Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Resource Assessment of Olkaria I Geothermal Field, Kenya

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Keywords: Olkaria, Resource, Assessment, Simulation

ABSTRACT

Olkaria I geothermal reservoir currently occupies an area of 4 sq. km and has been exploited for the purpose of generation of 45 MW electricity since 1981. 32 wells have been drilled in this area and the majority of them were drilled to less than 1600 m depth with the shallowest being 901 m. One well (OW-5) was deepened from 901 m to 2200 m in 1998 and its power output increased to 5 MWe from less than 1 MWe. Current total steam output from the producing wells is 213 kg/s and only 126 kg/s is being utilized. The excess steam can be used to generate an extra 30 MWe and furthermore, if all the shallow wells are deepened to 2200 m, there is a strong possibility of winning more steam to generate more power. It is also possible to extend the resource area by 3 sq. km and more wells drilled thereby making it possible to increase the generating capacity. This paper presents an assessment of the power potential of Olkaria I field. It is concluded that the field can produce up to 100 MWe or more for the next 25 to 30 years if the shallow wells are deepened and the resource area extended by 3 sq. km.

1. INTRODUCTION

Olkaria geothermal field is located within the Great East African Rift Valley and about 120 km to the northwest of Nairobi City. The greater Olkaria geothermal field covers an area of more than 120 km^2 and is now divided into several sectors (Figure 1) for exploitation purposes. Sectors that are already under exploitation are Olkaria East (Olkaria I), Northeast (Olkaria II) and West (Olkaria III).

