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WELL TESTING AND RESERVOIR ENGINEERING STUDIES AT THE TENDAHO GEOTHERMAL FIELD , ETHIOPIA

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ABSTRACT

In this paper the 6 wells drilled in the Tendaho geothermal field are briefly described. Formation temperatures and initial pressures for each well are estimated and a conceptual reservoir model presented. The Tendaho reservoir is divided into a shallow sedimentary reservoir of 220-250°C temperature and a deep one in volcanic basalts, ranging from 220-270°C in temperature. Inflow comes from depth in the east and flows diagonally to the surface, causing reversed temperatures in the present wellfield. Production data analysis indicate permeability-thickness in the range of 3-10 Dm in the shallow reservoir. A wellbore simulator study shows that the present wells maintain high flowrates despite either a 5 bars reservoir drawdown or a 20°C reservoir cooling. Both volumetric reservoir assessment and TOUGH2 reservoir model indicate that the present wellfield can sustain 70 kg/s production rate for 20 years.

1. INTRODUCTION

Investigations for geothermal resources in Ethiopia dates back to 1969. The first 8 deep geothermal exploratory wells were drilled in Lakes District at Aluto Langano geothermal field from 1981 to 1985. A combined binary cycle pilot power plant with a capacity of about 7.8 MWe, from the 4 productive wells is operational since July 1998.

The Tendaho geothermal field is located in the north-eastern part of Ethiopia, some 600 km from the capital city, Addis Ababa (Figure 1). Drilling of deep exploratory wells started in October 1993. Three deep and one shallow wells (1-4) were drilled by May 1995 (Figure 2). These wells led to the discovery of a shallow reservoir in the vicinity of wells TD2 and TD4. Drilling of two additional shallow wells commenced on December 20, 1997 and completed on February 20, 1998. The existence of a shallow 230-250 °C liquid dominated reservoir was confirmed in the Tendaho cotton plantation (often called Dubti).

In this paper the formation temperatures and initial pressures for Tendaho wells are estimated. From the formation temperature and pressure distribution, a conceptual reservoir model is constructed. Production data are analysed and future well performance for two wells predicted. Pressure transient tests from the newly drilled wells are analysed and permeability estimated. Resource evaluation for the shallow reservoir is carried out by applying the volumetric method. In order to determine the confidence intervals of the volumetric resource assessment method, the Monte Carlo statistical method is employed. Additional modelling work is done by the multi-dimensional reservoir simulator, TOUGH2 in order to support the conclusions drawn by the volumetric method. Finally the size and pre-feasibility study of a small pilot power plant instalment is discussed.

2. DATA SOURCES

Stratigraphy, Chemistry, Resistivity, Downhole temperature and pressure

Tendaho geothermal field is one of the three geothermal prospect areas within the Tendaho graben, which covers an area of about 4000 km^2. Two deep and 3 shallow wells have been drilled in the thermally active zone of the Dubti area and one deep well (TD3) was drilled 7 km away from the rest of the wells. Information about the wells in Tendaho are summarized in Table 1.

The results of drilling indicate that in the Dubti area, the upper 600-700 metres are lacustrine sedimentary sequences with interlayered basalts. The lower parts are the Afar Stratoid Series, basaltic sequence that represent the floor of the Tendaho sedimentary basin (Aquater 1996). The water discharged from the wells is of sodium chloride type. Total dissolved solids are low, with a TDS value for TD4 at atmospheric separator of 2.2 g/l. Noncondensable gases are less than 0.2 Nl/kg. Main recharge elevation for the Tendaho geothermal system was estimated to be 3000 m.a.s.l., within the upper portion of the escarpment. The NE boarder of the Tendaho cotton plantation, where the intensive thermal activities are concentrated and proved to be productive, was also pointed out to be promising by low resistivity anomalies (Oluma, et al., 1996). Figure 2 shows the resistivity anomaly together with the wells.

A total of 131 downhole temperature and pressure surveys were carried out by using Amerada and Kuster mechanical gauges.

