A preliminary update of natural state numerical model of Olkaria geothermal system, Kenya

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Abstract

A field-wide 3-D natural state numerical model of the entire Olkaria geothermal system was developed in 1987 by G.S.Bodvarsson and K.Pruess. The model simulated the geothermal system to be recharged at a total rate of 600 kg/s from two major distinct upflow zones located in Olkaria Northeast and Olkaria West. The upflow zone in Olkaria Northeast recharged the system at 250 kg/s of 1290 kJ/kg water and the one in Olkaria West at 350 kg/s of 1090 kJ/kg of water. The recharge from the two upflow zones mixed near well OW-201 and discharged at 260.5 kg/s to the south and 175.1 kg/s to the north through Ololbutot fault and Olkaria fracture, respectively. Steam loss from the system amounted to 126 kg/s. Between 1987 and 2000, 46 new additional wells were drilled and tested in the greater Olkaria geothermal system. While data from some of the newly drilled wells have agreed quite well with those calculated by the 1987 model, several other data, especially from the Olkaria Central wells, have shown big variations. An attempt has therefore been made to recalibrate the 1987 model with the new data acquired from the 46 additional wells. The same numerical grid has been used and the results have indicated a slight variation in recharge rates and enthalpies. The upflow in Olkaria West in the updated model is 245 kg/s of 1200 kJ/kg water and that in the East (both Northeast and east field) is 320 kg/s of 1290 kJ/kg water. The discharge to the south in the updated model is 304.3 kg/s and to the north is 134.4 kg/s. Steam loss from the system is 128 kg/s.

Keywords: *Olkaria, natural state,TOUGH, simulation.*

1 Introduction

Olkaria geothermal system is located in the East African rift valley to the south of Lake Naivasha and 120 km northwest of Nairobi city. The geothermal system covers an area of more than 120 km^2 and is associated with a central volcano that is among several ones situated within the central Kenyan rift.

Exploitation of this resource for the purpose of producing electricity started in 1981 in Olkaria East Field when the first 15 MWe generation unit was put online with the second and the third 15 MWe in 1982 and 1985, respectively. From 1985 through the 90s intense surface exploration and deep drilling was done in the neighbouring areas resulting in demarcation of adjacent fields in Olkaria West, Northeast, Central and Domes (Figure 1). A 13 MWe binary plant installed by Ormat Inc. started operation in August 2000 in Olkaria West and a 64 MWe plant is nearing completion in Olkaria Northeast.

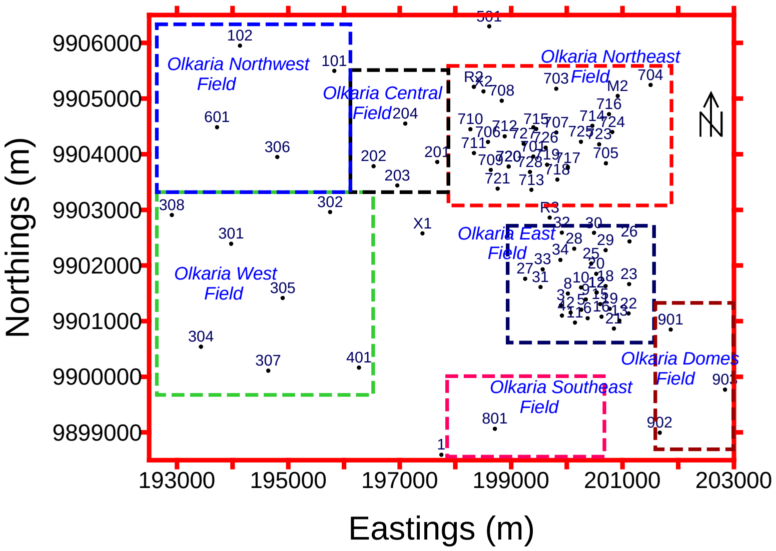

Figure 1: Location of wells and fields within the greater Olkaria geothermal system.