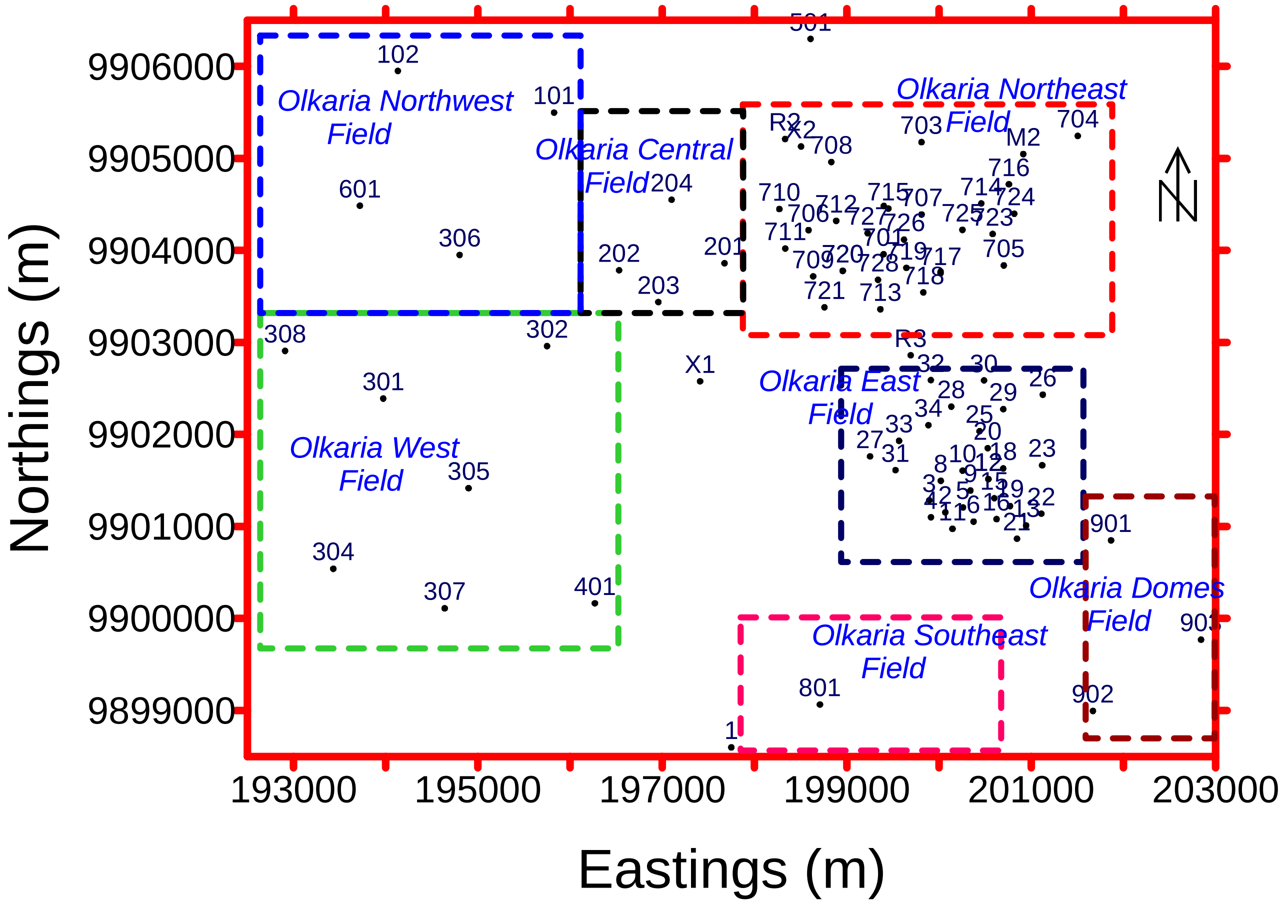

Figure 1: Location of production sectors within the greater Olkaria geothermal field

The first 15 MWe turbine in Olkaria I started generation in 1981 and the field has been producing 45 MWe since its full commissioning in 1985 while Olkaria II, which was commissioned in October 2003 is now producing 70 MWe. Olkaria III started production from its phase 1 in the year 2000 and has been producing 12 MWe from a binary power plant, since then. There are more plans for further expansion in all these sectors.

Olkaria I field (Figure 2) taps a boiling two-phase liquid dominated reservoir overlain by a 100 – 200 m thick steam zone capped by a 700 m thick cap rock. Initially, 23 wells (all drilled to depths ranging from 900 m to 1685 m, except OW-19 drilled to 2484 m) within a 2 km^2 area, supplied steam for the three units but as time progressed, some of the wells (mainly drilled to depths between 900 m to 1200 m) declined in output and had to be isolated. New make-up wells were drilled to restore the generating capacity, which had declined to 31 MWe by 1994 (Mwangi, 2000). Four make-up wells were connected in 1995, two more in 1996 and another two in 2001. After connection of the make-up wells, and deepening well OW-5 from 900 m to 2200 m, total steam available from the existing exploitable wells now exceed what is required to generate 45 MWe and this calls for a re-evaluation of the generating capacity. This is the subject of this paper.

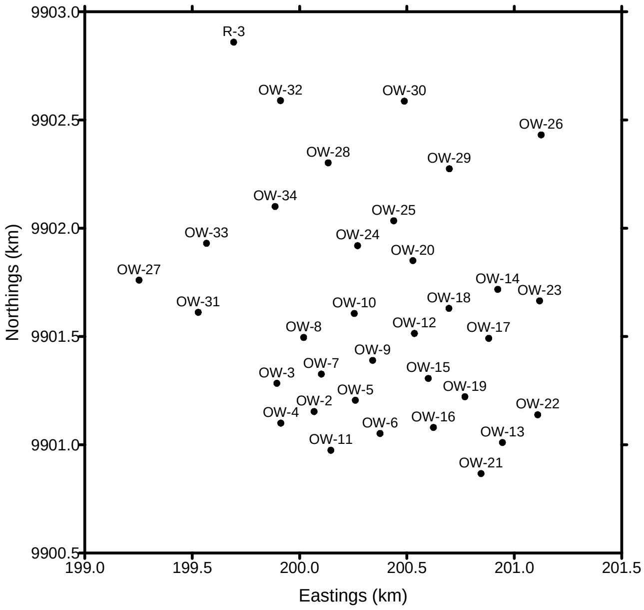

Figure 2: Location of wells in Olkaria East field

2. WELL CHARACTERISTICS AND CURRENT FIELD STEAM PRODUCTION

Initial temperature and pressure profiles obtained in wells drilled in Olkaria I follow boiling point for depth curve from the point where the steam zone intercepts the water reservoir (Figure 3). Steam zone temperatures averages at 240 °C and pressures of 33 – 36 bars. At depth, average temperature at 1500 m is 300 °C and at 2200 m is 330 °C. Wells discharge neutral sodium chloride waters with chloride concentrations in the range of 200 – 350 ppm and on average the discharge composition is 25 % water and 75 % steam. Productive aquifers are associated with contact between lavas, porous pyroclastics and fractured trachytes. Wells intercept these permeable aquifers at different depths spanning the whole of the drilled zone.

