LHUKD, LHUCE, LHUKF |

The well is represented by the first column of the WK242 model. The second column represents the casing (from the top surface to a depth of 575 m) and liner (from a depth of 575 to 989.8 m) of the well (see Figure 5). All the other columns represent the reservoir rock surrounding the well.

The initial permeability of the reservoir rocks in the WK242 model varied from 0.5 mD to 2200 mD in the horizontal direction and 0.5 mD to 200 mD in the vertical direction. To assist with model calibration the upper zone of the Waiora formation (WO rock-type) is divided into three sub-categories and the Karapiti rhyolite (Kb rock-type) is divided into two sub-categories (not shown).

The rock-type structure of the THM15 model is shown in Figure 6. In the THM15 model, most of the rock has a porosity of 0.05, except for Post Oruanui Tephra (TPHRA) and Alluvium (ALLUV) (0.15) and Mid Huka Falls (MHUK) (0.10). As in the WK242 model, in the THM15 model the well is represented by the first column. The second column represents the well casing (from the top surface to a depth of 100 m) and liner (from a depth of 100 to 155 m).

The initial permeabilities in the THM15 model range from 1 to 200 mD in the horizontal direction and 0.5 to 40 mD in the vertical direction, respectively. Again to assist with model calibration the Upper, Mid and Lower Huka Falls formations (UHUK, MHUK, LHUK rock-types) are divided into sub-categories (not shown).

2.3. Boundary and Initial Conditions

Top boundary: In the WK242 model the first layer is assigned a temperature of 18.3°C and pressure of 1 bar. The THM15 model has a lower surface temperature than in the WK242 model with the first layer assigned a temperature of 14.0°C. This imposes the atmospheric pressure and temperature conditions at the top of the model.
In addition, during the simulation of heating-up, leakage into or out of the top of the well is allowed by assigning a recharge boundary condition to the top block in the well. The recharge coefficient is set to 1.0E-09 m$^3$, the recharge enthalpy is set to the value corresponding to the atmospheric temperature and the recharge pressure is atmospheric (101,350 Pa).

Figure 5. WK242 model showing the well (no colour), casing, liner and formations.

Figure 6. THM15 model showing the well (no colour), casing, liner and formations.
**Side and base boundary:** The side and base boundaries are treated as no-flow boundaries (i.e. no heat or mass coming into or out of the system). The side boundary of the model grid is designed to be far enough away from the well that boundary effects do not affect the system.

**Initial conditions:** The initial temperature distribution in each model was set to the final stable heated up temperature. A quasi-equilibrium pressure distribution was obtained by running the models for a few time steps with the specific heat of all rock-types set to a high value. Then this was used as the initial pressure distribution.

### 2.4. Calibration of the Model of WK242

The completion test simulation was divided into two stages. In the first stage, cold water is injected into the wellbore at different rates. Then, during the second stage, heating-up is simulated with results being output at various times (e.g. 1 hour, 1 day and 1 week). The results from the WK242 model at 6 times, as shown in Table 2, were kept and compared with the data.

In the calibration process, permeabilities and porosities were adjusted to match the model results to the temperature and pressure profiles of the well at the key observation times (see Table 2). The upper and lower bounds of horizontal and vertical permeability were set to be 1000 and 0.001 mD, respectively. For porosity, the upper and lower bounds were set to 0.3% and 35%, respectively. These limits were applied during the calibration process.

| Time (seconds) | Remarks               |
|---------------|-----------------------|
| 16,800        | Injection at 120 tonnes/hour |
| 21,180        | Injection at 84 tonnes/hour   |
| 23,880        | Injection at 42 tonnes/hour   |
| 29,880        | Heating-up for 1 hour      |
| 115,980       | Heating-up for 1 day       |
| 594,000       | Heating-up for 7 days      |

The aim of the calibration process is to adjust the model parameters (permeabilities and porosities) to obtain a good match of the model results to the observed data. Matching all the data during both the injection and the heating-up stages was not an easy task. Some of the model settings (e.g. liner depth) were not accurately known and may also affect the model results.

