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ANALYSIS OF DELIVERABILITY CURVE FOR EVALUATING POTENTIAL PROBLEMS IN THE SUBSURFACE OF GEOTHERMAL FIELD

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ABSTRACT

In this study, the deliverability curves of several wells from two geothermal fields, namely geothermal field X and Y are evaluated. From those deliverability curves, it can be analyzed the various problems encountered in the sub-surface wellbore and/or reservoir of a geothermal field. Both qualitative and quantitative interpretations of the deliverability curves are used in the analysis.

The analysis is begun with the qualitative interpretation of deliverability curves by comparing them with known typical deliverability curves. Knowing the typical of the deliverability curves, then the properties of wellbore and reservoir are inputted to the coupled wellbore-reservoir model. The suspected parameters represented the potentials problems then are taken into account to get the best matching between measured and calculated parameters, especially the mass flow rates and wellhead pressures.

The results of the analysis showed that for the studied fields, the potentials problems in the sub-surface can be categorized as the reservoir pressure decrease, the permeability changes and the fluid phase changes in the reservoir.

Keywords: Deliverability curves, Wellbore-Reservoir model, Sub-surface problems

INTRODUCTION

One of the problems faced by almost all developers in the geothermal field is the decline of the fluid production in the wells over the time. This phenomenon is something normal because as the field starts production, the fluid is extracted from the geothermal reservoir, then the pressure in the reservoir will decrease naturally. This decline would really be a serious problem, if the rate of decline is significant, so that this causes the large decline in fluid production that will eventually shorten the economic life of a geothermal field (Khasani, et. al., 2001).

In order to maintain the rate of decline in production becomes so small that the economic life of a field can be achieved, it is necessary to take the appropriate actions to anticipate such above rate of decline. There are a number of events or phenomena that may cause the decrease in production of a geothermal field. In addition to the decline in reservoir pressure naturally, then some of the other causes of decreased fluid production is any damage in the area around the production well, fluid injection is not programmed properly, and mechanical problems that occur in the wells. Thus, in order to determine what actions will be done, it must be evaluated what caused the decline in production.

In this research, the deliverability curves of several wells from two geothermal fields, namely geothermal field X and Y will be evaluated. It is expected that those deliverability curves may represent the various problems encountered in the fields.

OBJECTIVES

In order to find out what the causes of the decline in the production of a geothermal field, then there are at least two analyzes to be done. The first analysis is to identify the problems that occur in the fluid gathering system in which the visual observations of one of the most prominent is the precipitation of silica that causes the diameter of the pipe to be very small compared to the nominal value initially. Thus, it is certain that this is one of the causes of the problem of decreasing production. However, how much the contribution of this phenomenon to the problem of declining production, a quantitative study is needed. The second analysis is whether there is a problem that appears in both the reservoir or in the production well, such as damage to the area around the well, the entry of fluid reinjection into the reservoir is not well programmed or mechanical problems in the production wells. In this study, only limited studies to evaluate the second issue, that is the analysis of the characteristics of the fluid due to changes in reservoir parameters and/or production wells. This should be given priority since we cannot visually determine and describe what exactly the process that is underway in both places.

From the above explanation, then the main objectives of this study are as follows:

1. To develop the deliverability curves from production data of several wells from two geothermal fields for different measurement times.
2. To interpret qualitatively the possible reasons on the changes of deliverability curve for each well.
3. To simulate the deliverability curves to understand the causes of its changes quantitatively using wellbore simulator coupled with radial flow in reservoir.

STEP OF ANALYSIS

Qualitative Analysis of Deliverability Curves

One of the tools that can be used to evaluate the performance of a well is deliverability curve that is one that connects the mass flow rate of fluid to the wellhead pressure. This curve can be obtained by measuring the two parameters mentioned above for several measurement points by rotating/operating the wellhead valve openings for various positions.

By knowing the shape of the curve at different times, it can be analyzed problems that cause the change in shape of the curve. There are two main sources are likely to be the cause of the shape changes, i.e., parameter changes in the well and/or reservoir. Typical forms along with possible deliverability curve changes can be seen in Figure 1.

