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Numerical Analysis of MCY01 Production Well Mechanism: Understanding of Well "Coughing" Phenomenon and Irregular Productivity

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ABSTRACT

Production well optimization is one of the key elements to the success of geothermal power plant operation. The MCY01 production well has been in operation since 2013 to supply steam to one of the Mercury-operated geothermal plants. Since 2015, MCY01 has been experiencing an irregular cycle or coughing phenomenon in which well head pressure (WHP) and productivity vary while flow control valves (FCV) are set constant. In order to optimize its production, an evaluation has been carried out to understand the production coughing mechanism.

The most likely hypothesis of MCY01 irregular performance is thought to be due to competing feed zones (FZ) and the fluid connectivity of each feedzone to neighbouring wells. Flowing PTS (pressure, temperature, and spinner) analysis from 2013 to 2015 indicates the flow rate contribution of the bottom two feed zones have changed significantly over time.

In order to validate the hypothesis of the competing feed zones, the numerical model, coupled with wellbore simulator, has been developed. Mercury's internal wellbore simulator (Paiwera) is designed to model single phase, two-phase and steam flow in geothermal wells. It identifies the adjustments to perform at its best in simulating the diverse characteristics found in the reservoir during production. When the production time is updated, the wellbore simulator delivers the updated flow rate change at each feedzone with the time from the reservoir into the wellbore.

The numerical model is well processed and MCY01 mechanism is explained by the competing feed zone numerical model. The summary of MCY01 numerical model analysis are:

- The MCY01 reservoir pressure trend is determined by the total produced mass of nearby production wells (MCY02/03).
- The long-term WHP increment is not due to reservoir pressure recovery. The mobility change due to saturation causes deliverablity curve changes at specific WHP pressure.
- The numerical model suggests the irregular coughing phenomenon could be minimized when MCY01 is operated at the non-coughing zone.
- Decline rate analysis at the normalized WHP of 24 barg is conducted based on generated deliverability curve from simulation during calibration and scenario periods.

The process of MCY01 competing feed zone model and analyzed simulation results discussed in this paper demonstrates how the numerical model evaluation addresses the better understanding of the geothermal reservoir and practical recommendations on reservoir field survey.

1. INTRODUCTION

Mercury NZ ("Mercury"), formerly known as Mighty River Power, both retails and generates electricity in New Zealand. Generation of electricity is at present from two fuel sources, these being hydro and geothermal. Mercury operates five geothermal power plants across four different high-temperature geothermal fields in the Taupo Volcanic Zone in the central North Island of New Zealand, with some plants operated on behalf of joint-venture partners. The geothermal power plants operate as base-load generators, thus they require stable production flows to the power plant to ensure high capacity factors. Periodically make-up wells are drilled, and MCY01 began production in 2013.

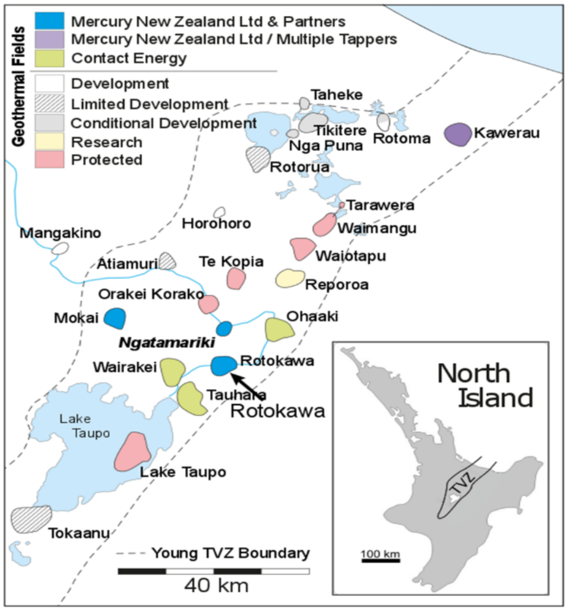

Figure 1: Location of known geothermal fields in the Taupo Volcanic Zone (TVZ) on the North Island of New Zealand as identified by Schlumberger resistivity surveys (Bibby et al., 1995).