3. INITIAL WELL TEMPERATURES AND PRESSURES

3.1 General information

Temperature is one of the most important parameters needed for geothermal reservoir analysis. Information obtained from temperature logs can be useful for heat flow estimation, location of aquifers, temperature distribution in geothermal reservoirs, reservoir assessment and efficient resource exploitation management. The initial reservoir pressure is also of importance. It delineates possible upflow zones of the reservoir as a pressure high or low. Repeated pressure logs during warm-up may also show the depth of the major feed zone of the respective well (pivot point analysis).

Complete temperature recovery in a new well may take anywhere from a few hours to a few months. A long wait for temperature recovery could cause a sizeable increase in drilling costs. Therefore predictions of formation temperatures has to be done using other methods. The methods are based on temperature logs taken during drilling stops, or collection of such logs, forming a temperature recovery curve spanning several hours to months.

The formation temperature estimation for the Tendaho geothermal wells is done by applying one of the ICEBOX software packages (Arason & Bjornsson, 1994; Helgason, 1993). The program BERGHITI used here, offers two methods of calculation: the Albright method and the Horner plot.

The following text describes briefly the initial pressures and formation temperatures for the 6 wells.

3.2 Well TD1

The Albright method gave similar results to the measured static temperatures, where as the Horner method's estimates are lower. This could be due to the effect of circulation time.

The shape of the formation temperature suggests that the heat transfer in the upper 600m is by conduction with an average temperature gradient of about 370°C/km. Temperature increases from surface down to 950m and is constant to about 1100m depth. From 1100m to about 1400m, there is temperature reversal. The deepest part of the hole section (1700- 2200m) the temperature gradient is positive with <20°C/km. By comparing the formation temperature profile and the boiling point with depth curve, one can conclude that the reservoir is under single phase liquid condition at all depths.

The initial pressure is calculated from the estimated formation temperature by using the PREDYP program (Arason & Bjornsson, 1994). The calculated initial pressure is almost identical to one of the measured static profiles. A feed zone is most likely at about 900m depth with initial pressure of abut 80 bars and 270°C temperature. The shut-in wellhead pressure is stable at 5.3 bars showing that the deep reservoir is over pressurized (well full of water).

3.3 Well TD2

The estimated temperature is near identical to a run, which was measured in 1996 after 2 years of shut-in condition. This implies that the well's temperature is in equilibrium with the geothermal system. From surface to about 425m, the temperature follows the BPD curve. From 425m to about 800m, there is a temperature reversal. From 800m to about 1400m depth, temperature increases slightly and is nearly constant below 1400m. The temperature reversal could indicate that the well is located in an outflow area of the geothermal field.

The estimated initial pressure follows the boiling depth curve from surface to about 450m depth in good agreement with the measured temperature. Below this depth the pressure gradient is slightly higher than that of the BPD in accordance with a shut-in wellhead pressure of 5.4 bars. This leads to the conclusion that the Tendaho reservoir can be divided into a deep and a shallow reservoir. The shallow reservoir is characterised by boiling and pressure potential in equilibrium with the surface, where as the deep system is ovrerpressurised and in single phase water condition.

3.4 Well TD3

Estimates by the Albright method are relatively higher than the last static profile, whereas the estimates made by Horner method are lower. The static temperature is almost the average of the estimates made by both methods. As it is most likely that the well temperature has stabilized in the last run, it is taken as the formation temperature. A zone of hotter fluid is clearly visible at 50m depth from a temperature log during drilling. This indicates a geothermal outflow somewhere near the well.

The formation temperature profile suggests that the temperature gradient is about 250°C/km in the upper part of the well. Below 550m the gradient is low (~ 20°C/km). The well has a stable water level at about 25m depth.

3.5 Well TD4, TD5 and TD6

Almost all temperature profiles follow the boiling point for depth curve. The formation temperatures of these shallow wells is therefore assumed to be the same as the boiling point for depth curve.