It is assumed that for all cases, enthalpy and gas content does not vary or change excessively. Curve A, a basic form and represent the results obtained from wells that received liquid inflow from the reservoir with high permeability. It is assumed that water flows into the well and had flashing at a certain depth in the well. Curve B shows the effect of the pressure drop in the reservoir. Curve C shows the effect of reservoir pressure increase, or an increase in water temperature or gas content. Curve D illustrates the influence of scaling in the well while the curve E indicates the effect of low permeability. For both curves D and E deliverability curve at low flow (high wellhead pressure) did not increase because additional restriction produces little effect on the low flow rate.

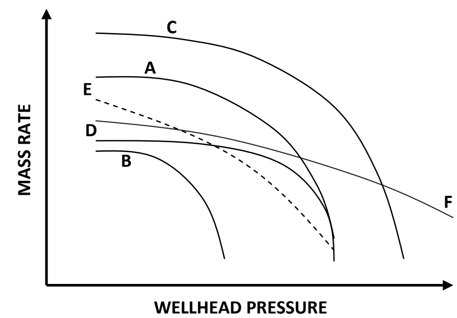


Figure 1: Deliverability curve: shape variation of the mass flow rate of the wellhead pressure. (Modified from Grant, et. al. (1982)).

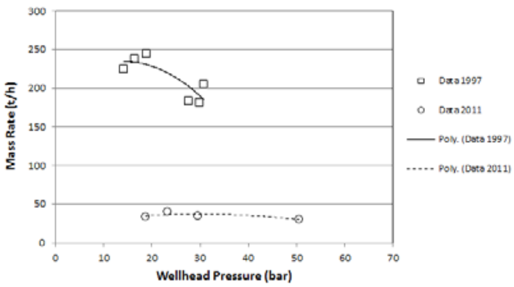
Additional restriction due to scaling is proportional to the square of the flow rate while the restriction due to a decrease in the permeability of the reservoir is linear. Curve F is obtained when the reservoir produces two-phase fluid (at the same pressure as in curve A).

In this study, there are six different wellbores from two different geothermal fields, namely geothermal field-X and geothermal field-Y where their deliverability curves will be evaluated. They are called as Well-X1, Well-X2 and Well-X3 from geothermal field-X, while Well-Y1, Well-Y2 and Well-Y3 from geothermal field-Y. Each well has two deliverability curves that were obtained at different times. How the shape and value are different for both deliverability curves become the challenging points that will be evaluated in this study.

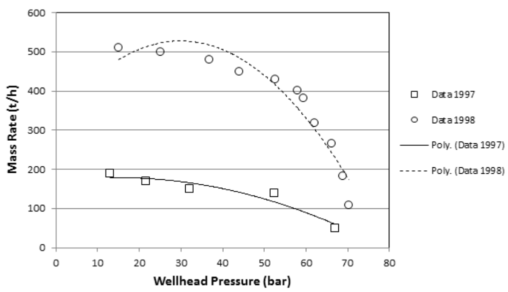
Wells at geothermal field-X

Figure 2 shows the measured data and the trend lines as approximation for deliverability curves for (a) Well-X1, (b) Well-X2, and (c) Well-X3 that were measured in different times for each well. For Well-X1, it can be seen that there are six points of measured data in 1997 for plotting deliverability curve. The points were obtained from two steady state conditions during production test where the values fluctuated in some amount for each condition. On the other hand, the measured data in 2011 resulted in the smoothed curve indicating that no significant fluctuations during measurement.