Since mid-2014 MCY01 has seen irregular well performance, with productivity changes both upwards and downwards with a constant FCV position. This observed irregular cycle or production coughing is shown in 2. The more frequent production coughing is observed from mid-2015 to mid-2016. The pattern of coughing phenomenon is irregular oscillation and during coughing phenomenon, the production rate had declined. To limit the rate of coughing, operation of the well. It is then followed by productivity increase and less frequent coughing started from mid-2016.

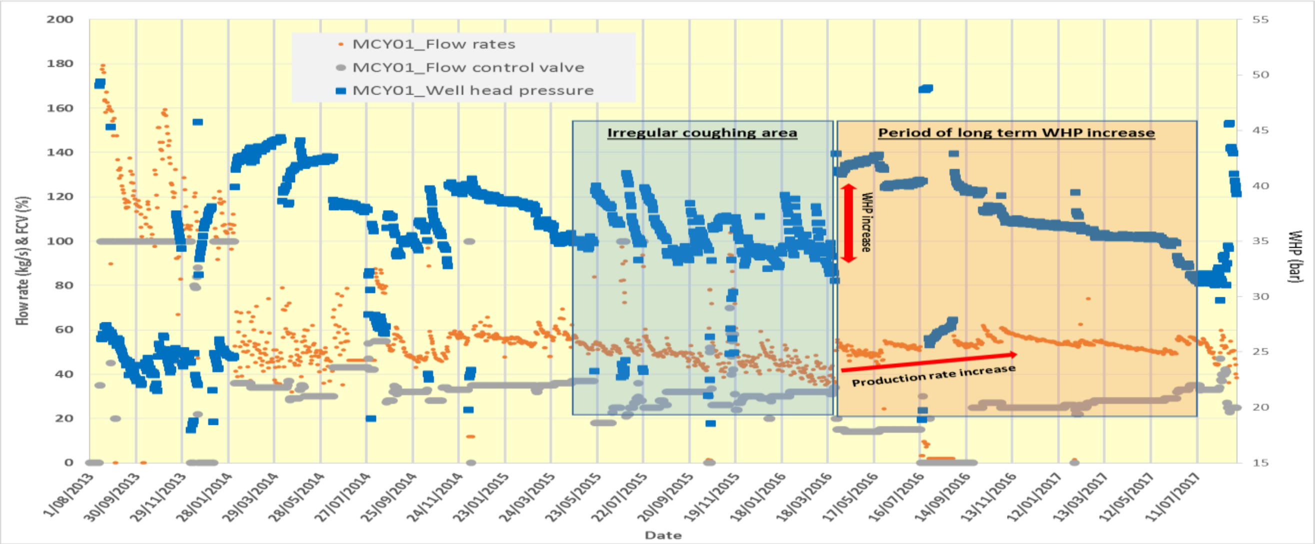

Figure 2: Measured MCY01 production, well head pressure (WHP) and Flow control valve (FCV).

Stable well flows are important at the power plant, as there are flow limits within the power plant. When coughing of the MCY01 well occurs automatic responses are not fast enough and therefore either the set-point needs to be lowered (with a plant generation output reduction) to allow for coughing to occur or manual operator intervention is required. To understand better the cause and well operation options an analytical process has been conducted using surface data and several down hole surveys, providing some rational hypotheses. The most likely hypothesis is that the two feedzones (FZ) have been competing with each other, resulting in an irregular WHP coughing phenomenon. When the WHP was increased in March 2016 the longer-term productivity increase after this point is thought to be caused likely by a deliverability curve change (due to mobility changes) and not due to reservoir pressure recovery.