Originally, the permeability values of the reservoir rocks in the WK242 model varied from 0.5 mD to 2200 mD (see Table 3). In the first stage of manual calibration, permeabilities of the rock-types from the surface to a depth of 400 m were changed. A change from 700 mD to 1 mD in the horizontal permeabilities had a significant effect on the temperature profiles, but a lesser effect on the pressure profiles. The permeabilities of rock-types WOs, Kbs, Kb5 and WOe were decreased successively by 20%, 50% and 100%. These changes improved the pressure and temperature profiles for WK242.

The porosities of the rocks were also varied, producing much less significant changes in the temperature and pressure profiles. Thus variations in porosity were not considered further.

The final step of manual calibration of the WK242 model targeted depths from 600 to 800 m. The following horizontal permeabilities were assigned in the model: 0.3 mD for WOs and Kbs; 7.5 mD for Kb5. The simulation results show a good agreement with the temperature and pressure profiles. Table 3 summarises the parameters for the initial model and the best manually calibrated version of the WK242 model. Permeabilities are in milli-Darcies ($10^{-15}$ m$^2$).

### 2.5. Calibration of the Model of THM15

Data at 4 observation times were used for calibrating the model of THM15, as shown in Table 4. In the model of THM15, 17 rock-types were assigned as a starting point for model calibration. The assigned
rock-types with associated permeabilities are shown in Table 5. The available measured data set for calibration includes the temperature and pressure during the injection test and heating-up period.

Table 3. Initial values and best manually calibrated values of rock permeability in the WK242 model.

| Depth | Rock-Type | Permeability (mD) | Permeability (mD) |
|-------|-----------|------------------|------------------|
|       |           | Initial model    | Calibrated model |
| 0-50  | SF        | 700              | 1050             |
| 50-200| OF        | 700              | 1050             |
| 200-275| HF       | 0.5              | 0.75             |
| 275-425| RBy      | 2200             | 3300             |
| 425-475| WO8      | 800              | 1200             |
| 475-725| WO4      | 400              | 900              |
| 725-775| WOs      | 50               | 0.30             |
| 775-825| Kbs      | 50               | 0.30             |
| 825-1025| Kb5   | 500              | 7.5              |
| 1025-1200| WOe | 1                | 0.015            |

Table 4. Output times where observation data are available for THM15.

| Time (seconds) | Remarks                      |
|----------------|------------------------------|
| 8,180          | Injection at 11 tonnes/hour  |
| 12,170         | Heating-up for 1 hour       |
| 181,090        | Heating-up for 2 days       |
| 644,555        | Heating-up for 7 days       |

2.5.1. Forward Modelling of THM15
The initial model of THM15 had horizontal permeability values between 1 mD and 200 mD. The vertical permeability values ranged between 0.5 mD and 40 mD (see Table 5). In the first stage of calibration, all permeabilities were gradually increased by 20%, 50% and then 100%. The changes in the results were observed to identify which parameters needed to be adjusted. It was found that the simulated pressure profile during injection moved closer to the measured data.

The following stage involved adjusting the rock permeabilities around the depths of 100 to 150 m. This depth range was represented by the following rock-types: UHUKB, UHUKC, UHU KD, MHUKA, MHUKB, MHUKC, MHUKD, LHUKA and LHUKB. These rock-types initially had low permeabilities. The permeabilities at these depths had to be increased by a factor of 10 for the model results to fit with the temperature data. The best set of parameters from this manual calibration process were used as the initial guess in the model that was subjected to automated calibration with the inverse modelling technique. Table 5 summarises the values of rock permeability for the best manually calibrated model.
## Table 5. Initial set up and best manually calibrated values of rock permeability in the THM15 model.