After connection of makeup wells in 1996, there was more steam available from the field than required to generate 45 MWe. The reason being that wells drilled as makeup wells were deeper and targeted known faults thereby intercepting more permeable aquifers and ended up being large producers. Today there is a total of 213 kg/s of steam available at the wellhead and only 115 kg/s is required for power generation. It is therefore worthwhile to consider how the excess steam can be utilized.

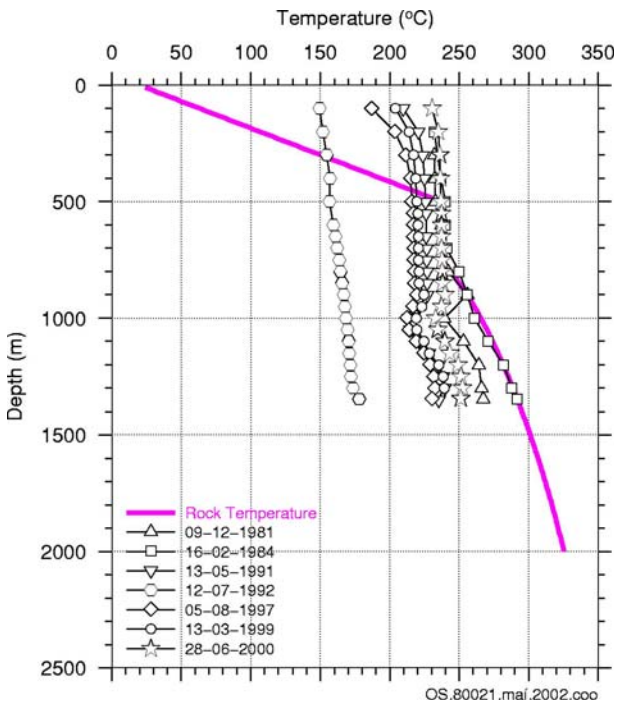

Figure 3: Temperatures in well OW-21, a typical Olkaria I profile

3. ASSESSMENT OF THE GENERATING CAPACITY

3.1 Use of available excess steam at the wellhead

As mentioned in the previous section, about 98 kg/s of steam is excess and with the current generating units at Olkaria I, this can produce more than 30 MWe. This therefore implies that without drilling any new wells, the field is currently capable of producing at least 75 MWe.

3.2 Deepening existing shallow wells to tap from the deep boiling liquid reservoir

Well OW-5 was drilled to 900 m in 1975 and connected to the power plant in 1981. By 1996, its steam output had declined to less than 2.5 kg/s from more than 8 kg/s it was producing in 1986. A decision was then made to deepen it to 2200 m depth so as to tap its deep reservoir. The results of this was fruitful when in 1998 it was flow tested and revealed that its steam output had increased to over 11 kg/s. The well was then connected back to the power plant and is now supplying a steady steam for power generation. Figure 4 shows that pressure decline in this area where the well is located has only occurred at depths above 1600 m, which happen to be the depth at which the majority of the wells in this field are drilled. Below this depth, pressure profiles show that the reservoir is intact and if the shallow wells can be deepened, then more steam can be accessed from the current production area.