TD4 has two feed zones at around 250m and 330m depth. The initial reservoir pressure at the major feed zone (250m) is about 22 bars.

The major feed zones for wells TD5 and TD6 are located at 400m and 300m. The estimated initial pressures at the feed zones are 34.5 and 25.6 bars respectively. The shut-in wellhead pressures for the three shallow wells range from 21 to 22 bars.

4. A CONCEPTUAL RESERVOIR MODEL

Conceptual models are used in all stages of geothermal energy exploration and exploitation. Typically, exploration wells are located to delineate a resource, and production wells to intersect areas of high temperature and permeability. The location of these wells are in most cases based on a conceptual model of the reservoir. In turn the data from new wells are then used to confirm, or more likely, improve the conceptual model (Okandan, 1988). Conceptual reservoir models also serve as an integral part of numerical reservoir models, as they provide the basis for the model geometry, boundaries, recharge sites etc.

The formulation of a conceptual model for the Tendaho geothermal field is based on the available temperature and pressure distributions, which shall be improved in future by the drilling of additional wells and longer production history.

Figure 3 shows a E - W temperature cross-section through wells TD1, TD5, TD6, TD2 and TD4. The higher temperature at shallow depths around well TD2 suggests that the high temperature fluid flows from depth around TD1 and then laterally to a shallower level towards TD2. The temperature reversal at TD2 is also noticeable.

Figure 3 also serves as a conceptual model for the Tendaho geothermal field. A hot fluid recharge at a temperature of about 270°C flows, from the east towards well TD1. This is also suggested by the location of the low resistivity anomaly (Figure 2). Around TD1 the recharge rises to about 1100m and then flows towards TD4. Two reservoirs domains are suggested for the Tendaho area. A shallow reservoir BPD, may have a reservoir thickness of about 300m and a temperature of 230-250°C. Due to the close spacing and the limited number of the shallow wells, the areal extent of the reservoir is unknown. From the temperature cross-section, one may suppose that the geothermal reservoir lies relatively at greater depth east of TD5. In the vicinity of wells TD4 and TD2, feed zones are at shallower level compared to that of TD5.

5. PRODUCTION TESTING

The Lip pressure method, which was proposed by Russel James (1970) was employed in Tendaho.

Due to the limited capacity of the waste water disposal ponds and other reasons, the wells at Tendaho have been tested for production only for a short period of time. The tests performed and the results obtained are summarized as follows

Well TD1: Is nonproductive. During a spontaneous discharge through a 1" bleed line, the well produced a few kg/s fluid of high enthalpy for few hours.

Well TD2: It produces about 15 kg/s total fluid at a wellhead pressure of about 3 bars. The enthalpy of the discharged fluid is estimated at 920 kJ/kg. The low wellhead pressure is most likely due to low reservoir permeability and temperature. The well produces from multiple feed zones.

Well TD4: The production capacity of the well is as high as 70 kg/s total flow. The average production of the well through the 4" lip pipe was 50.4 kg/s total fluid at a wellhead pressure of 14.4 bara. The fluids enthalpy was about 1065 kJ/kg and the steam flow rate 14 kg/s.

Well TD5 : The maximum total flow rate is attained during discharge through 5" diameter lip pipe (48.5 kg/s at 10.4 bars wellhead pressure). This implies that during discharge through 6" pipe, the flow in the well is choked through larger diameter pipe resulting in no flow rate increment.

Well TD6 : The average production rate at a wellhead pressure of about 5 bars was 33 kg/s total fluid with an enthalpy of 990 kJ/kg.

6. ANALYSIS OF PRODUCTION DATA

Only limited amount of production data are available so far for the Tendaho geothermal reservoir. The data available can be grouped into two categories, 1) short term completion tests and 2) short term discharge tests. In the following section, the production data is analysed in terms of reservoir permeability and future well performance.