| Depth  | Rock-Type | Permeability (mD) | Permeability (mD) |
|--------|-----------|-------------------|-------------------|
|        |           | Initial model     | Calibrated model  |
|        |           | $r$ $z$           | $r$ $z$           |
| 0-40   | TPHRA     | 200 40            | 400 80            |
| 40-65  | ORUAN     | 20 4              | 40 8              |
| 65-85  | ALLUV     | 100 20            | 200 40            |
| 85-100 | UHUCA     | 20 4              | 40 8              |
| 100-105| UHUKB     | 20 4              | 40 8              |
| 105-110| UHUKE     | 20 4              | 40 8              |
| 110-115| UHUKD     | 20 4              | 40 8              |
| 115-120| MHUCA     | 40 8              | 80 16             |
| 120-125| MHUKB     | 40 8              | 80 16             |
| 125-130| MHUKC     | 20 4              | 40 8              |
| 130-135| MHUKD     | 20 4              | 40 8              |
| 135-140| LHUKA     | 1 0.5             | 2 1               |
| 140-145| LHUKB     | 1 0.5             | 2 1               |
| 145-150| LHUKC     | 1 0.5             | 2 1               |
| 150-155| LHUKD     | 1 0.5             | 2 1               |
| 155-160| LHUKE     | 1 0.5             | 2 1               |
| 160-200| LHUKF     | 1 0.5             | 2 1               |

### 2.5.2. Inverse Modelling of the THM15 Completion Test

The THM15 inverse modelling process started with the initial estimate of the permeabilities for the 17 reservoir rock-types used in the THM15 model. Each rock-type contributes three parameters: the horizontal permeability, the vertical permeability, and the porosity. The upper and lower bounds for permeability were set at 1000 mD and 0.001 mD respectively, while the upper and lower bounds for the porosity were set at 0.35 and 0.003, respectively.

For the model with the initial estimates of parameter values, an objective function of 38,300 was calculated. The simulator iTOUGH2 adjusts the parameters iteratively until convergence is achieved (i.e. the objective function is no longer decreasing). The result of the first optimisation showed a total reduction of 29,804 in the objective function. This corresponds to a 77.87% reduction in the objective function. The sensitivity analysis of porosity and permeability for each rock-type and its effect on the objective function is shown in Figure 7 and 8.

Figure 7 illustrates the sensitivity results for porosity. It shows that the most important parameters are the porosity of UHUKE, followed by the porosities of MHUKA and UHUKE.

Figure 8 shows the permeability parameters that have the most influence and those with the least influence on the fit of model results to the data. In particular it shows that the most influential parameters in the model are the horizontal permeability of UHUKE, followed by horizontal permeability of UHUKE, LHUKE and UHUKE.

The original weight of the observed pressure in the objective function was 0.001 and it was gradually increased to 0.002, 0.005 and finally to 0.5 in an effort to improve the fit of the model results to the pressure profiles. A better match was achieved with the weight of 0.5. For the temperatures, the weight was varied from 1 to 10, with the highest value given to the temperature observations that were poorly matched with the early iTOUGH2 results.

A sequence of twenty-four iTOUGH2 simulations were carried out experimenting with the weights for the various observations. This was a frustrating process as several of the simulations produced little or no improvement in the objective function. The best fit to the measured data was achieved with simulation #8, with a final objective function value of 3,772.
For this simulation, the weight of the temperature observations was set to 2 for layers between 90 m and 140 m depth, except in two layers centered at 112.5 m and 132.5 m depth where it was set at 1. For pressure observations, in all layers the weights were set to 0.5. Table 6 shows the best estimates for the rock permeability.

![Figure 7](image)

**Figure 7.** Sensitivity of the objective function to the porosity for each rock-type in the THM15 model (before optimisation).