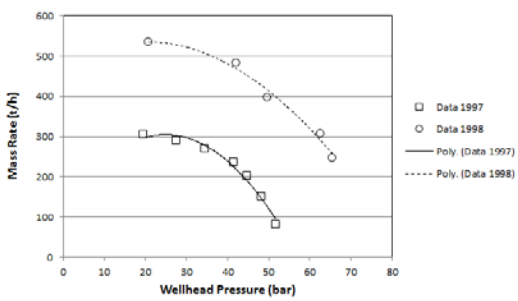
Based on Figure 1, then the qualitative interpretation is that there had been phase change in the reservoir, i.e., it became two-phase reservoir (curve F). For Wel-X2, by comparing curves A and E in Figure 1 with both curves in Figure 2 (b), it can be interpreted that there was a change in the reservoir permeability around the well. Finally, for Well-X3, there had been pressure or temperature change in the reservoir.



(a) Well-X1



(b) Well-X2

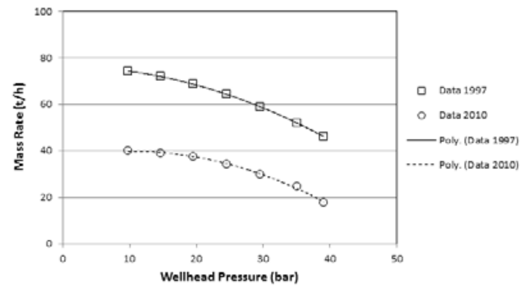


(c) Well-X3

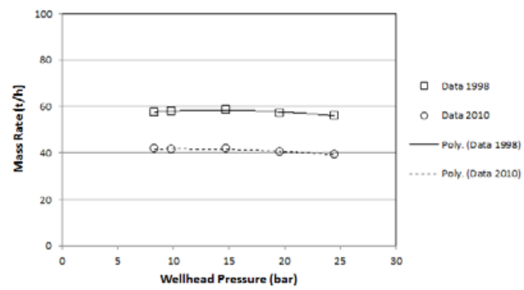
Figure 2: Measured deliverability curves for (a) Well-X1, (b) Well-X2, and (c) Well-X3 at geothermal field-X.

Wells at geothermal field-Y

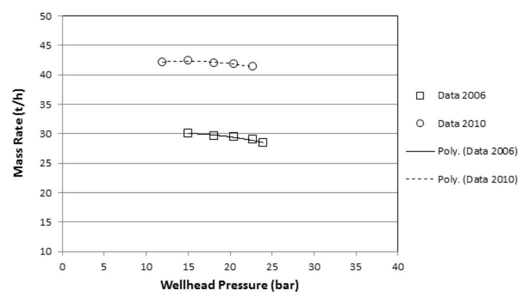
Measured data along with their deliverability curves for wells at geothermal field-Y is shown in Figure 3. All deliverability curves for wells in geothermal field-Y showed similar type which can be interpreted as there might be a change in reservoir pressure or temperature. The only difference is for deliverability curve for Well-Y3 which is the value for the later one is higher than that of earlier one.



(a) Well-Y1



(b) Well-Y2



(c) Well-Y3

Figure 3: Measured deliverability curves for (a) Well-Y1, (b) Well-Y2, and (c) Well-Y3 at geothermal field-Y.

<u>Numerical Analysis of Deliverability Curves</u>

In order to further evaluate in more detail quantitatively on deliverability curve, it is necessary to create a model that will produce deliverability curve from the calculation. These results will be compared with the deliverability curve based on field data. If the similar tendency of the results have not been obtained, then appropriate adjustments by changing the variables of both the well and the reservoir is needed. In this study, the program developed at Laboratory of Energy Resources Engineering Kyushu University was utilized.

A brief explanation of the developed wellbore-reservoir model is as follows. In geothermal wells producing from a hot water reservoir the flow of fluid starts at depth where the temperature is lower than the saturation temperature corresponding to the local pressure, that is the fluid flows in a single-phase as shown in Figure 4 (a). Two-phase flow begins at a depth where the fluid temperature and saturation temperature become equal; the liquid than flashes to the vapor. The other possible case is that the fluid starts flashing in a reservoir as it flows toward the well, and the steam-water mixture enters the well as shown in Figure 4 (b). In this case, only two-phase fluid flows in the wellbore. However, during the production stage a decrease in the reservoir pressure may happen. In this case, the flash starting point may move out from the well into the reservoir. Opposite case may occur when fluid temperature decreases due to a mixing of low-temperature injected water. If the former case occurs, there is a possibility that two-phase fluid occupies reservoir entirely as shown in Figure 4 (c). Besides the above phenomenon that can occur due to the increase/decrease in reservoir pressure, it can also be caused by the parameter changes both in the well and the reservoir.