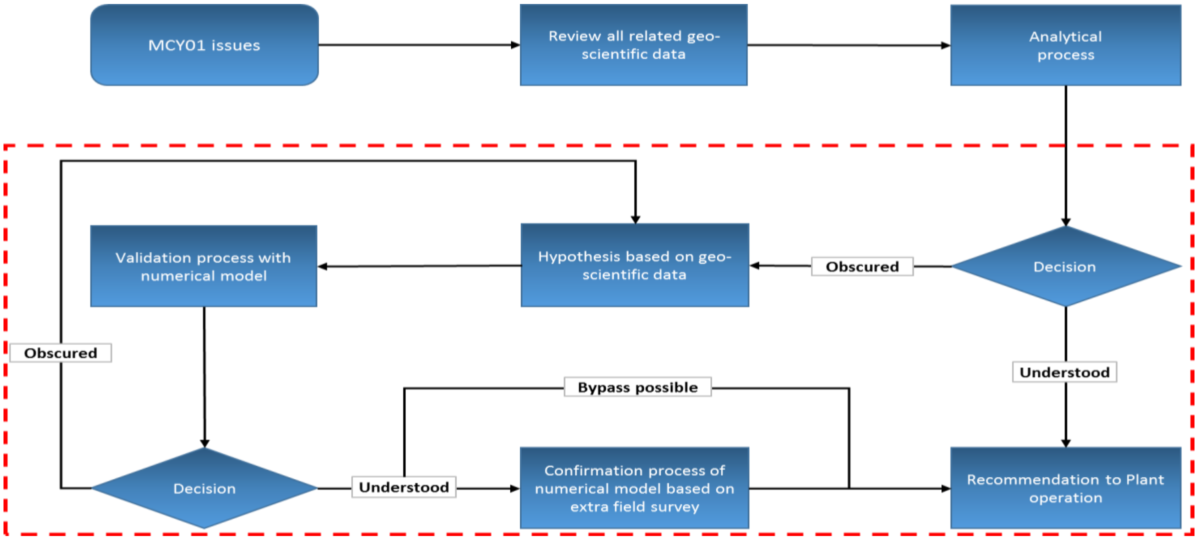

Figure 3: MCY01 coughing phenomenon flowchart

Figure 33Figure 3 shows the MCY01 production well problem-solving process. However, the understanding of MCY01 mechanism was not clear because there is limited subsurface data to validate the hypotheses. To reveal a valid understanding of the MCY01 mechanism, it is necessary to have a better understanding of reservoir behaviour in the vicinity of MCY01. The red dash in Figure 33 describes the hypotheses validation process with a numerical model coupled with wellbore model. The primary objective of this evaluation is to validate the hypothesis that MCY01 has competing feed zones, and to understand reservoir changes with time and the correlation between wellbore and reservoir pressure changes. Moreover, the numerical model also provides quantitative predictions of future reservoir conditions and production characteristics for various well operation strategies.

2. NUMERICAL MODEL SET-UP

The MCY01 competing feed zone model has been built and calibrated to understand the well performance of MCY01. The three-dimensional 3087 block grid system covered an area of 0.75 km by 0.51 km with an elevation of 50 m down to -3050 m. This is shown in Figure 44.

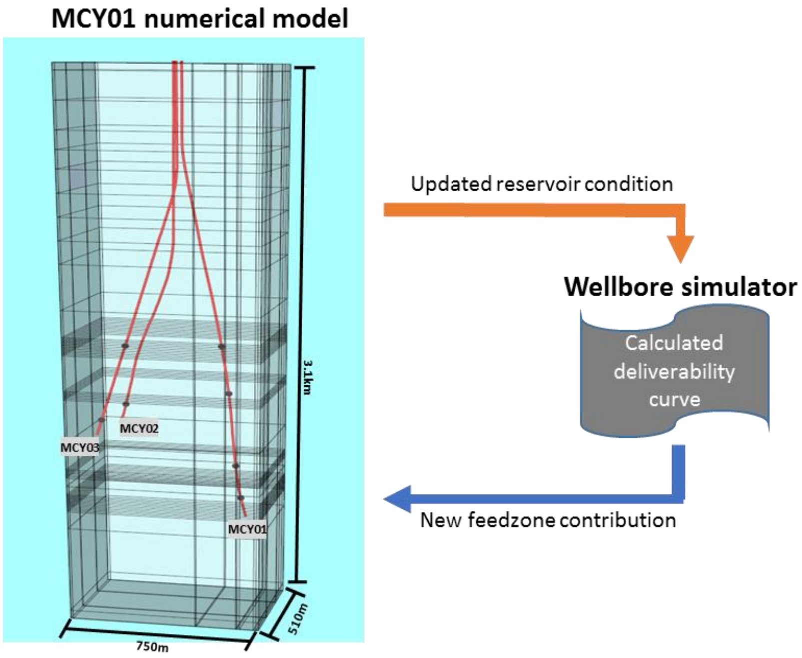

Figure 4: MCY01 competing feed zone model

The model overview and boundary conditions are:

- MCY01 feed zones are highly discretized (only 10m thick blocks)
- The production wells of MCY01/02 are included. No calibration process was conducted. MCY01/02 represents flow connectivity to MCY01 area
- All production wells are coupled with wellbore simulator
- Boundary conditions:
    - Upflow: 10 kg/s at 1370 kJ/kg
    - Fixed blocks (FB): marginal recharges from fixed blocks. It allows the MCY01 model to behave like a normal full-field model
        - FB1 at -600m: intermediate aquifer
        - FB2 at -1400m: shallow reservoir recharge
        - FB3 at -1745m: main reservoir recharge
        - FB4 at -2198m: deep reservoir recharge

3. SIMULATION RESULTS AND HYPOTHESIS TO NUMERICAL MODEL

The productivity of MCY01 shows a steady decline after commissioning and no noticeable change in enthalpy has been observed over that time period. However, as mentioned, it is important to understand the cause of irregular well coughing and long-term WHP increases as these impact on both the well asset and wider reservoir management strategies. Based on the geoscientific data, the most likely hypothesis that cause the observed well behavior was defined and the numerical model was used to enhance understanding of the hypothesis.

In this paragraph, the calibration results between measured data and simulation results will be discussed as well as how the hypothesis was applied to the numerical model.

Figure 55 shows the matching of WHP and enthalpy between the model simulation and measured data. The calibration results indicate that the trend of MCY01 productivity decline is highly correlated with neighbouring wells of MCY02/03. When the history of MCY01 production flow rates and WHP are compared shown in Figure 2, it was often found that the WHP trend contradicts the MCY01 production flow rates. When the production flow rate is increased, the WHP should be reduced. However, it is intermittently observed that the production rates and WHP increased or decreased at the same time.

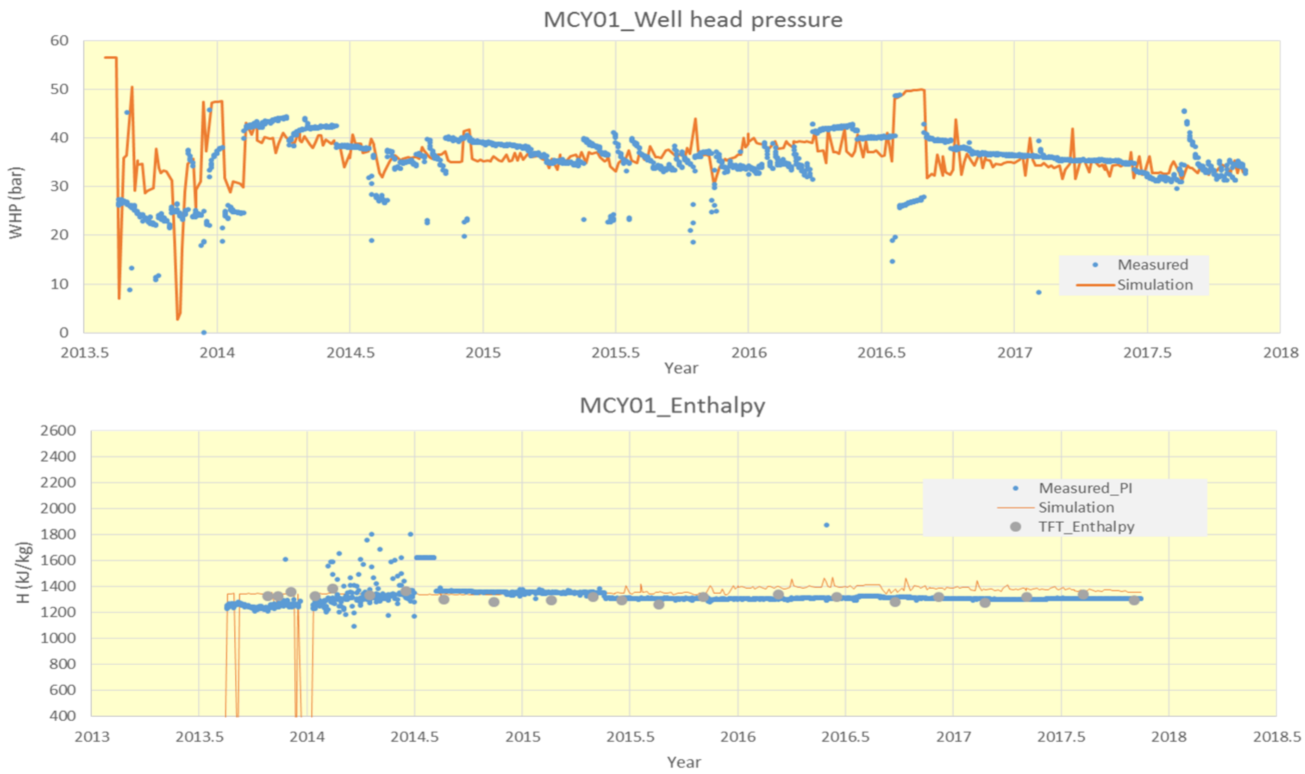

Figure 5: The calibration results between measured (blue dot) and simulation output (orange line)

