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The Utilization of Transient Output Measurement to Characterize Geothermal Reservoir Properties Using AWTAS for Well 2H-21 at Hatchobaru Geothermal Field, Japan

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ABSTRACT

The continuous measurement of mass flow rates during output testing from a geothermal production well 2H-21 of Hatchobaru geothermal field, Japan are relatively short. Field data from a horizontal discharge into a twin separator was used to evaluate and understand the transient behavior of the near-well characteristics. The data was recorded every second for: the pressure drop across the steam orifice plates, the pressure at the separators, and the water level at weir box. The atmospheric pressure was also measured daily. The valve opening was changed three times during the measurement to obtain the output curve of the well. The measured mass flow rates and pressure at the wellhead then were used as input data to wellbore simulator. The results of calculated well bottom pressures then were inputted into AWTAS (Automated Well-Test Analysis System) to evaluate the properties of the reservoir. Three different types of radial reservoir model were used including uniform porous media, dual porosity fracture/matrix model, and the fractional dimension model. The best match for the down-hole pressure data was achieved with the fractional dimension model.

1. INTRODUCTION

A part from a geothermal reservoir management, a regular measurement of wellbore performances such as pressure, mass flow rate and enthalpy at the wellhead during the production stage is required to evaluate the well productivity. This is because as a production stage of the field begins the well performances reflect wellbore and reservoir conditions such as decline of reservoir pressure and temperature and scaling in the wellbore. There are two common physical methods for measuring steam and water flow rates; (a) lip pressure method and (b) the orifice and weir method. In the lip pressure method, the fluid is discharged from the well directly to the atmosphere. It is then measured at the extreme end of the discharge pipe using a liquid-filled gauge to damp out pressure fluctuations (Grant et al., 1982). In the latter method, the orifice is used for steam flow rate which discharged from the separator and the weir for the water flow rate leaving from the separator (Lindeburg, 1992). The wellhead pressure is usually measured using a bourdon gauge. In order to avoid any thermal and chemical contamination on the surface soil and vegetation near wellbore by discharging fluids to the atmosphere, the latter method is preferable for flow measurement.

One of the problems found in the mass flow rate and wellhead pressure measurement is whether and when the well discharge reaches stable conditions after operating the wellhead valve. When the wellhead pressure is changed, the steam and water flow rates would also change, then stabilizes as the time elapsed. In practical conditions, the time required for the flow rates to stabilize is determined according to operator experience. Therefore, a continuous measurement of steam and water flow rates is necessary to understand transient discharge behaviors in details. Field measurement with developed equipment was conducted at the production well, 2H-21, in Hatchobaru, Oita Prefecture, Japan. The measurement was carried out during the routine maintenance of the power plant.

Besides the well productivity as the results of the continuous measurements, the information on measured mass flow rate and wellhead pressure are valuable and may be utilized for evaluating the reservoir properties, mainly those that are close to the wellbore. This evaluation is very important because properties may change during production stage. By utilizing the wellhead data into the wellbore software, and inputting the calculated results at well bottom into reservoir software, e.g. AWTAS, the reservoir properties such as permeability and porosity can be determined. These values may be used at the beginning of estimation and before real down-hole measurement which mignt be both take time and cost consuming.

2. LOCATION MAP

Figure 1 shows the location map of the Hatchobaru geothermal field and wells. Well 2H-21 is located at the Hatchobaru geothermal field situated 1100 m above sea level in the central part of Kyushu. The power station of 2x55 MW installed capacity is now in operation. The well has a maximum static temperature of 252^{o}C at a depth of about 2100 m and is 2500 m long (Fujikawa and Ikegami, 1992).

The basic design of the Hatchobaru power station is of a double flash system having a steam-hot water mixture transport pipeline for both units. The advantage of using this system is that the generating output can be increased to about 20%. There are 24 production wells for steam production and 11 wells for reinjection.