The geothermal system is liquid dominated and is recharged by hot up flowing fluids from zones in the West, Northeast and East fields. The upflow zones are associated with the intersection of prominent faults within the geothermal system such as the NE trending Olkaria fault and the NW, NNW trending faults (Figure 2).

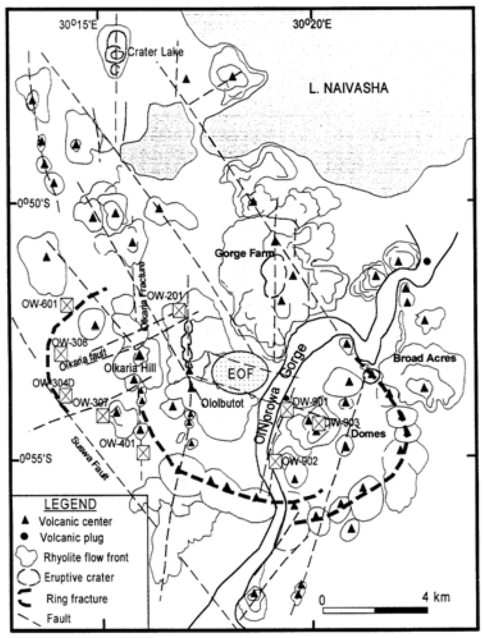

Figure 2: Geological structural map of Olkaria geothermal system. In the numerical grid, inflow and outflow through the prominent faults (Olkaria Fracture, Olkaria Fault and Ololbutot fault), are represented by alphabetical letters A, B, C, D and E.

Between the upflow zones in the east and west is a low temperature and pressure zone of Olkaria Central, which is associated with the N-S trending Ololbutot fault. Temperatures and pressures in wells drilled in the upflow zones follow boiling point with depth with steam cap forming below the cap rock. Wells in Olkaria Central field have temperature inversions at depth. Subsurface stratigraphy of the wells show that from the surface (which is at an average of 2000 m a.s.l) to 1400 m a.s.l, the rocks consist of quaternary comendites and pantellerites with an extensive cover of pyroclastics. Below these, the dominant rocks are trachytes with thin intercalations of basalts and tuffs. The rock stratigraphy is essentially horizontal (Muchemi, 1999).

A field-wide 3-Dimensional natural state numerical model was developed in 1987 by Bodvarsson and Pruess (Bodvarsson and Pruess, 1987) and was calibrated against the thermodynamic data obtained from the wells that had been drilled by then. The model agreed quite well with the measured data and the conceptual model. From 1987 to present, more than 46 new wells have been drilled in the greater Olkaria geothermal system and there has been a serious need to update the numerical model to conform to the new findings. This paper presents a preliminary update done to the old model in 2002 (Ofwona, 2002) whereby the thermodynamic data from most of the new wells have been incorporated.

2 Model description

2.1 Grid geometry

The TOUGH2 model developed to represent Olkaria reservoir covers an area of 110 km^2 and is partitioned into 128 blocks. Vertically, the model assumes an impermeable caprock of 700 m thick beneath which underlies a permeable reservoir of 850 m that is further partitioned into three layers giving a total of 384 grid blocks (Figure 3).