3.1 The concept of competing feedzone

The downhole surveys from 2013 indicate that MCY01 has four feedzones. Over time, the contribution in the top two feedzones has remained almost unchanged, but the bottom two feedzones have been found to change as they continued to compete with each other. The third feed zone contribution starts from 27% in 2013, 63% in 2014 and 43% in 2015 and fourth feed zone contribution starts from 33% in 2013, 5% in 2014 and 22% in 2015. The numerical model has been built based on competing feed zone hypothesis and Figure 66 shows how the model is able to generate the contribution changes of feed zones 3 and 4. This constant change in feed zone contribution is due to the sudden decrease and recovery of the reservoir pressure in the vicinity of the two bottom feed zones. In the numerical model, the bottom feed zone is located in an area of good permeability and the good permeability is surrounded by poorly permeable regions creating sudden pressure changes as the well has produced. The numerical model has been used to reduce the uncertainty of the hypothesis and to have a better understanding of the irregular coughing phenomenon.

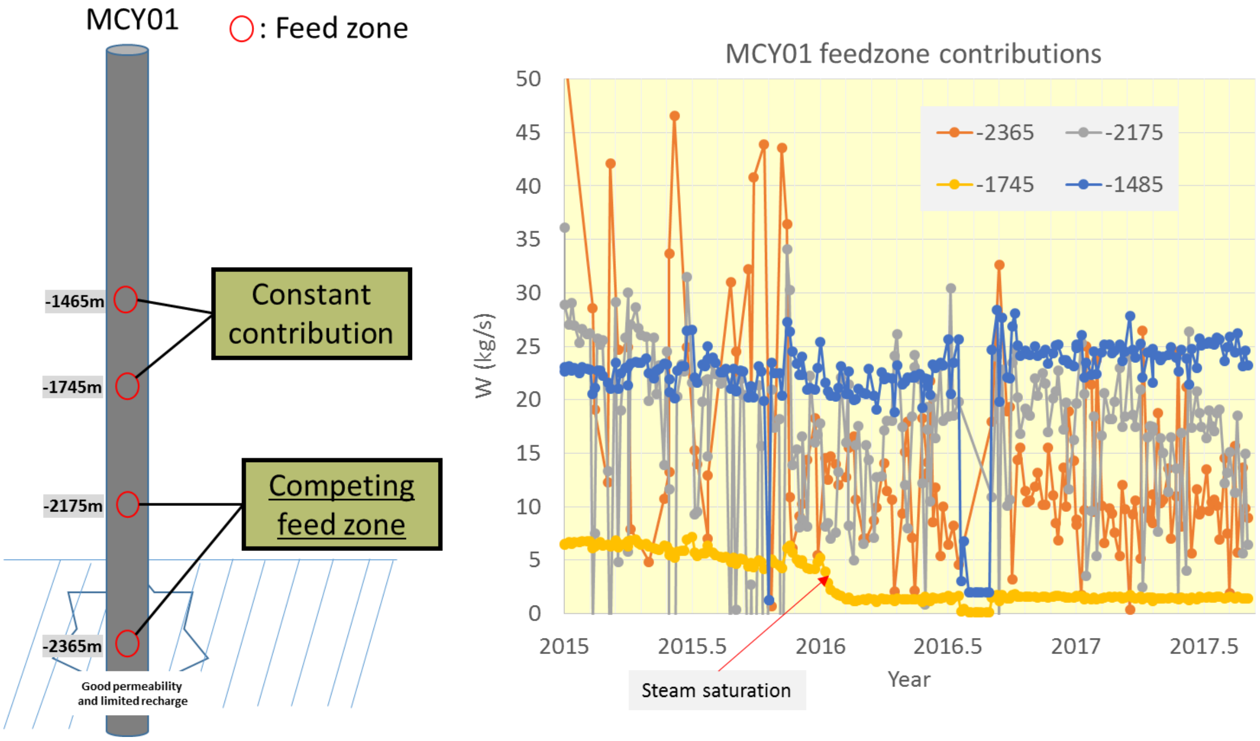

Figure 6: The concept of competing feedzone (left) and feedzone behavior from simulation (right).