6.1 Permeability estimation

Well TD5 : Two fall-off and one pressure build-up tests were carried out at 290 and 490m depths. The analysis result indicates that the permeability-thickness ranges from 2.4 to 10 Dm. The injectivity tests at 290 and 490m depths resulted in injectivity index estimates of 3.7 and 3 kg/s/bar respectively.

Well TD6 : Only one fall-off test at 300m depth is available for analysis. The permeability thickness-product is 6.2 Dm. The injectivity index is estimated at about 5 kg/s/bar.

For comparison, a common value of the permeability-thickness product in various geothermal systems is in the range 1-100 Dm (Björnsson & Bodvarsson, 1990). The short term production data points therefore towards favourable production characteristics for the shallow Tendaho system. Also noticeable is the high injectivity index of the wells. It ranges between 3 and 5 (kg/s)/bar. Recent survey in the Svartsengi field in Iceland shows an injectivity index in the range 2-10 (kg/s)/bar in a reservoir of 100 Dm permeability and 240°C temperature (Björnsson, 1998). Wells productivities there has proven to be above the average in the long run, suggesting that the Tendaho system is also favourable for production. The limited extent of the shallow wellfield however, is of concern and must limit the long term production capacity (i.e. the heat in the storage limits the production capacity rather than the fluid in storage).

6.2 Well performance

As it is of interest to predict the future performance of the Tendaho wells, a simple, quantitative study was performed on the well output data. By applying the wellbore simulator HOLA (Björnsson, 1993) one can predict the influence of future reservoir pressure and enthalpy changes on the well.

For the newly drilled shallow well TD5, the estimated productivity index for the feedzone is $6x10^{-12}m^3$. Using this productivity index, output curves were calculated for different reservoir conditions.

The simulation exercise suggests that a reservoir pressure drawdown of 5 bars causes 10 kg/s mass flow rate reduction. For stable reservoir pressure but an enthalpy decline to 900 kJ/kg, which corresponds to 210°C reservoir temperature instead of the 220-240°C at present, the well still can produce at high flowrates, but this may require flowing wellhead pressures close to separator pressure.

Well TD4 was also simulated for possible output curves. The simulation indicates that the productivity index of the well is high ($60x10^{-12}$ m^3). A best fit for the output data was obtained for an enthalpy of 970 kJ/kg.

7. RESOURCE ASSESSMENT

7.1 General

Evaluation of geothermal resource requires knowledge of many parameters such as the area extent of the field, the thickness of the reservoir, temperature and pressure distribution, porosity, density and heat capacity of the rock. The quantity and quality of available data are the limiting factors for the accuracy of the resource estimate.

In the following a resource evaluation is carried out for the Tendaho shallow reservoir. It is based on a rough calculation on the available thermal energy in the reservoir. An estimate for the production capacity is made by the volumetric method. As several of the factors/parameters, used for the estimate, are only known approximately, an attempt is made to define the accuracy of the calculations by applying random distribution in some of them.

7.2 The volumetric method

The volumetric method involves calculation of the thermal energy contained in a given volume of rock and water and then the estimation of how much of this energy might be recoverable.

For the calculation of the thermal energy in the subsurface of the Tendaho shallow geothermal reservoir, the following assumptions were made: Initial reservoir temperature =240(°C), reference temperature =200(°C) ,heat capacity of rock =1000 (kJ/kg°C), density of rock =2700 (kg/m^3), porosity =0.2(-), radius of shallow reservoir, = 700 m and reservoir thickness =300m Here it should be noted that some of the above values are based on the analysis in Chapters 3 and 4.

For the above mentioned assumptions the estimated heat energy is $5.2x10^{16}$ J. The electrical power potential of the reservoir is calculated as 1.3 MW. Here we assumed a recovery factor of 0.25, a load factor of 0.8, a conversion efficiency from thermal to electrical of 0.05 (back pressure turbine) and a plant life of 20 years

This estimate should be taken as a best guess for the small wellfield known at present. Although one may find tempting to use a larger value for reservoir area, it would only provide an estimate for a possible reservoir volume. Note also that by using the same presumption for the deep system except that now the reservoir thickness is 1200 m, radius 1 km and temperature 260°C, an electric power estimate of 16 MW_e is attained. Larger power plant operation in the area should therefore concentrate on the deep system.