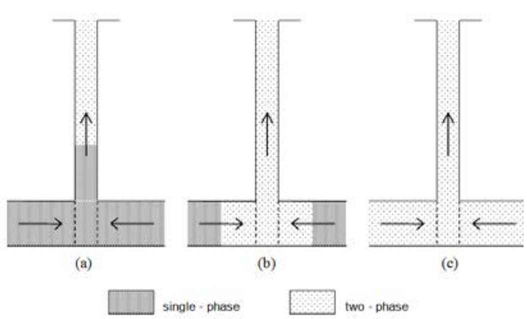


Figure 4: Schematic of wellbore and reservoir model.

The presence of various fluid conditions in the wellbore illustrated in Figure 4 is due to some factors that come either from well specification or reservoir conditions. The parameters associated with reservoir properties that may play an important role are permeability of reservoir and reservoir pressure and temperature. This is one reason why the reservoir model should be included in the wellbore model.

Well-X1

In order to analyze numerically, it is required the parameters for wellbore and reservoir. Unfortunately, not all reservoir parameters are available especially permeability-thickness, so in this study it is assumed to be $10x10^{-12}$ m^3.

The initial reservoir temperature in 1997 was 285^0C while there was no information for initial pressure. So, in this case the pressure at the well bottom (feed zone) must be assigned when running the program for producing well. From the qualitative analysis, it has been understood that the reason why the deliverability curve shifted from 1997 to 2011 is because the reservoir changed into two-phase one. One of the reasons was that the reservoir pressure had declined significantly due to production and at the same time it was probably there was no good reinjection system for fluid to return back to the reservoir. Another possible reason was because of the shortage of recharge water, mainly from rain water.

The numerical simulation for two-phase reservoir is a bit complicated. This is because the fluid parameters are independent with the pressure and temperature. One parameter that is almost impossible to measure is the water saturation. Therefore, in order to start calculation this must be determined first. In this study, the initial water saturation is assumed to be 0.5. The simulation of calculated deliverability curves together with measured data is shown in Figure 5.

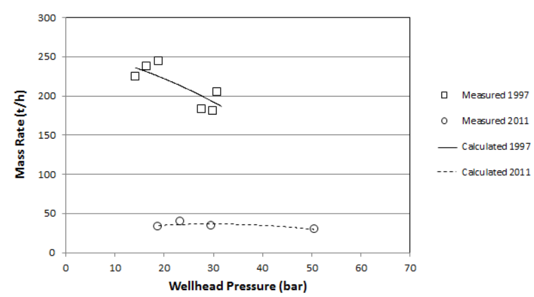


Figure 5: Deliverability curves for Well-X1.

Table 1 shows the comparison of wellhead pressure and respective other simulated parameters in 1997 and 2011 for the Well-X1.

Table 1: Comparison of calculated parameters in 1997 and 2011 for Well-X1.

1997			2011		
Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)
16.6	107	8.90	23.2	66.1	41.4
19.4	114	10.9	50.5	82.4	33.7
27.1	143	13.8	29.6	73.2	22.3
29.9	146	13.9	18.8	53.3	26.9

From Table 1, we can see that for the same wellhead pressure operations, there had been feed zone pressure declines at about a half. The decrease in feed zone pressures may reflect that in reservoir pressures. This condition should be given pay attention for example by evaluating the presence or the effectiveness of reinjection system. The calculated results showed that the steam quality at the wellhead increased in 2011 from about 1.5 to 2.5 times larger. However, this did not mean that the output capacity increased. This was because that the enthalpy remained similar at about 2800 kJ/kg while the total mass rate decreased significantly. The decrease in the power output is illustrated in Figure 6.