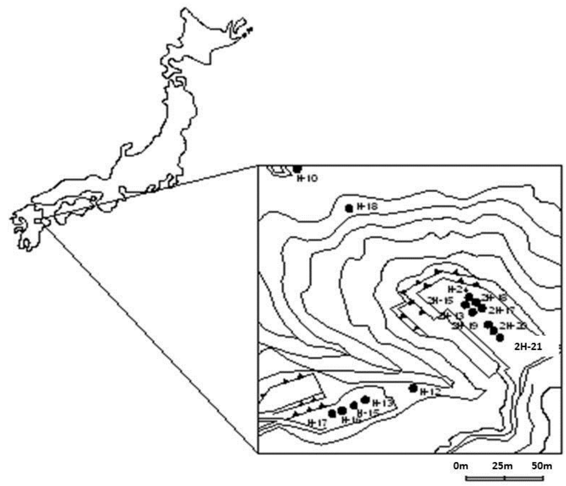


Figure 1: Location map of Hatchobaru geothermal field.

3. SET UP OF APPARATUS

In this study, the flow rates of Well 2H-21 were measured during the maintenance when production wells discharged to atmosphere through silencers. The apparatus and equipment used in the measurement are illustrated in Fig. 2. They consist of equipment available at the site, such as separator, orifice, valves, and weir box. Other equipment, i.e. power supply, laptop computer, pressure and water level sensors, etc. were prepared before the measurement.

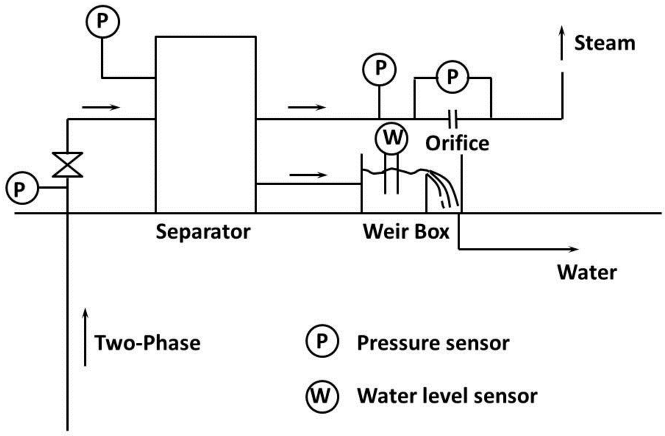


Figure 2: Lay out of continuous measurement.

The separator pressure, the upstream pressures at the orifice, the pressure difference at the orifice and water level at the weir box were measured every second electronically (Sawada, 1965). The measured data were then used to calculate steam and water flow rates. The procedure for measurements is as follows. The mixture of steam and hot water from the production well is separated through twin separators. The separated hot water is discharged through a weir box while steam flows through two discharge pipes. As there are two sets of separator for the well, pressure measurements at separator and orifice were conducted for each system. A contracted weir box built by the separator was used for measuring hot water flow rate. The data collected during this measurement was the hot water level in the weir box. The steam flow rate was measured using orifice flow meters which were installed at each discharge pipe. The pressure of the separators and upstream of the orifice as well as the pressure at the orifice were measured with pressure transducer. All measured pressures were recorded every second electronically and stored in the computer through AD converter.

4. FLOW RATE CALCULATION AND ANALYSIS

The calculated flow rate through each component is shown in Fig. 3. The flow rate calculation using the measured pressures at the orifice and the water level in weir box data is based on the standard formula. Steam flow rates at respective discharge pipe are calculated and summarized to introduce steam flow rate of the well. The thermodynamic properties of the fluid are calculated using the package program PROPATH (Ito et al., 1993). Steam flow rates are calculated for the period from 9:40 a.m. to 15:00 p.m. where the measurement in the very early period is excluded because of a malfunction of the power supply. The atmospheric pressure was 90.4 kPa. The wellhead pressure was measured using Bourdon gauge which was installed at the wellhead. By using measured values as mentioned above and the standard formula, the mass flow rates of hot water and steam at the separator, and at the wellhead, are calculated.

The closing operation of valve from 9:10 to 9:24 a.m. resulted of the decrease in total flow rate (1). During this period, the total flow rate change is controlled by the water flow rates (2 and 3). The water flow rates at the separator and wellhead are higher than the steam flow rates. The steam flow rates seems to be more stable than water flow rates as shown during the period from about 9:50 to 11:48 a.m.