3.2 The deliverability curve changes due to saturation

Interestingly, the capacity of the MCY01 productivity has increased abruptly since mid-2016. After the increase, the deceleration trend was similar to that before the increase, and the specificity of the MCY01 performance was not found when the productivity increased. Identifying the cause of the increase in the MCY01 productivity is also important in establishing MCY01 performance forecast. If the productivity increment is due to the reservoir pressure recovery, it can be seen as a substantial increase in the MCY01 productivity. If it is due to the other factors, it might not be an actual increase in the MCY01 productivity so careful consideration must be applied into the MCY01 operation plan.

In analyzing available geo-scientific data through an analytical process, no evidence was seen of a sudden pressure recovery in the vicinity of MCY01 reservoir in mid-2016. One notable difference from a 2015 downhole survey is that the flash points were between -2100m and -2400m under throttle (34 barg WHP) and fully open conditions (26 barg WHP), but there were no significant changes in total produced enthalpy at the surface.

The numerical model has been processed based on the specificities and the change of the productivity may not be due to the reservoir pressure recovery, but the change of deliverability due to steam saturation at the second feedzone. Figure 77 shows that the feed zone location (left) and the plots (right) from the numerical output. It can be seen that the deliverability increases at a specific WHP due to the change in steam saturation at the second feed zone. As a result of analysis of the numerical model output, because the steam saturation inside the wellbore increased, the maximum deliverability pressure (MDP) increased. However, as shown in Figure 55, the overall enthalpy change is negligible. The reason for this can be found in the reduction to the second feedzone contribution shown in Figure 66 due to the mobility changes.

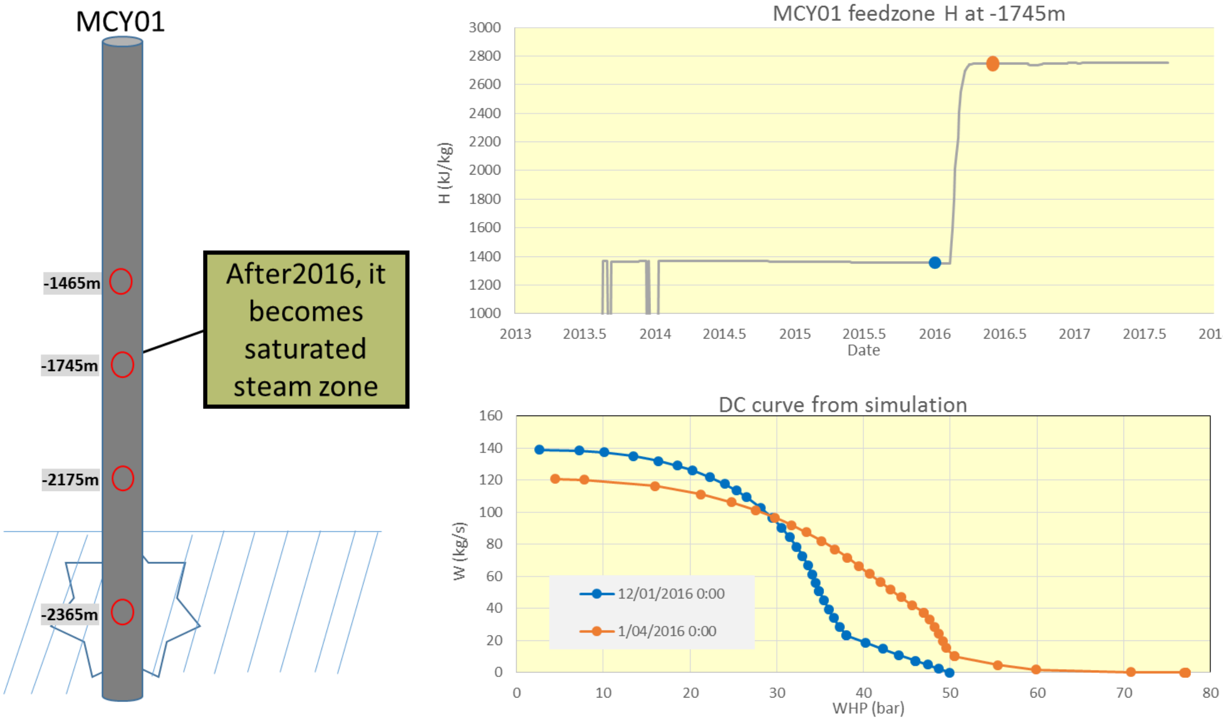

Figure 7: The concept of long-term WHP increment (left) and the simulation plots of 2nd feedzone enthalpy (top right) as well as deliverability curves (bottom right).