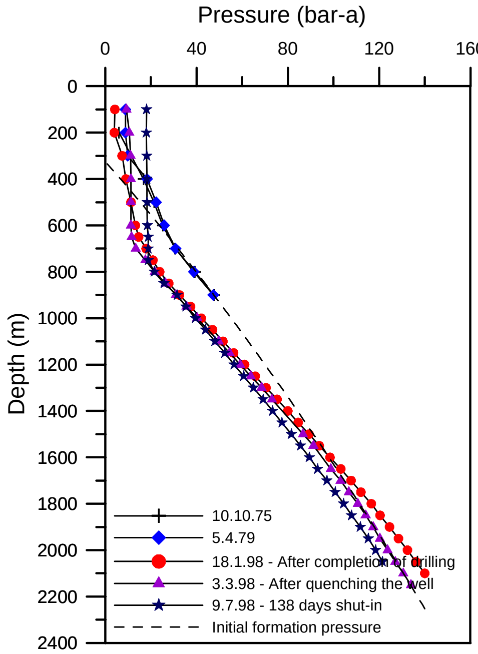

Figure 4: Downhole pressures in well OW-5

If we use the steam conversion rates for the generating units at Olkaria I of 2.55 kg/s per MWe, then well OW-5 increased in output from about 1 MWe to 5 MWe by deepening from 900 m to 2200 m. Assuming that if all the wells that are currently drilled to 1200 m depth or less are to be deepened to 2200 m, then each could produce an extra 4 MWe. Wells OW-12, 10, 13 and 14 (drilled to 900 m, 1183 m and 1049 m respectively) could then give 16 MWe more. Similarly, we can assume that wells drilled to 1200 m – 1400 m will produce an extra 3 MWe when deepened to 2200 m implying that wells OW-2, 3, 7, 11, 15, 16, 17, 21 and 23 (drilled to 1350 m, 1357 m, 1308 m, 1221 m, 1302 m, 1306 m, 1237 m, 1348 m and 1329 m) would give an extra 27 MWe.

Wells drilled between 1400 m – 1600 m would give an extra 2 MWe when deepened to 2200 m implying that wells OW-8, 18, 20, 22, 25 and 29 (drilled to 1600 m, 1406 m, 1406 m, 1406 m, 1600 m and 1599 m respectively) would give 12 MWe. Wells drilled between 1600 m to 1800 m would give an extra 1 MWe implying that wells OW-4, 6, 24, 26, 28 and 30 (drilled to 1661 m, 1685 m, 1620 m, 1607 m, 1605 m and 1602 m respectively) would give an extra 6 MWe.

The total extra power that would be obtained from deepening shallow wells would amount to 61 MWe. This means that from the existing production area, Olkaria I could produce up to 106 MWe if all the shallow wells were deepened to 2200 m.

3.3 Extending the production area

Area within the Ololbutot lava flow (Figure 5) has never been drilled due to its rough and rugged terrain. However, resistivity map at 1000 m.a.s.l (Figure 6) shows that it is a favorable area that might have a high potential for steam production.

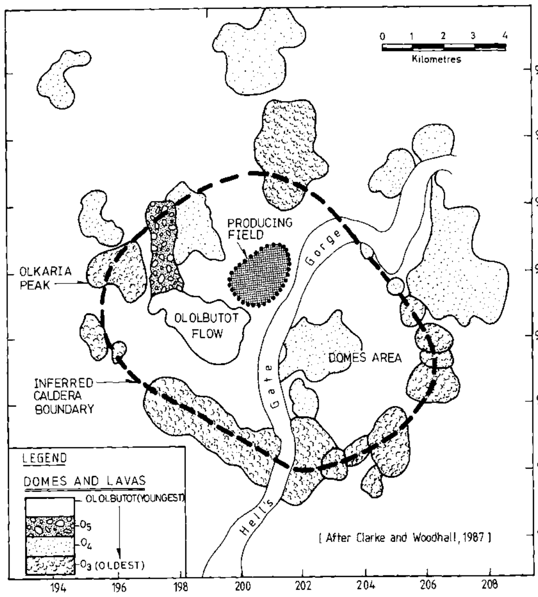

Figure 5: Map showing Ololbutot lava flow in relation to the production field

If the area within the 15 Ohm-m low resistivity anomaly is considered for expansion, then wells can be drilled within the area marked by the dotted square.