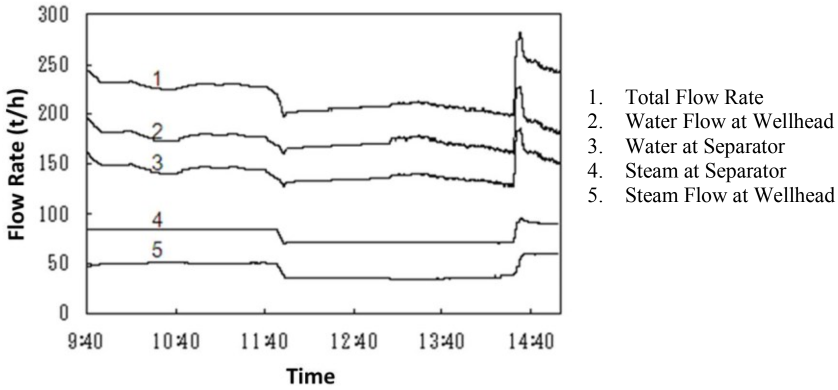


Figure 3: Mass flow rate through each component versus time.

When the valve was closed from about 11:48 to 11:53 a.m., the water flow rates at the separator and the wellhead show gradual decrease. The decrease in the flow rates are small at the beginning of the closing operation of valve then increases as the time elapsed, while the steam flow rates decreases linearly. The responses in the form of impulse are observed for the total and water flow rates immediately after the closing valve operation stopped at 11:53 a.m. Then the well was left to stabilize until 14:28 p.m. To judge the time needed to stabilize the flow, the valve was closed at 11:53 a.m., changes in the total and the steam flow rates with time were evaluated. At 11:53 a.m. the lowest total flow rate was measured to be 197.33 t/h, then it increased gradually as time passed and reached relatively stable value around 203 t/h at about 12:00 a.m. The recorded total flow rate after closing the valve at 12:03, 12:13 and 12:23 p.m. are 203.0, 203.6 and 204.4 t/h.

On the other hand, the steam flow rate at the wellhead reached the lowest value of 36.5 t/h at 11:53 a.m. During the period of 12:03, 12:13 and 12:23 p.m., they were 36.7, 36.5 and 36.5 t/h. This suggested that the steam flow stabilized quickly soon after the closing valve. In other words, the time for the discharge rate to stabilize is mainly due to water flow rate. Furthermore, during the period of 14:28 – 14:40 p.m. when the valve was full opened, it was observed that the steam flow rate at the separator increases sharply however before the valve was full opened the flow rate reached the maximum then decreased and stabilized quickly. On the other hand, for the separated water after reaching the maximum value the flow rate showed continuous decrease and took a considerable time to stabilize. The measured total flow rate at 15:00 p.m. showed that the decrease rate of the flow rate was 10.55 t/h/s. This means that the flow had not reached stable condition. From this measurement, it can be noted that the behaviors of flow rate change with time for water is different from that for steam. The valve operation that results in the decrease or increase in flow rates causes the steam to stabilize faster than that for the water.

5. DELIVERABILITY CURVE

When the wellhead pressure is changed by the valve operation, the total flow rate also changes. Figure 4 shows the measured wellhead pressure with time. The respective mass flow rates are presented in Fig. 3.

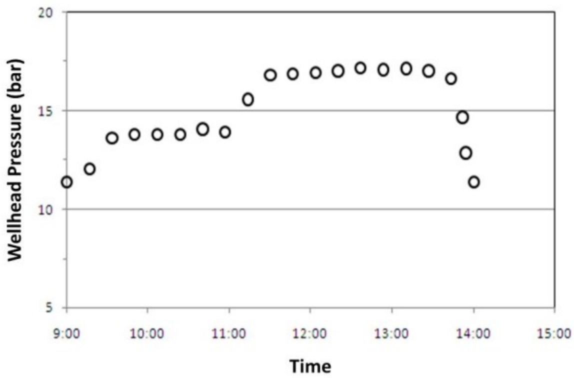


Figure 4: Wellhead pressure with time.