**Table 6.** Manually and automatically calibrated values of rock permeability for the THM15 model.

| Depth  | Rock-Type | Permeability (mD) Manual Calibration | Permeability (mD) Automatic Calibration |
|-------|-----------|--------------------------------------|----------------------------------------|
|       |           | r         | z         | r         | z         |
| 0-40  | TPHRA     | 400       | 80        | 1.06E-3   | 1.0E-3    |
| 40-65 | ORUAN     | 40        | 8         | 1.00E-3   | 2990      |
| 65-85 | ALLUV     | 200       | 40        | 3160      | 1.06E-3   |
| 85-100| UHUKA     | 40        | 8         | 1.06E-3   | 1.0E-3    |
| 100-105| UHUKB    | 40        | 8         | 29.2      | 1.0E-3    |
| 105-110| UHUKC    | 40        | 8         | 0.142     | 1.0E-3    |
| 110-115| UHUKD    | 40        | 8         | 91.5      | 1.03E-3   |
| 115-120| MHUKA    | 80        | 16        | 1.06E-3   | 1.04E-3   |
| 120-125| MHUKB    | 80        | 16        | 1.06E-3   | 1.06E-3   |
| 125-130| MHUKC    | 40        | 8         | 3.96      | 2.1       |
| 130-135| MHUKD    | 40        | 8         | 322       | 1.12E-2   |
| 135-140| LHUKA    | 2         | 1         | 0.318     | 3160      |
| 140-145| LHUKB    | 2         | 1         | 0.486     | 3160      |
| 145-150| LHUKC    | 2         | 1         | 0.929     | 3160      |
| 150-155| LHUKD    | 2         | 1         | 2.1       | 0.321     |
| 155-160| LHUEK    | 2         | 1         | 2990      | 8.68E-2   |
| 160-200| LHUKF    | 2         | 1         | 3160      | 2990      |
The results shown in Table 6 are not entirely satisfactory as they show several of the parameter values have gone to very small values (1.0E-18 m$^2$) or very high values (3160 m$^2$). These correspond to lower and upper bounds, respectively, and they are an indication that those parameter values are not well determined by the observations and the overall inverse modelling problem is ill-posed. There are two ways of dealing with this problem: (i) discard those parameter values and re-set them to the initial estimates, or (ii) include regularisation by adding to the objective function a term that penalises change from the initial parameter values. The second method has the effect of keeping parameters that are not identified by the data close their initial values. For future work, regularisation options will be investigated further.

3. Result and Discussion

3.1. Simulation Results for WK242
The results for the best model are shown above. Figure 9 shows results for injection at 84t/h, Figure 10 shows result for injection at 42t/h, Figure 11 shows results for heating-up after 1 hour and Figure 12 shows results for heating-up after 7 days.

The match to pressures in Figure 9 is very good and the match to temperatures is good. The mismatch in the temperatures between depths of 500 m and 600 m may be due to the casing being set too low in the model. The cooling between 800 m and 1000 m depth is more widely spread in the model results than in the data. It may be possible to improve the match by subdividing the Kb5 rock-type into several sub-categories.
Similarly the match to pressures shown in Figure 10 is very good and the match to temperatures is also good. As with the results in Figure 9 the mismatch in the temperatures between depths of 500 m and 600 m may be due to the casing being set too low in the model.

The 1 hour heating results shown in Figure 11 are good for both temperature and pressure. For the 7 day heating results shown in Figure 12 the match to the pressures is very good and the match to the temperatures below 350 m model is also satisfactory. However, above 350 m in the model there is a small upflow of steam which maintains a nearly constant temperature of 221˚C up to the surface, whereas the data shows much cooler temperatures and no upflow of steam. This is likely due to the top boundary condition of the model allowing fluid flow. Modification of the top boundary condition may be required to improve the match to shallow temperatures. This zone is well above the end of the casing and therefore the mismatch to the data there does not affect how well the model calibration process is determining the feed-zones below the casing.

From the temperature and pressure analysis of simulated and measured data, it can be deduced that WK242 well is very permeable.

Figure 9. WK242 temperature and pressure profiles - Injection at 84 t/h.
Figure 10. WK242 temperature and pressure profiles - Injection at 42 t/h.

Figure 11. WK242 temperature and pressure profiles after heating-up for 1 hour.
3.1.1. Potential Feed-zone(s)

Based on the field data and simulated profiles for the temperature and pressure, as well as the reservoir rock permeabilities, it can be ascertained that WK242 has multiple feed-zones. From Table 3 and temperature and pressure profile analysis, it can be concluded that the vapour-dominated zone around depth 560 – 630 m (WO4) is more permeable than other formations, with the permeability ranging between 300 – 900 mD.