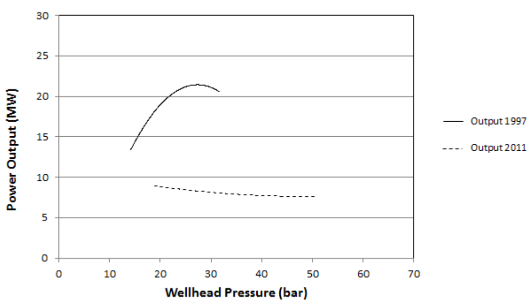


Figure 6: Power outputs in 1997 and 2011 for Well-X1.

Well-X2

The similar situation unfortunately, not all reservoir parameters are available especially permeability-thickness, so in this study it is assumed to be $10x10^{-12}$ m^3 in 1998. The measured deliverability curves are shown in Figure 7. Based on the typical curves shown in Figure 1, then they are similar situation with curves A and E where they can be interpreted that there has been a change in reservoir permeability. Permeability reservoir in 1997 is smaller than the permeability in the year 1998.

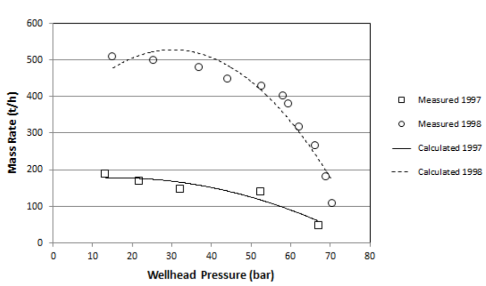


Figure 7: Deliverability curves for Well-X2.

Based on the available information, it was obtained that the deliverability curve measured in 1997 coincided with the condition where the drilling of wells had just completed. As for the deliverability curve measured in 1998, the well was on the production stage. From this finding, it can be concluded that the cause of permeability in 1997 is smaller because the condition of drilled wells that had just completed, resulted in the reservoir formation near the well might be filled by a material such as drilling mud, cement and/or cutting. While in 1998, the condition of the reservoir was relatively more permeable because the well had just finished to be cleaned before beginning the production stage. In order to get the best matching for deliverability curves in 1997 and 1998, the permeability-thicknesses are assigned to be $7.54x10^{-12}$ m^3 and $10x10^{-12}$ m^3, respectively.

Table 2 illustrates the values of wellhead pressure and respective other simulated parameters in 1997 and 1998 for the Well-X2.

Table 2: Comparison of calculated parameters in 1997 and 1998 for Well-X2.

1997			1998		
Wellhead Pressure (bar)	Permeability -Thickness (m^3)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Permeability -Thickness (m^3)	Quality at Wellhead (%)
13.2	$7.54x10^{-12}$	14.5	15.2	$10x10^{-12}$	47.2
32.6	$7.54x10^{-12}$	16.1	36.0	$10x10^{-12}$	16.6
52.5	$7.54x10^{-12}$	15.9	52.5	$10x10^{-12}$	15.9
66.9	$7.54x10^{-12}$	16.4	65.8	$10x10^{-12}$	16.1

From Table 2, it can be seen that the quality of steam at the wellhead almost remains the same except for low wellhead pressure of about 13 – 15 bar at around 14 and 47 %, respectively. As the enthalpies also remain constant and the total mass rate is lower in 1997, then the power output in 1997 also less than that of in 1998 as illustrated in Figure 8.

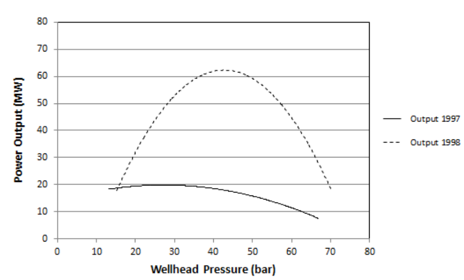


Figure 8: Power outputs in 1997 and 1998 for Well-X2.