7.3 The Monte Carlo probability method

The Monte Carlo probability method deals with the quantification of the uncertainties or probability distributions in the parameters involved in reserve estimation (Sarmiento, Z., 1993). The method was applied for the Tendaho shallow reservoir. The randomness of the uncertain values was defined either by square or triangular probability distributions. The estimated production capacity was finally plotted as a histogram.

The histogram indicates the range of probability estimate from 0.5 to 4.5 MW_e with the most likely value in the range 1-1.5 MW_e.

8 NUMERICAL MODELLING

It is of interest to confirm the result of Monte Carlo statistical method by using some kind of a distributed parameter, numerical model. The model should in particular account for phase changes and different nature of the outer reservoir boundaries. In the following, a simple production analysis is performed with the aid of the TOUGH2 simulator.

8.1 TOUGH 2

TOUGH, which stands for "Transport of Unsaturated Ground water and Heat", is a multi-dimensional numerical model for simulating the coupled transport of water, vapour, air and heat in porous and fractured media. It is a member of the MULKOM family of multi-phase, multi-component codes, which is being developed at Lawrence Berkeley Laboratory (Pruess, 1987). In 1993 the TOUGH2 version was released. It differs from the former one mainly by much faster execution time.

8.2 The numerical reservoir model

For convenience a simple, radial grid was used as a reservoir model for the Tendaho geothermal field. A simple 1-D, radial flow in a single layer horizontal reservoir of 300m thickness is assumed. The computational mesh consists of 10 grid blocks with ΔR=1m, and 40 additional grid blocks with $\Delta R_{i+1}=\alpha\Delta R_i$ out to a radius of 2000 m. The grid is identical to that of sample problem 4 in the TOUGH manual, except that the thickness is 300m instead of 100 m (Pruess, 1987).

8.3 Model calibration

Pressure build-up data from well TD5, which was collected after 123 hours discharge at an average flow rate of 37.5 kg/s, was used to calibrate the model. A good fit was obtained by using an inner permeability of 33 mD and an outer permeability of 200 mD (kh is 10 and 60 Dm respectively). A constant 20% model porosity was used. The model permeability next to the well is similar to the ones presented in Chapter 6 but, 10 times higher in the outer part.

8.4 Future performance of the shallow reservoir

As the limited production from the Tendaho reservoir puts no constraints to the reservoir volume, or nature of recharge, a total of 8 prediction cases were performed. Both closed and fully open reservoir was considered, a constant 250°C reservoir temperature or declining temperature from 250°C in the grid centre to 150°C 2 km away, in accordance with the temperature of the low permeable well TD3. The permeability of the outer grid blocks was either constant as 200 mD or a combination of 200 mD permeability out to 700 m and then a reduction to 20 mD.

Rather than allowing variable production through a productivity index, it was decided to request a constant flow of 70 kg/s. Of these, 35 kg/s were taken from the centre grid block, and the other 35 kg/s from block 34, 200 m away from the centre. The 70 kg/s value was simply chosen as it provides 10 kg/s of high pressure steam under no boiling conditions in the 230-250°C reservoir.

Out of the 8 model cases, 4 sustain the 70 kg/s total production easily. Of them 3 have open boundary but one is closed. In Figure 4 the flow of high pressure steam from the feed points considered is shown. What is noteworthy in the Figure is that 4 cases sustain easily 2-4 MW_e production in a back pressure turbine (5 kg/s per MW). In cases 5 and 6, a substantial boiling occurs, resulting in a higher enthalpies and hence higher steam flowrates. These cases are therefore also considered here to be reasonable for the prediction period, since the total production will be reduced from the 70 kg/s requested, and the pressure drawdown.