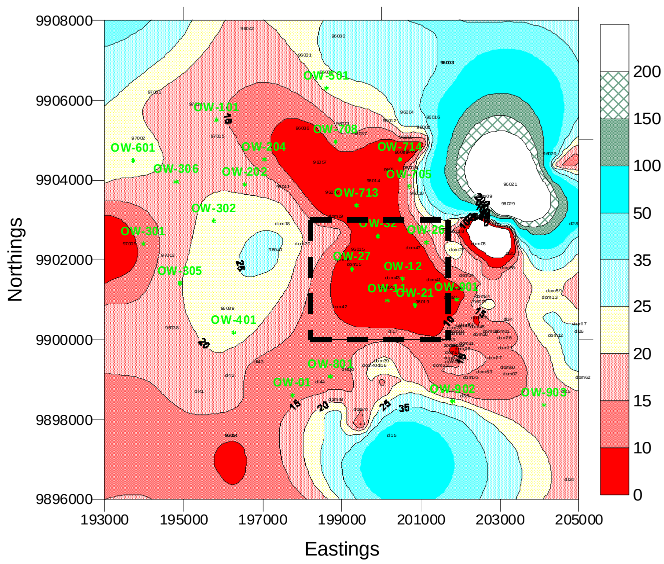

Figure 6: Resistivity (Ohm-m) at 1000 m.a.s.l

This implies that the total production area would range between 7 km^2 to 8 km^2. The amount of power that could be generated from this area is estimated in the next section.

4. ASSESSMENT BY STORED HEAT METHOD

Assessment by stored heat method is favored here because the area being suggested for expansion has not been drilled. Reservoir properties to be encountered here are therefore assumed to be similar to those encountered in the present Olkaria I production field. Parameters for the stored heat calculations are summarized in the following section.

Volumetric stored heat

The total heat in place is given by the equation:

$$H = A.h.(H_r + H_w) \quad (1)$$

where *H*, *A*, and *h* are stored heat, reservoir area and reservoir thickness respectively. The subscripts *r* and *w* denote rock, and water.

$$H_r = (T_i - T_f).(1-\phi).C_r\rho_r \quad (2)$$

where T_i, T_f, C, ρ, ϕ are reservoir temperature, base temperature, specific heat capacity, density and porosity respectively.

$$H_w = \rho_{wi}.\phi.(h_{wi} - h_{wf}) \quad (3)$$

where *h* is the enthalpy and the subscripts *wi*, and *wf* denote water at reservoir temperature and base temperatures respectively.

The final estimate of power potential is then calculated using the following equation:

$$E = \left[\frac{H.R_f.\eta}{F.L}\right] \quad (4)$$

where E, R_f, η, F and L are power plant capacity, recovery factor, conversion efficiency, plant capacity factor and plant life respectively.

<u>Reserve Area</u>

The total area to be considered here will include the present 4 km^2 production area plus the surrounding area covered by the 15 Ohm-m low resistivity anomaly. This is roughly encompassed by the dotted square in Figure 6. The minimum area would be about 7 km^2 if the higher resistivity zones encroaching into the low resistivity area are taken into account and the maximum would be 8 km^2 if area within the dotted square is considered. Well OW-26 appears in the 15 Ohm-m zone and its temperature and pressure profiles follow boiling point for depth curve so we can assume that wells to be drilled within this zone will be boiling.

<u>Reservoir Thickness</u>

Casing depths for wells already drilled in Olkaria I ranges from 500 – 600 m. If all the wells are to be drilled to 2200 m, the reservoir thickness will vary from 1600 m to say, 800 m.

<u>Recovery factor</u>

Recovery factor is a function of porosity. In Olkaria I, studies from numerical simulations have come up with a porosity value of 6% (Bodvarson et. al., (1987), Ofwona (2002)). Muffler and Cataldi (1978) have defined a linear relation between porosity and recovery factor. For a porosity of 6%, the Cataldi plot gives a recovery factor of 15 %. Bayrante et. Al., (1992) used a recovery factor of 20% for assessment of Mahanagdong project in Philippines for the same porosity. In this paper, a recovery factor of 20 % is used.

<u>Reservoir fluid temperature</u>

The reservoir fluid temperature can be taken as the average of the steam zone temperature (240 °C) and bottom hole temperature (330 °C). This is about 285 °C.

<u>Rock density</u>

A rock density of 2700 kg/m^3 is used.

<u>Conversion Efficiency</u>

A conversion efficiency of 12% is used.