Well-X3

The measured pressure and temperature profiles during warm-up in 1997 showed that the final stable values were 157 bar and 300^0C, respectively. The well was drilled in to a depth of 2570 m. For the numerical calculation purpose, the permeability-thickness of the reservoir is assumed to be $10x10^{-12}$ m^3. The deliverability curves are shown in Figure 9.

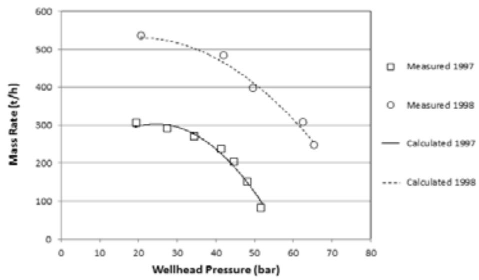


Figure 9: Deliverability curves for Well-X3.

From Figure 9, it can be seen that the deliverability curve in 1998 is in the upper position meaning that for the same wellhead pressure the mass rate is higher. This indicated that there had been an increase in the reservoir pressure and/or temperature from 1997 to 1998 that was mainly caused by recharge of natural rain water. This situation might be happened because during that time the production stage had not been commissioned yet. The production test was aimed to check the condition and performance of the well before entering the production stage which was started in 2002.

Table 3 shows the comparison of wellhead pressure and respective other simulated parameters in 1997 and 1998 for the Well-X3.

Table 3: Comparison of calculated parameters in 1997 and 1998 for Well-X3.

1997			1998		
Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)
19.2	148.8	10.0	20.6	158	4.2
41.0	214.2	6.7	41.2	218.4	6.8
48.5	219.5	6.8	49.8	222.7	6.9
52.0	221.7	7.1	62.5	245.9	3.5

From Table 3 and the confirmation about the production status of field indicated that the infiltration of recharge water and with no production resulted in the increase in the reservoir pressure by about 1.03 times larger for 1 year from 1997 to 1998. This suggested that the presence of recharge water, mainly from the rain water gave significant effect to the reservoir pressure.

The interesting feature was found for the produced power output as illustrated in Figure 10.

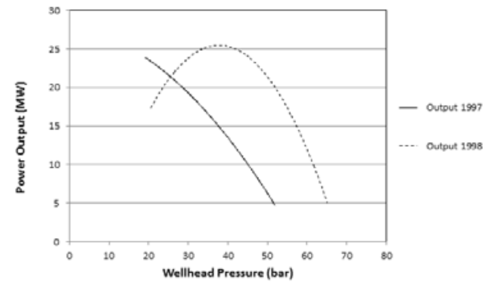


Figure 10: Power outputs in 1997 and 1998 for Well-X3.

For the relatively low wellhead pressures (less than about 35 bar), both deliverability curves gives a bit similar outputs. While the power outputs are different significantly for wellhead pressures more than 35 bars. This was because even the quality at wellhead for deliverability curve in 1997 was much higher than that of in 1998, but total mass rate for the same wellhead pressure in 1998 was higher, as a result the steam rates were relatively the same. This will give the similar outputs because the enthalpies of the steam for both conditions were relatively similar at the values of 2780 kJ/kg.

Well-Y1

Well-Y1 was drilled up to the vertical depth of 1487 m. Two production tests were carried out in 1997 and 2010 where their deliverability curves and the calculated ones are presented in Figure 11. For numerical analysis purpose, the permeability-thickness of the reservoir is assumed to be $8x10^{-12}$ m^3.

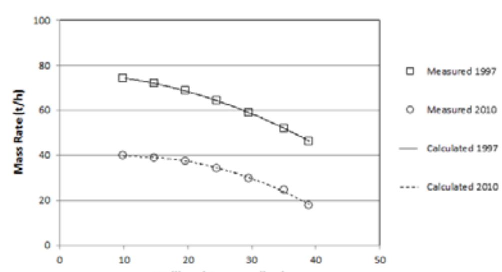


Figure 11: Deliverability curves for Well-Y1.