In summary, the sensitivity study shows that all but 2 cases of 8 sustain 2 MW_e electrical production in a back pressure turbine for up to 20 years. In the 2 failing cases, flowrates may constrain maximum power generation. These two, however, have in common very rapid enthalpy change in comparison with the other 6 cases. A 0.5- 1 year flow testing period is therefore recommended before a decision of building a pilot plant is taken. If the total flowrate, enthalpy and the chemistry of the produced fluid remain relatively constant through the test, building pilot plant seems reasonable. Otherwise a longer testing or a smaller turbine size may become necessary.

9. CONCLUSIONS

1. The Tendaho geothermal field appears to be divided into two reservoirs; a shallow reservoir and a deep one. The shallow reservoir is hosted in sedimentary formation but the deep one in volcanic basalts.
2. The shallow reservoir is characterised by boiling and pressure potential in equilibrium with the surface. Its thickness is around 300m and a temperature of 230-250°C is observed.
3. The deep system is overpressurised by about 5 bars and in single phase water condition. The temperature ranges from 220-270°C.
4. A hot fluid recharge at a temperature of about 270°C flows from the deep reservoir, from the E towards well TD1. Around TD1 it rises to about 1100m and then flows diagonally towards TD4.
5. As the short term well testing indicate adequate permeability in the shallow reservoir (kh=3-10 Dm), one may conclude that the heat in storage limits production capacity rather than the fluid in storage.
6. Wellbore simulation study shows that the present wells will maintain high flowrates, despite a reservoir pressure drawdown of 5 bars or a cooling down to 210°C. The cooling, however, may reduce flowing wellhead pressures down to general separator pressures (7 bars-a).
7. Volumetric analysis and numerical model indicate that the presently known shallow reservoir likely sustain a 1-2 MW_e power generation in a back pressure turbine for 20 years.
8. Before deciding to build a pilot power plant, a ½ to 1 year flowtest is recommended. This will provide much better insight on the reservoir boundaries and possible phase changes during production.
9. The suggested 1-2 MW_e size of a pilot plant should not as all be taken as the final capacity of the Tendaho reservoir. On purpose the study concentrated only on a small subvolume of the presently known geothermal reservoir. Further exploration, drilling and exploitation most likely will raise this estimate substantially.

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REFERENCE

Aquater (1996) : Tendaho geothermal project, final report, MME, EIGS-Government of Italy, Ministry of Foreign Affairs, San Lorenzo in Campo

Arason, P., and Björnsson, G., 1994: ICEBOX. User's guide. Orkustofnun, Iceland

Björnsson, G. and BodvarssonG.,, (1990): A survey of Geothermal Reservoir Properties. Geothermics, Vol. 19, No. 1, pp. 17-27

Björnsson, G., Arason P. and Bodvarsson S., 1993: The wellbore simulator HOLA, version 3.1; User's guide

Björnsson, G., (1998): Acceptable injectivity in new wells of the Sudurnes Regional Heating system, evaluated from step-rate pumping in Svartsengi, Eldvörp and Reykjanes (Icelandic)

Helgason, P., 1993 : Step by step guide to BERGHITI. User's guide. Orkustofnun, Reykjavik

James R., 1970: Factors controlling borehole performance. UN Symposium on the Dir. Util. of Geothermal Resources, Pisa, Italy, Geothermics, Vol. 2, Part 2, pp. 1502-1515.

Okandan E., 1988: Geothermal reservoir engineering , NATO ASI Series, Kluwer Academic Publishers, Dordrecht/Boston/London

Oluma B., Ayana D. and Demisse Y., 1996: Geophysical survey of Tendaho geothermal field, MME, EIGS, Geoth. Expl. Proj. P1-23 (unpublished report)

Pruess, K. (1987) : TOUGH User's Guide. Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

Sarmiento, Z., 1993: Geothermal development in the Philippines. UNU G.T.P., Iceland, report 2, 99 pp.