<u>Stored heat calculation results</u>

Various input parameters to this analysis are summarized in Table 1. Most likely estimates are given as well as estimated probability distributions and minimum and maximum values for different input parameters like porosity, thickness of reservoir, average temperature, conversion efficiency, reservoir area and recovery factor. The results show a frequency distribution peak at a power capacity of 100 MWe but with a broad range from 80 to 150 Mwe due to the inherent uncertainties of the input variables (Figure 7). Figure 8 shows that there is a 50 % chance of producing more than 120 MWe.

Table1: Best Estimates and probability distribution

Input	Units	Best Guess	Probability Distribution		
			Type	Min	Max
Area	km^2		Rectangular	7	8
Thickness	m	1,200	Triangular	800	1600
Rock Density	kg/m^3	2,700	Constant		
Rock Spec. Heat	kJ/kg°C	1	Constant		
Porosity	%	6	Triangular	1	12
Temperature	°C	285	Triangular	240	330
Base Temp.	°C	180	Constant		
Fluid Density	kg/m^3	783	Steam Table		
Fluid Spec. Heat	kJ/kg°C	4.2	Steam Table		
Recovery Factor	%	20	Triangular	15	25
Conversion Efficiency	%	12	Triangular	10	15
Plant Life	years	25	Triangular	20	30
Load Factor	%	95	Constant		

5. DISCUSSION

The volumetric heat calculations show that 100 MWe can be accessed from the extended Olkaria I production area, which is a possibility because the resistivity measurements show that this area exists beneath the Ololbutot lava flow. Of this 100 MWe, 45 MWe is being produced from the present 4 km^2 production field. It is also possible to get an extra 61 MWe by simply deepening the existing shallow wells or drilling the deep wells at the same pads as the shallow wells. This might however be limited by the recommended spacing of 11 wells/km^2 (Bodvarsson, 1987) and so all the old shallow wells may not be targeted. Given that there is already excess steam available at the well head and the fact that deepening well OW-5 gave a very positive result, it is very encouraging to plan for a bigger power plant in Olkaria I.

So far, well measurements done in all shut-in wells in the greater Olkaria Geothermal field has not indicated any drawdown as a result of production from Olkaria I. Further numerical simulation, though, need to be done in order to investigate the effects of increased production from Olkaria I and II.

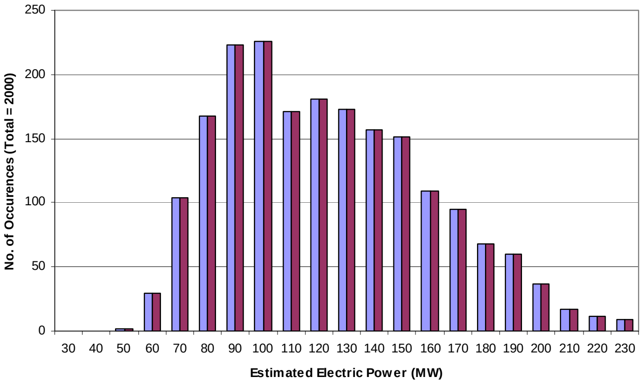

Figure 7: Frequency distribution of Power Capacity

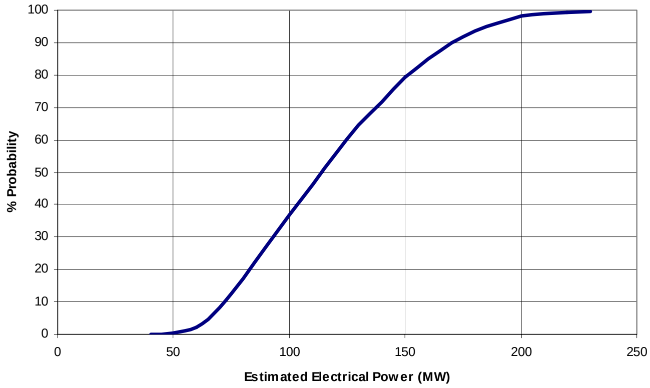

Figure 8: Cumulative frequency distribution

6. CONCLUSION

It is concluded that Olkaria I field can produce up to 100 MWe or more for the next 25 to 30 years if the shallow wells are deepened and the resource area extended by 3 sq. km**.**

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