The interpretation of the shifting of the deliverability curve down from 1997 to 2010 is because of the decrease in pressure and/or temperature in the reservoir. This decrease seems to be natural due to fluid production. Assuming that the reservoir is liquid single-phase, the realistic matching is not achieved because the reservoir pressure in 2010 is higher than that of in 1997. Therefore, the model then is changed to two-phase reservoir for both conditions with initial water saturation are 0.5. This assumption is quite reasonable because of the relatively flat type of deliverability curve. How the reservoir decreased as the fluid was extracted can be figured in Table 4.

Table 4: Comparison of calculated parameters in 1997 and 2010 for Well-Y1.

1997			2010		
Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)
10.1	72.88	47.0	9.9	51.18	47.0
19.6	70.19	42.6	19.6	50.66	42.6
29.6	66.52	39.3	29.6	49.28	39.3
39.0	64.00	36.6	39.0	64.00	36.6

From Table 4, it can be seen that in average the reservoir pressure decreased by about 0.75 times from 1997 to 2010 or there was an average decrease rate in the reservoir pressure at about 6 bars per year. This reservoir pressure decrease will in turn result in the decrease in the power output as shown Figure 12. It can be recognized that the power output decreased at about 0.5 times during 13 years production. It can also be seen that for both power output curves trend take linear decrease. This was because the steam flow rates also decreased linearly while the enthalpies of the steam remained constant at about 2800 kJ/kg.

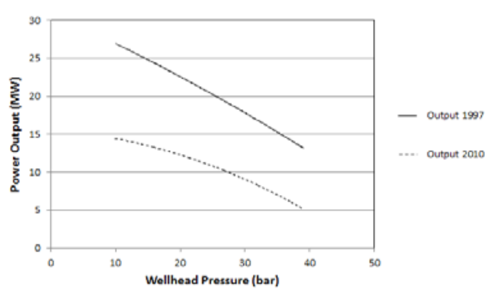


Figure 12: Power outputs in 1997 and 2010 for Well-Y1.

Well-Y2

Well-Y2 was drilled up to the vertical depth of 1951 m. The deliverability curves and the calculated ones for 1998 and 2010 are shown in Figure 13. The permeability-thickness of the reservoir is assigned as $10x10^{-12}$ m^3 for numerical analysis.

Interpretation of the deliverability curves for Well-Y2 is similar to that of Well-Y1 except that the flatness of the curves for Well-Y2 is almost horizontal. This means that a confidence interpretation that the fluid in the reservoir is two-phase one can be surely accepted. To further analyze quantitatively what happened for the fluid in the reservoir, the parameters as shown in Table 5 is required.

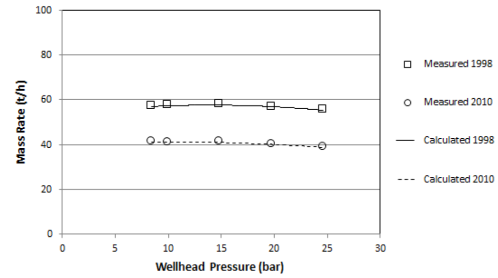


Figure 13: Deliverability curves for Well-Y2.

Table 5: Comparison of calculated parameters in 1998 and 2010 for Well-Y2.

1998			2010		
Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)
8.38	48.00	28.1	8.38	42.35	33.1
14.76	61.72	29.1	14.72	50.60	29.1
19.58	62.15	26.5	19.61	51.64	26.5
24.56	64.20	24.3	24.52	54.60	24.3

From Table 5, it can be recognized that in average the reservoir pressure decrease was about 0.83 times from 1998 to 2010 or there was an average decrease rate in the reservoir pressure at about 0.8 bars per year. Figure 14 shows the power output decrease of Well-Y2 from 1998 to 2010.

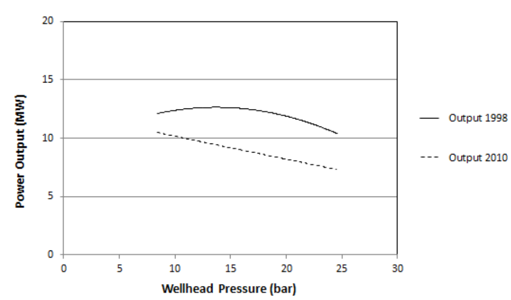


Figure 14: Power outputs in 1998 and 2010 for Well-Y2.