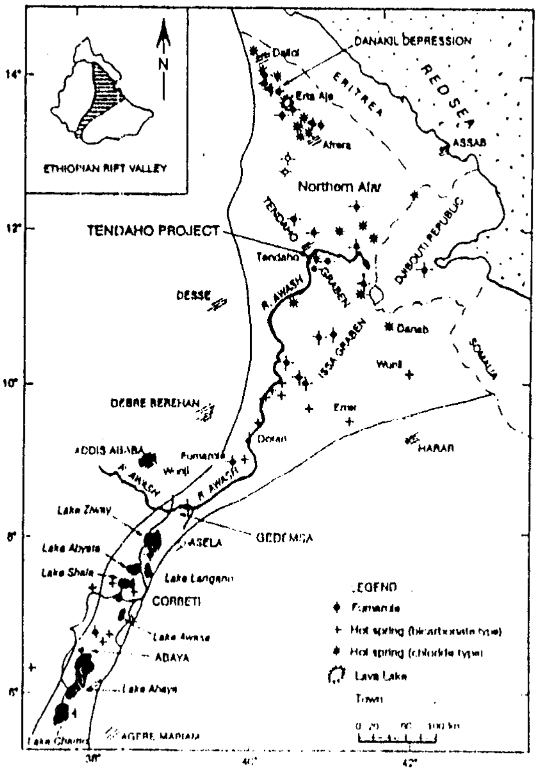

Figure 1. Geothermal areas in the Ethiopian rift valley

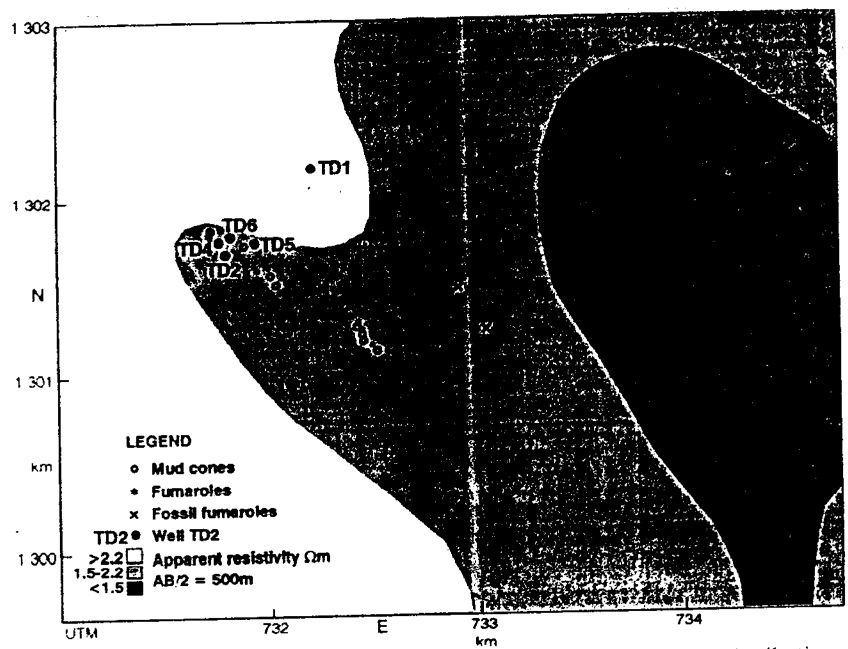

Figure 2. Location map of Tendaho geothermal wellfield and resistivity distribution

Table 1: An overview of the Tendaho Geothermal Wells

Well No.	TD1	TD2	TD3	TD4	TD5	TD6
Drill date: From To	 29/10/93 27/02/94	 13/03/94 10/05/94	 07/09/94 19/10/94	 27/04/95 09/05/65	 20/12/97 14/01/98	 01/02/98 20/02/98
Location (UTM) East (m) North (m) Elevation (m.a.s.l)	 73237708 1303746 365.9	 731412 1302823 365.7	 728652 1309451 366.8	 731363 1302941 365.2	 731558 130290 366.3	 731670 1302919 366
Well Design: Casing depth (m) 20″ 13 3/8″ 9 5/8″ Liner 7″ MD (m) V D (m) KOP (m) Inclination (°) Direction	 130.5 575 850 800-1500 2196/1550* 2196/1550*	 111 607 854.5 809-1807 1811 885 17 N50E azimuth	 62 404.5 830 681-1362 1989 1989	 24 109 210 181-463 466 466	 47.6 136 220 202-508 516 516	 40 123 217 209-504 505 505
Status of the well	Non-productive	Productive	Non-productive	Productive	Productive	Productive