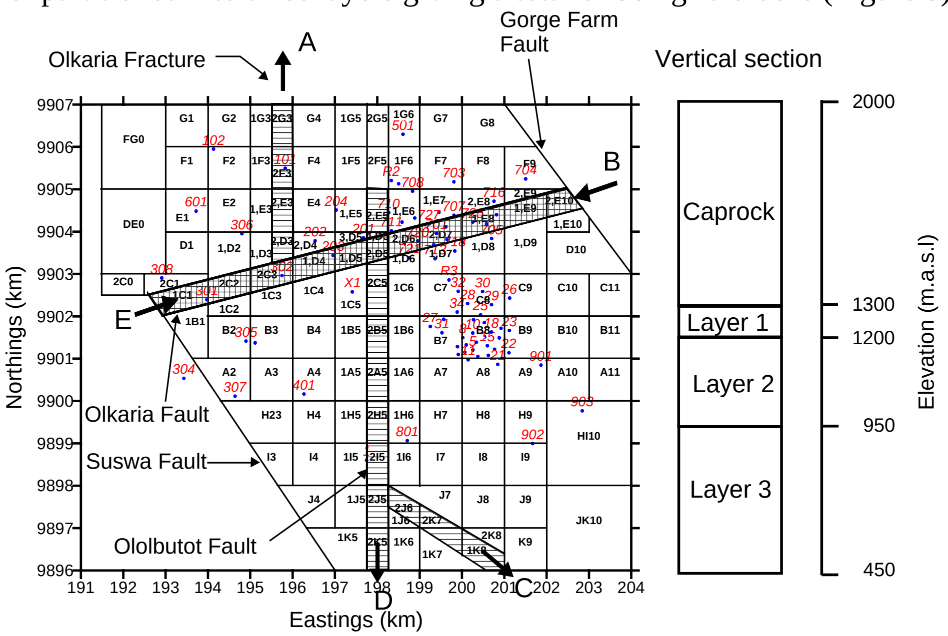

Figure 3: Grid block layout.

2.2 Boundary conditions

The major hydrogeologic features of the Olkaria system include Olkaria fracture, Olkaria fault, Suswa fault, Gorge farm fault and Ololbutot fault (Figure 2). In the model, two major upflow zones located near the western and eastern ends of the Olkaria fault recharge the hydrothermal system. The fluid from the upflow zones move along the Olkaria fault as they undergo conductive cooling as well as cooling by steam loss to the surface and converge in Olkaria Central zone. Major outflow with substantial loss of steam and cooling occurs towards the south along the Ololbutot fault and towards the north along Olkaria fracture zone. The reservoir is assumed bounded in the east and west by no flow boundaries and in the north and south by constant pressure boundaries of 45 bars at 1075 m a.s.l and 28 bars at 1075 m a.s.l, respectively. The hot upflows are treated as the source of hot fluids at the base of the model.

2.3 Fluid and rock properties

The rock properties used were similar to those in the 1987 model and changes were made only where well tests had shown otherwise and in cases where no information was available, the values chosen were simply guessed. A rock type with defined rock properties (values of permeability, porosity, density and thermal conductivity) was assigned to each model element. Table 1 shows the rock properties assigned to the major structures in the geothermal system.

Table 1: Rock and fluid properties.

Rock properties	Fluid properties	Permeabilities, m^2 (x 10^{-15})		
Density: 2650 kg/m^3 Heat capacity: 1000 J/kg °C Thermal conductivity: 2.0 W/m°C Relative Permeabilities: $k_{rs}(S_s) = (S_s - 0.05)/0.55$ $k_{rw}(S_w) = (S_w - 0.40)/0.60$	Approximated as pure water and all properties based on steam tables		Vertical	Horizontal
		Olkaria Fault	230	230 x 230
		Olkaria Fracture	250	250 x 250
		Ololbutot Fault	500	500 x 500

2.4 Match to measured data

The natural state was simulated for 10,000 years until a steady situation agreeing closely with the current temperatures and pressure values in most parts of the reservoir was found. It was a long trial and error procedure, slightly changing the rock parameters and boundary conditions. Important adjustable parameters in the model were the strength of the upflow (both enthalpy and flow rate), vertical and horizontal permeabilities, and the strength of outflow and steam losses along the prominent hydrogeologic structures. The observations were measured or inferred downhole temperature and pressure profiles and surface heat flow estimated to be 400 MWt (Glover, 1972).

3 Results

The results of simulation are shown graphically for a few selected wells in the Figures 4-7. They show graphs detailing pressures and temperatures calculated by the recalibrated model (open squares connected with lines) and those from the 1987 model (filled black stars) in relation to the measured or inferred formation temperatures and pressures (broken lines). We can observe that the 1987 model matches the data pretty well except for the wells within the low temperature zone in Olkaria Central field. To obtain a reasonable match for these wells, I had to reduce the upflow rate from the west and permeability in the Olkaria fault and Olkaria fracture zones and increased the permeability of the East field thus allowing more fluid to divert south through the present production field instead of moving to the Central field. Other minor adjustments in permeabilities on other elements were also necessary. Table 2 shows the updated flow rates compared to those obtained by the old model.