Before 9:00 a.m., the well was kept in full open and stayed in a stable condition, then the flow rate was changed successively by throttling the valve. It can be observed from Fig. 4, that the valve was firstly closed halfway gradually during the period of 9:10 – 9:24 a.m. During this period, the increase of wellhead pressure of about 17 kPa/min was observed, and then the well was left to reach stable condition. The second valve operation was conducted during the period of 11:48 – 11:53 resulted in a wellhead pressure increase rate of 54 kPa/min. And finally from 14:28 – 14:40, the well was left full open for the last measurement with the wellhead pressure decrease rate of 46 kPa/min. It can be seen that the increase in the wellhead pressure is accompanied by the decrease in mass flow rates and vice versa.

The deliverability curve for Well 2H-21 was obtained by plotting wellhead pressures against mass flow rates which were recorded during the three periods of time when the flow stabilized (9:24 – 11:48 a.m., 11:53 a.m. – 14:28 p.m., and at about 15:00 p.m). They were 1.38 MPa and 232 t/h, 1.71 MPa and 208 t/h, and 1.14 MPa and 240 t/h, respectively, as shown in Fig. 5. From the figure, it can be seen that the decrease in wellhead pressure is followed by the increase in total mass flow rate. The curve profile as well as the fact that at a point corresponding to 1.14 MPa and 240 t/h during valve full open operation, suggest that this value is almost at maximum flow rate that could be obtained from the well.

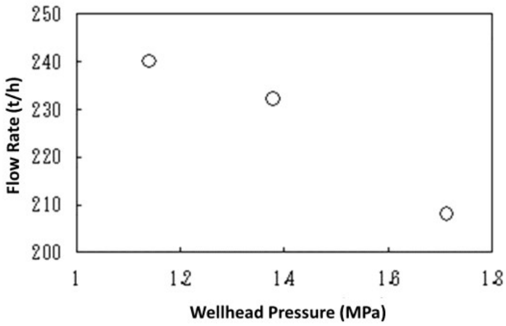


Figure 5: Deliverability curve for Well 2H-21.

6. RESERVOIR PROPERTIES EVALUATION

During the exploitation stage the reservoir may change in pressure, temperature, and chemical components due to fluid extraction. This may lead to changes in the reservoir properties such as permeability and porosity due to scaling. Therefore, it is beneficial to utilize transient measured mass flow rates as well as pressures at the wellhead in order to evaluate the reservoir properties, such as permeability and porosity. In this study, a transient wellbore simulator (WELBORE) (Miller, 1980) and radial reservoir models (AWTAS) (O'Sullivan et al., 2005) were used for this purpose.

6.1 Wellbore Simulator (WELBORE)

WELBORE is a computer code for simulating transient, one-dimensional two-phase or single-phase non-isothermal fluid in a wellbore (Miller, 1980). This kind of wellbore simulator is useful to evaluate well test results and then to analyze the set of transient measured data. WELBORE has two options in selecting the model, i.e. with or without a reservoir model. In this study, the second option was selected because the reservoir properties were evaluated using AWTAS software that can handle various reservoir types which are not provided by WELBORE.

The purpose of WELBORE in this study is to calculate transient downhole pressures required by AWTAS as input parameter for given mass flow rates and pressures at the wellhead. Because the wellhead pressures were measured intermittently with longer time interval of recording data compared with mass flow rate measurement, the technique used by Zarrouk et al. (2007) was adopted for downhole pressure calculation.

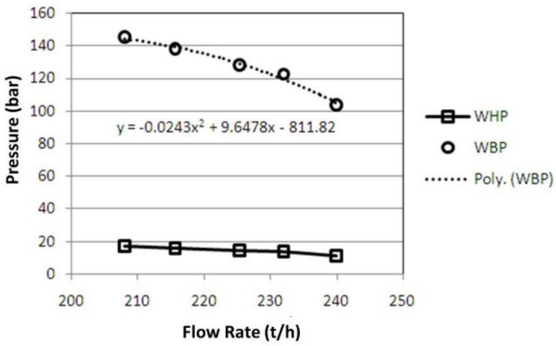


Figure 6: Modified deliverability curve for Well 2H-21 and the calculated downhole pressures (WBP).