MD: Measured depth, VD: Vertical depth, KOP: Kick-off point * current depth (re-drilled depth after well collapse)

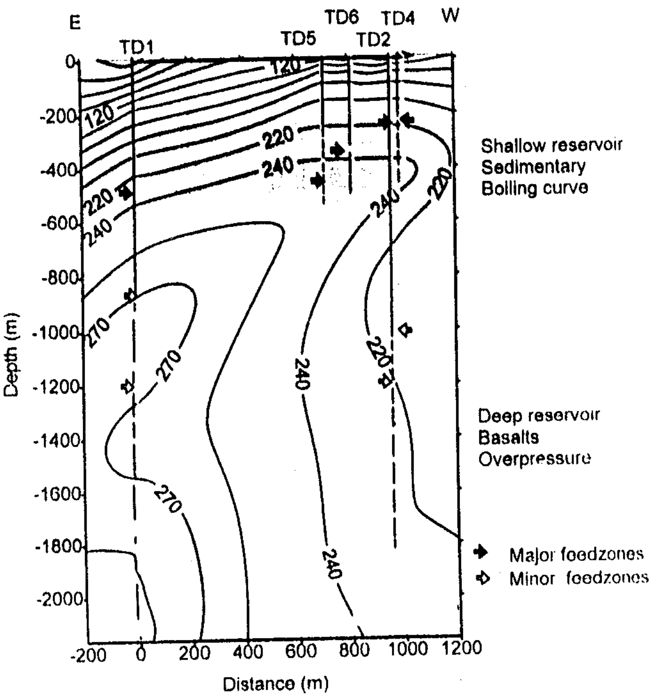

Figure 3. Temperature cross-section, Conceptual model

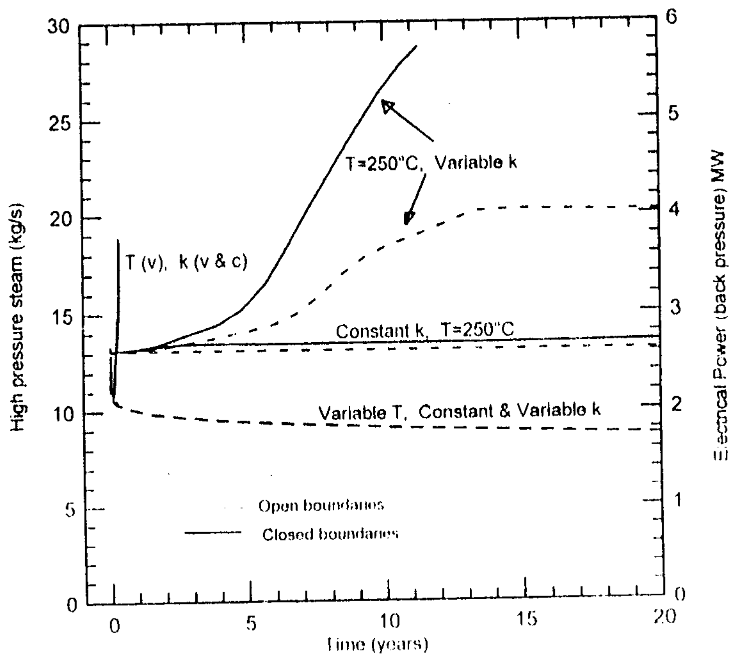

Figure 4. Results of performance study