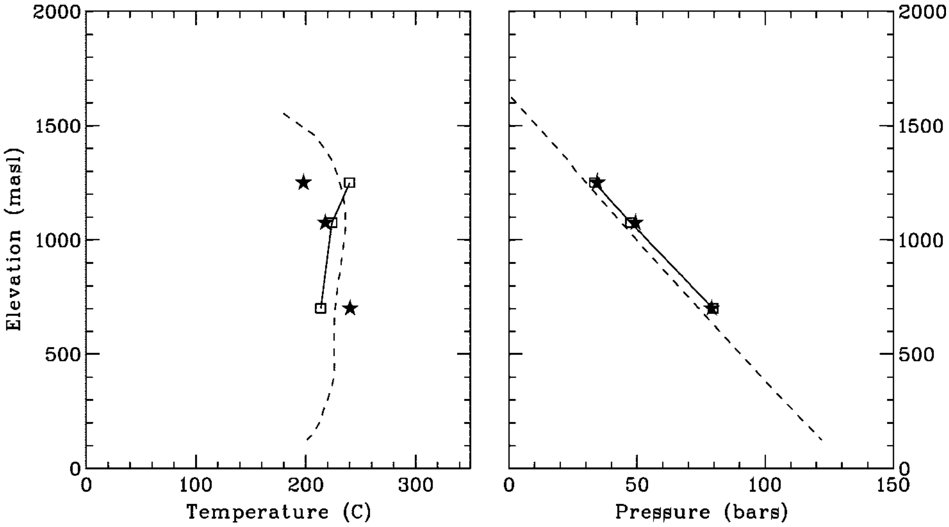

Figure 4: Match to temperature and pressure in well OW-201.

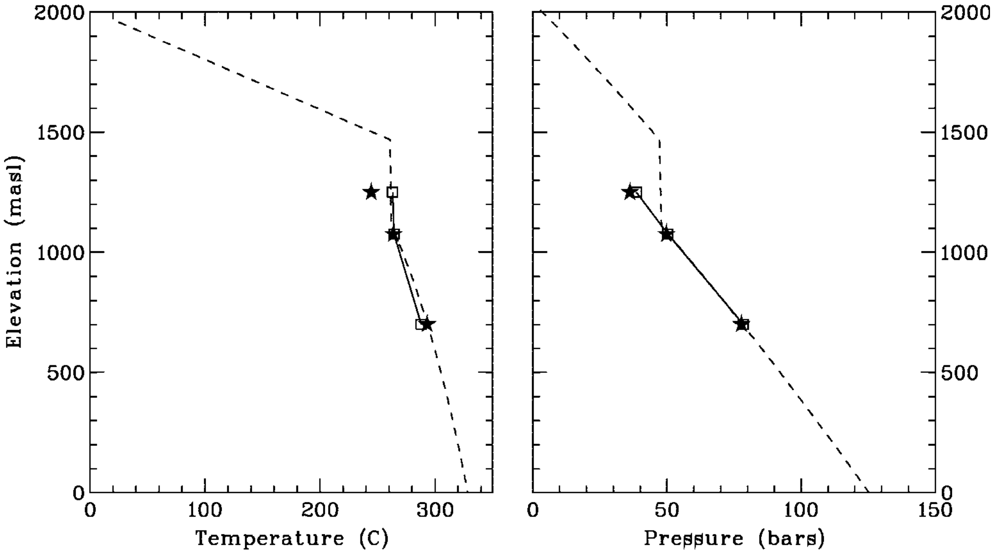

Figure 5: Match to temperature and pressure in well OW-32.