The deliverability curve shown in Fig. 5 was obtained by utilizing three points of measured mass flow rate data with respective measured wellhead pressure. These three data points were assumed to represent the stable fluid conditions (steady state). In order to evaluate downhole pressures, this deliverability curve was modified by adding several points to obtain more representative points. The steady state conditions were not actually to be considered, because the transient wellbore simulator was used for analysis. The modified deliverability curve and the approximation of calculated downhole pressures to account for the pressure drops in wellbore due to friction, gravitational, and acceleration loses is presented in Fig. 6. A quadratic function was the best option for fitting the correlation between mass flow rates and downhole pressures.

The calculated downhole pressures obtained by using the above approximate equation are required to be confirmed to give realistic numbers using WELBORE. This could be performed by consider them to be input data for WELBORE and the calculated wellhead pressures were compared with the measured ones. The result of matching process is shown in Fig. 7. It is obviously clear that a reasonable match has been achieved.

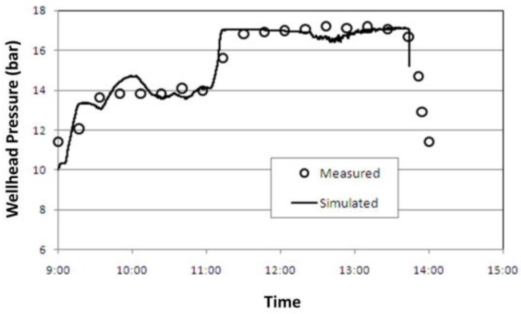


Figure 7: Comparison between measured and simulated wellhead pressures using WELBORE.

6.2 Radial Reservoir Models (AWTAS)

AWTAS is a software code that is used for analyzing physical properties of reservoir from the results obtained from well tests. It is capable for simulating complex non-isothermal systems and broader range of model types compared with traditional analysis (O'Sullivan et al., 2005). In the present study, three different types of reservoir models were calibrated, namely, homogeneous porous medium model, dual-porosity fracture/matrix model, and fractional dimension (fractal) model.

The calculated downhole pressures using WELBORE are used as matching parameters. Two sets of input parameters are used for calibration of the models. The first parameters are those that are commonly used in modeling purpose and have no effect on model performance as presented in Table 1. The second set consists of parameters that may affect the model performance and those that will be optimized by AWTAS. It depends on the considered model type, however most of the model types use permeability and porosity and additional parameter as optimized parameters.

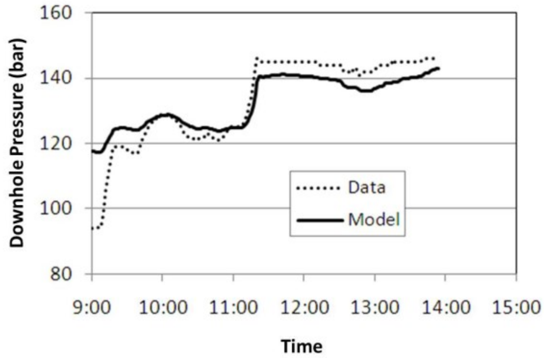
Table 1. Fixed parameters used in AWTAS.

Property	Value
Rock specific heat	1000 J/(kg.K)
Rock thermal conductivity	2.25 W/(m.K)
Rock density	2500 kg/m^3
Rock compressibility	10^{-10} Pa^{-1}

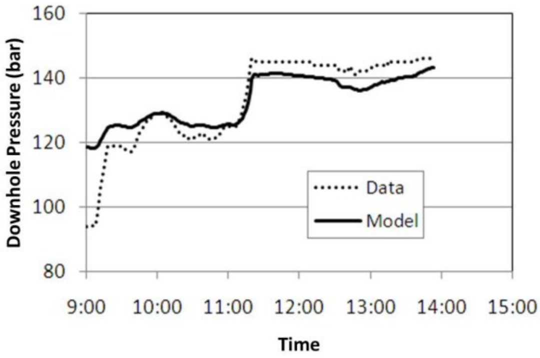
6.2 Model Calibration Results

The measurement took place from about 9:00 a.m. to 14:30 p.m. The experience at Hatchobaru field showed that prior to the measurement the well was left in full production then the mass flow rate was gradually decreased by throttling the valve. In order to get best match, the similar situation was implemented, i.e. the simulation was started for almost five hours with constant flow rates and downhole pressures from the start of measurement. This procedure was applied for the three models.