The first feed-zone, identified around depth 400 m (RBy), is accepting the steam from the 560 – 630 m zone. The rock has permeability ranging from 300 to 3300 mD. Another feed-zone is most probably located around a depth of 750 m, related to an inversion, with the permeability ranging from 0.3 to 18 mD. Another feed-zone is at 930 – 950 m (Kb5) with the permeability ranging from 7.5 mD to 300 mD.

3.2. Simulation Results for THM15

Results for THM15 are shown in Figures 13 - 16. The match to the temperatures is good in all cases. The match to the pressures is very good except for the 1 hour heating profile (Figure 14). In this case the data indicates that the water level in the well has not dropped significantly, whereas in the model it has dropped to around 30 m. Some further experimentation with the leaky boundary condition at the top of the well may produce an improvement.

The temperature profiles for 2 days and 7 days heating up both show small temperature reversals between 110 – 115 m and between 125 – 135 m. These are both well matched by the model.

The temperature profiles during heating-up, show that the well heats up quite slowly due to the very low permeability of the reservoir rocks, and after a week, the temperature has only reached 73°C.

3.2.1. Potential Feed-zone(s)

Based on table 6 and analysis of the temperature and pressure profiles, there are two main feed-zones. The first feed-zone is between 110 – 115 m (UHUKD), and the second is between 130 – 135 m (MHUKD). These zones are evident from the increase in temperature gradient during injection, as seen in Figures 15 and 16. The permeability values in the first feed-zone is 91.5 mD, while the second is 322 mD.
3.2.2. Sensitivity Results
A sensitivity analysis was conducted to identify the most important rock-types in the model. Changes in the parameter values in these rock-types will affect the simulation result most strongly.

The model behaviour of THM15 is sensitive to changes in the permeability and porosity values of particular rock-types. The most important rock-types are UHUKD and MHUKD at depths 110 m to 135 m respectively, consistent with the location of the two feed zones identified. From the many optimisation runs that were completed, the sensitivity analysis gave the consistent results, that the permeability associated with the UHUKD and MHUKD rock-types affected the model results most significantly. On the other hand, the model results were less sensitive to changes in the rock porosity as opposed to changes in the permeability.

The permeability of the UHUKD ranges from 0.001 mD to 91.5 mD, and MHUKD ranges from 0.0112 mD to 322 mD. It shows that the most sensitive parameters are the permeability of rock-types which are assigned to the permeable zones.

Figure 13. THM15 temperature and pressure profiles - Injection at 11 t/h.
Figure 14. THM15 temperature and pressure profiles – heating 1 hour.

Figure 15. THM15 temperature and pressure profiles – heating 2 days.
4. Conclusion
The main objective of this study was to develop numerical models of completion tests in the WK242 and THM15 wells. These numerical models were able to capture the most significant information related to each well, such as the potential feed-zone associated with the reservoir parameters (i.e. permeability and porosity). Accordingly, it is recommended that the numerical modelling of the completion test be undertaken before the production stage.

WK242 has two inflows (around depth 450 m and 750 m or at the RBy and WOs rock-types, respectively) and one loss zone (below 950 m in the Kb5 rock-type). THM15 has one inflow (around depth 135 m in the MHUKD rock-type) and minor loss (around 112 m in the UHUKD rock-type). The inflows and losses indicate the location of a potential feed-zone(s).

The study investigated the sensitivity of the model behaviour with respect to changes in permeability and porosity. Due to limited time, the sensitivity analysis was only carried out for the THM15 model through inverse modelling process with iTOUGH2. The results show that the model behaviour of THM15 is sensitive to changes in permeability rather than porosity. The model behaviour is most sensitive to the properties of the UHUKD and MHUKD rock-types for THM15, consistent with where the feed zones were identified.

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