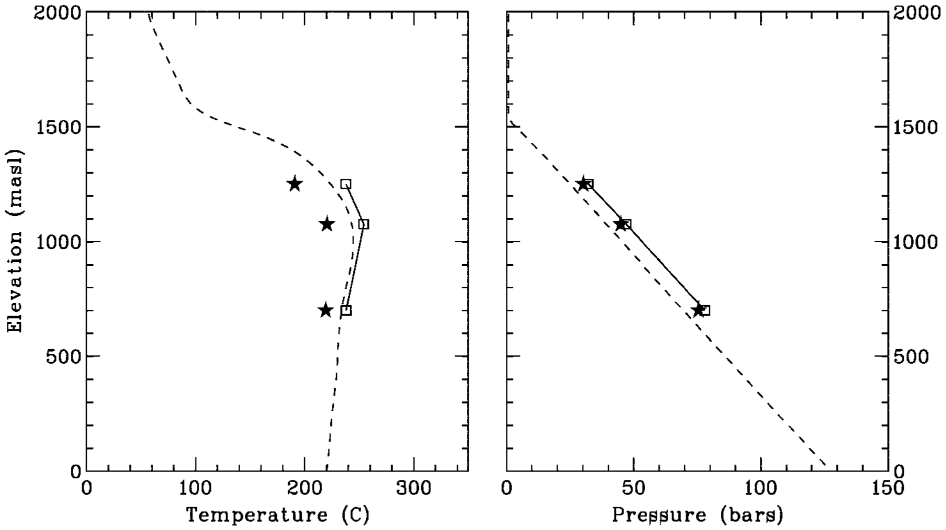

Figure 6: Match to temperature and pressure in well OW-401.

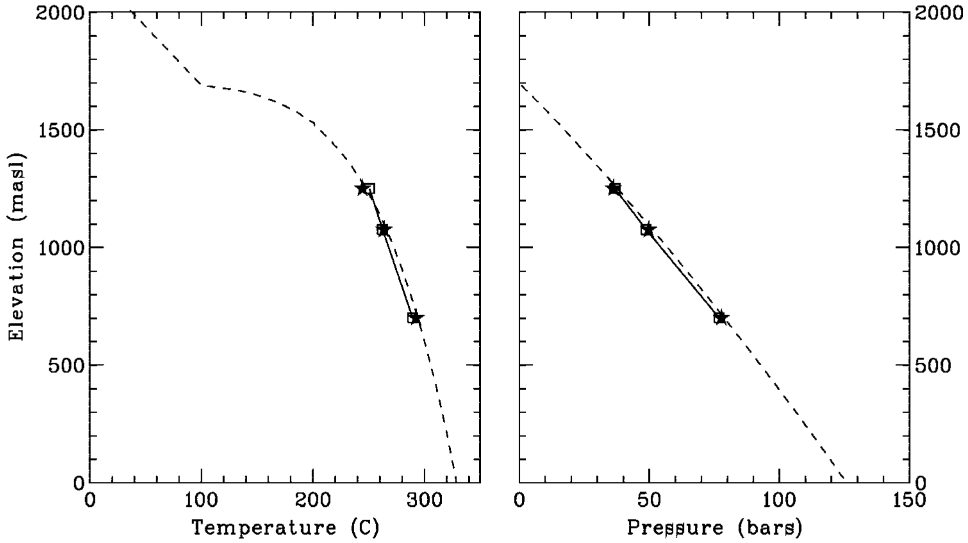

Figure 7: Match to temperature and pressure in well OW-720.

Table 2: Flow rates.

Flow rates (kg/s) and Enthalpies (kJ/kg)						
	A	B	C	D	E	Steam
Inflow		320(250)			245(350)	
Outflow	134.4(175.2)		137.8(107.6)	166.5(152.9)		128(126)
Enthalpy		1290(1290)			1200(1090)	2800(2800)

4 Conclusions

The present simulation results should be considered preliminary because the model did not consider deeper layers even though most of the wells are now drilled to depths below 0 m a.s.l. However, a reasonable match between calculated and observed values is obtained for the depth considered and the numerical model confirms pretty well the conceptual model. It shows that quite a huge quantity of water is circulating in Olkaria system in the natural state suggesting that good recharge can be expected during the exploitation life of the field. The challenge now will be to extend the vertical grid in order to cover the deeper zones.

5 References

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