4. SIMULATION OUTPUT ANALYSIS

The common analytical method such as Decline Curve Analysis cannot predict changes in reservoir temperature, pressure and mobility, making it difficult to calculate a normalized flow rate. However, by coupling the numerical model with a wellbore simulator, the normalized flow rate can be calculated. During the calibration process, output curves at each time step are printed as simulation output so that they can be used to generate the normalized production. The normalized flow rate plot at 24 barg is shown in Figure 88. The exponential decline (in the red dash line) is around 14%/year and calculated based on the normalized flow rate at WHP 24 barg.

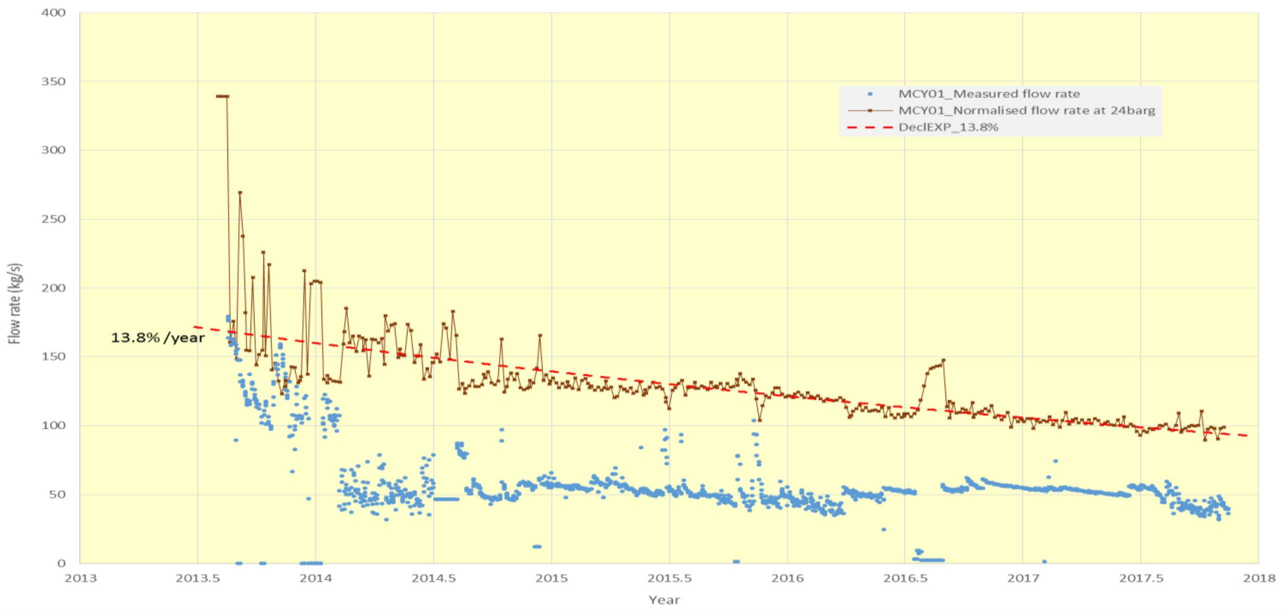

Figure 8: MCY01 normalized flow rate at 24 barg during calibration period

5. ANALYSIS OF FUTURE SCENARIO RUNS

All production wells in the numerical model are shut for one month to confirm the recovery of MCY01 productivity. When the MCY01 re-opened at WHP of 24 barg after a shut-in period, the MCY01 production rate of 410 t/h from the simulation is slightly higher than about 380 t/h (measured production rate) in 2014, and the flow rates returned promptly to the value before the shut-in period. It is predicted that the shut-in period of one month is not enough to return to the initial flow rates (as of 2013) and the amount of marginal recharge to MCY01 reservoir may be limited. As shown in Figure 99, all future forecast shows similar decline rates of about 9%/year. Compared to the calibration period (decline rate of 14%/year), the reservoir appears to be more stable with a reduction of about 5%/year in the decline rate.