It can be seen that the power output decreased at about 2.8 MW for 12 years production from 1998 to 2010 or at 0.23 MW per year. It can also be seen that the power output curve trend for 1998 takes a flat parabolic while for 2010 takes linear decrease. This was because the steam flow rates also decreased at the same trends while the enthalpies of the steam remained constant at about 2800 kJ/kg.

Well-Y3

Well-Y3 was drilled up to the vertical depth of 1703 m. Two production tests were conducted in 2006 and 2010 where their deliverability curves and the calculated ones are presented in Figure 15. For numerical analysis purpose, the permeability-thickness of the reservoir is assigned to be $10x10^{-12}$ m^3. The flat type of the deliverability curves suggested that the reservoir was filled with two-phase fluid. The interpretation why the deliverability curve for 2010 is located at the upper position was probably the reinjection system (additional wellbore) worked well during the production stage.

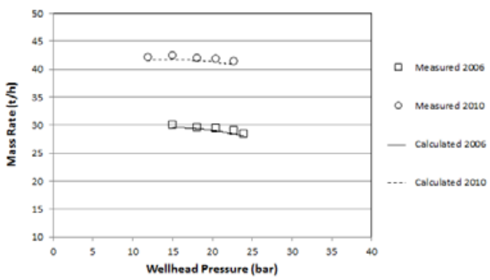


Figure 15: Deliverability curves for Well-Y3.

Table 6 shows the parameters changes of the fluid for both 2006 and 2010. It can be understood that during the injection of the fluid into the reservoir for 4 years from 2006 to 2010, there had been increase in reservoir pressure by about 1.1 times or 0.28 bar per year in average. This meant that the reinjection system contributed to the maintenance of the reservoir pressure, thus the production of geothermal fluid.

Table 6: Comparison of calculated parameters in 2006 and 2010 for Well-Y3.

2006			2010		
Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)	Wellhead Pressure (bar)	Feedzone Pressure (bar)	Quality at Wellhead (%)
15.00	39.27	28.8	15.00	47.03	28.8
18.15	40.38	27.2	18.14	47.68	27.2
20.49	41.87	26.0	20.49	48.71	26.1
22.75	43.52	25.2	22.75	49.80	25.1

The respective increase of the power output is illustrated in Figure 16. It can be found that the output has increased by about 1.5 times for 4 years or 0.74 MW per year. The power output decreased with the increase in the wellhead pressure linearly with relatively the same rate for both conditions.

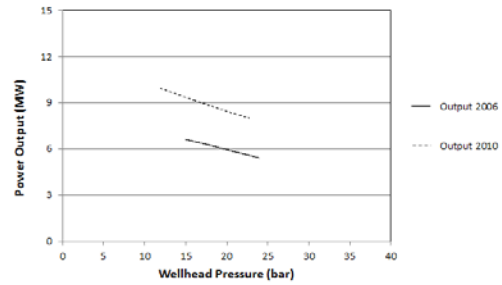


Figure 16: Power outputs in 2006 and 2010 for Well-Y3.

CONCLUSION

From the above discussion and analyses, it can be summarized some important findings as follows:

1. The deliverability curves changes with time of a production well can be used as a tool for evaluating of the problems or phenomena occurred in the subsurface surrounding the well located qualitatively.
2. In order to evaluate the problems quantitatively, it is required the numerical analysis using wellbore model coupled with reservoir model.
3. For the studied wells in this study, the problems or phenomena found such as the pressure decrease/increase in the reservoir, the permeability change in the reservoir and the fluid change in the reservoir into two-phase liquid.
4. There are a number of various problems or phenomena for wells at geothermal field-X, while there is only one problem or phenomenon found in wells at geothermal field-Y.

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