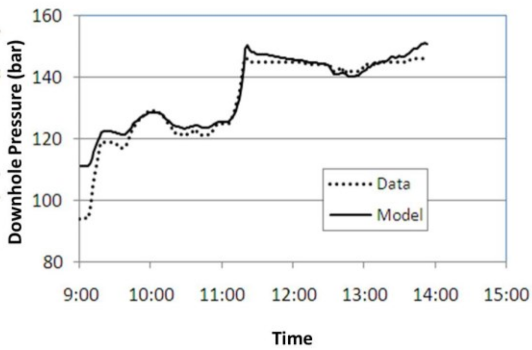
The homogeneous porous medium model assumes that the reservoir consists of a homogeneous porous medium throughout the feedzone layer, with the same permeability and porosity assigned to all model blocks (O'Sullivan et al., 2005). Therefore, in order to get the best agreement between the field data and model result for downhole pressures, permeability and porosity are varied. The permeability value of 4.1x10^{-15} m^2 and the porosity value of 0.1 give the best match for the model. The match result is shown in Fig. 8 (a). However it is obvious that the match result is reasonable.



(a)



(b)



(c)

Figure 8: AWTAS results. (a) Homogeneous porous medium model; (b) Dual porosity fracture/matrix model; (c) Fractional dimension (fractal) model.

In the dual-porosity fracture/matrix model, fluid flow from the reservoir to the well is treated as horizontal flow through a fracture zone, with (in and out) vertical flow between this zone and the adjacent low permeability matrix (Zarrouk et al., 2007). The flow in the radial direction in the matrix is negligible. The best match was achieved by assigning the permeability values for fracture and matrix to be 4.3x10^{-13} m^2 and 4.0x10^{-14} m^2, respectively. The porosity value of 0.1 is assigned for matrix while 0.2 for fracture zone. The thickness of the fracture is set to be 2 cm. The result of calibration is presented in Fig. 8 (b). The match result is similar to that of homogeneous porous medium model, but it gives larger permeability values.

The fractional dimension (fractal) model assumes that fractured reservoirs can be represented by fractal geometries (see e.g. Tateno et al., 1995). The implementation of this concept was proposed by Barker (1988), in which the volume swept out by the fracture system, and the area enclosing it, are assumed to increase according to fractional powers of the radial distance from the wellbore. Using this approach, the fractures in the network are assumed to be all perfectly connected. The variable parameters for this model are the same as those for homogeneous porous medium model, with the addition of the fractional dimension parameter n, which is allowed to take on any value in the range 1.0 - 3.0. The result of model calibration is shown in Fig. 8 (c). The better agreement match result is achieved compared with two previous models. This was achieved by assigning the permeability value of 7.36x10^{-14} m^2 and a porosity of 0.1 with addition fractional dimension parameter of 2.8. The last parameter may imply that the fluid flow in the reservoir take place closer to the spherical flow. As a whole, the calibration result indicate that the fractional dimension model may represent the reservoir type at the Hatchobaru, especially for region close to the Well 2H-21.

7. CONCLUSION

A continuous measurement system for steam and water flow rates at separator by wellhead has been developed. The results of the measurement can be used to evaluate the transient behaviors of well characteristics, mainly the time required for the well to stabilize after valve operation. Furthermore, the results of the measurement can be applied for evaluating the reservoir properties. Results are summarized as follows,

- The duration of valve operation affects the flow stabilization in wellbore.
- Well characteristics measurement should be made in a manner of flow rate decrease to minimize stabilization time.
- Steam flow rate stabilizes more quickly than water flow after valve operation ceased.
- The best agreement for the model calibration from the measured data of Well 2H-21 is achieved for the fractional dimension (fractal) model with the permeability and porosity are 7.36×10^{-14} m^2 and 0.1, respectively.

ACKNOWLEDGEMENT

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