For production optimization evaluation, several simulation runs have been conducted under various fixed WHP to see if by setting the well at a certain operating WHP can help minimize or reduce the coughing. It is interesting that based on the future scenario runs, the coughing phenomenon occurs when the WHP is between 26 barg and 34 barg and this is called the coughing zone. Therefore, it would be good to operate the well at WHP settings outside the coughing range in order to get a more stable production. The modelling results indicate that this could be either at a higher WHP (>38 barg) or at a lower WHP (<24 barg).

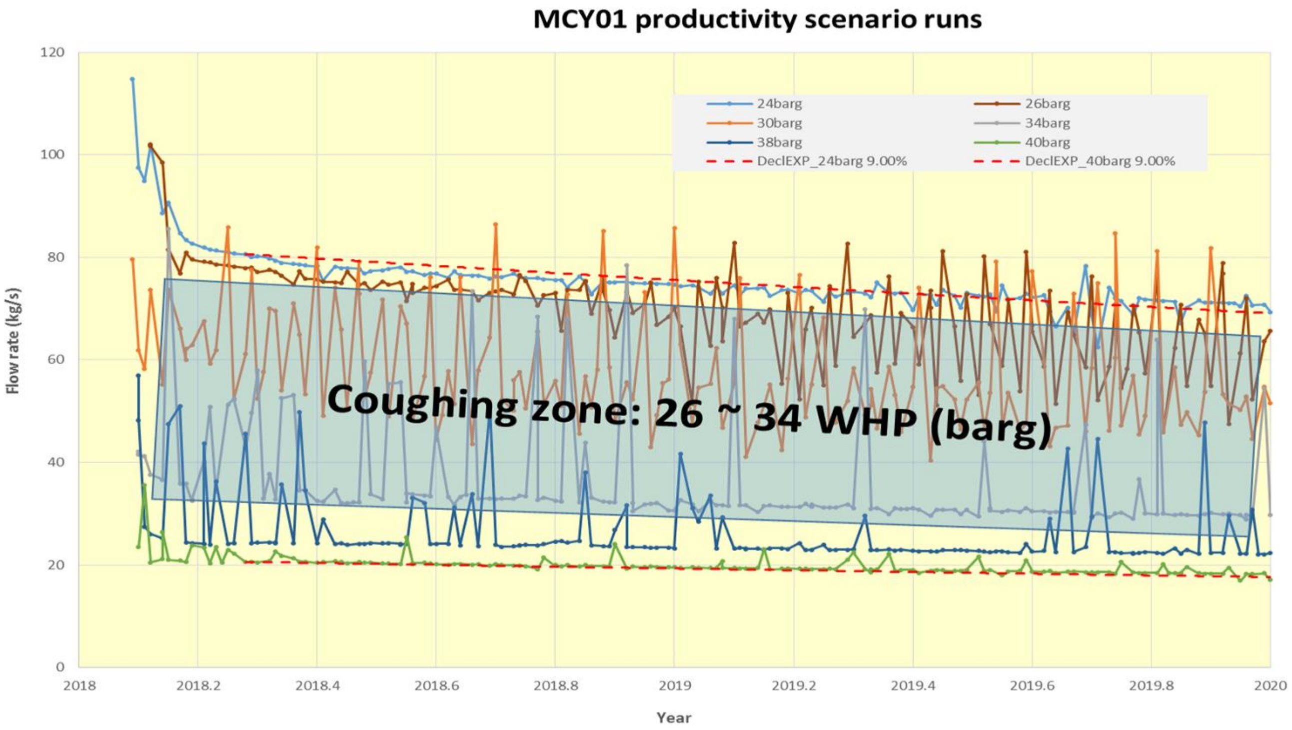

Figure 9: MCY01 scenario runs at various well head pressure settings

6. CONCLUSION

In this paper, a hypothesis is set-up to utilize the available geo-scientific data to the maximum, and a process of using the numerical model with wellbore simulator is carried out to confirm the hypothesis and to reduce the inconsistency. This process enables a more realistic data analysis and suggests a logical MCY01 management plan based on the research process.

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