Presented at Short Course IV on Exploration for Geothermal Resources,
organized by UNU-GTP, KenGen and GDC, at Lake Naivasha, Kenya, November 1-22, 2009.

KenGen
Kenya Electricity Generating Co., Ltd.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

Geothermal Development Company

# GEOTHERMAL EXPLORATION AND DEVELOPMENT OF THE OLKARIA GEOTHERMAL FIELD

**Peter A. Ouma**
Kenya Electricity Generating Company Ltd. (KenGen)
P.O. Box 785, Naivasha
KENYA
*pouma@kengen.co.ke*

## ABSTRACT

Several geothermal prospect areas have been identified in Kenya and are mainly located within the Kenyan Rift System. Olkaria prospect was the first to be explored and developed as Olkaria geothermal field, which is approximately 80 $km^2$. Due to its large size, it was found prudent to segment Olkaria geothermal field into seven sectors for ease of development. The sectors include Olkaria East, Olkaria North East, Olkaria Central, Olkaria South West, Olkaria North West, Olkaria South East and Olkaria Domes. Due to poor technology at the time, exploration work took over two decades before development of the first sector, which is Olkaria East. Olkaria reservoir produces two-phase mixture of steam and water in general proportion of 85% steam and 15% water and hence the resource is suitable for electrical power generation. Two types of power generation plants operate in Olkaria namely, the Ormat binary plants and the Mitsubishi geothermal condensing steam plants. A total of five power plants have been installed, two owned by KenGen, one by Ormat International and two by Oserian Development Company Ltd. The total installed power generation capacity of the four plants is 131.5 $MW_e$. Thus geothermal power installation constitutes about 12% of the national power installation and the plants operate as base load. Geothermal energy in Olkaria has mainly been utilized for electrical power production. Direct use has received little attention though recently Oserian Development Company Ltd leased a well from KenGen for direct use in horticultural farming. There are wells in Olkaria with extreme cyclic discharge characteristics and hence cannot operate with the other wells supplying steam to the power plants. Such wells, in the past, have either been turned to re-injection wells or simply rendered useless and yet are capable of supplying a lot of geothermal power for direct use. KenGen is looking at the possibility of economically selling geothermal energy from such wells to direct users either for recreational purposes or space heating.

## 1. INTRODUCTION

Several geothermal prospect areas have been identified in Kenya and are mainly located within the Kenyan Rift system. Olkaria prospect was the first to be explored and developed and became Olkaria geothermal field, located 125 km North West of Nairobi (Figures 1).

After extensive geo-scientific surveys in the early seventies, exploration drilling started in 1974 and continued through 1977. Following evaluation of the initial drilling results, a feasibility report was produced in 1977. The following year 1978, production drilling commenced and continued until 1983. Sufficient resource capacity was confirmed for installation of the first power plant of 45 $MW_e$ at Olkaria between 1981 and 1985.

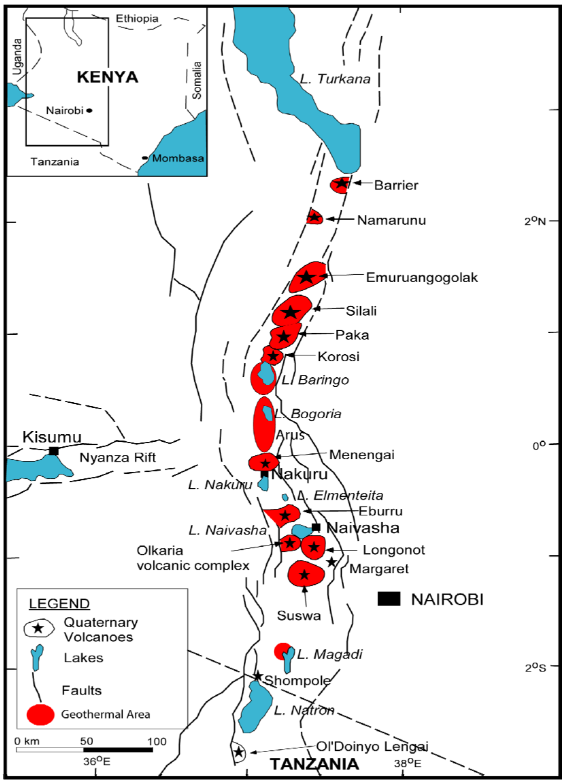


FIGURE 1: Location of Olkaria field

Further exploration continued in Olkaria and additional resource capacity was confirmed and the field size approximated to be about 80 $km^2$. It was therefore found prudent to segment Olkaria geothermal field into seven sectors for ease of development. The sectors are namely, Olkaria East, Olkaria North East, Olkaria Central, Olkaria South West, Olkaria North West, Olkaria South East and Olkaria Domes (Figure 2).

Additional power plants have been installed in Olkaria recently. These include a binary plant at Olkaria South West (Olkaria III) in 2000, with a capacity of 12 $MW_e$, a condensing plant at Olkaria North East (Olkaria II) in 2003, with a capacity of 70 $MW_e$ and another binary plant with a capacity of 2.5 $MW_e$ and condensing plant with a capacity of 2 $MW_e$ at Olkaria North West (Oserian) in 2004 and 2007 respectively. Three exploration wells were drilled in Olkaria Domes between 1998 and 1999 and appraisal drilling is in progress to appraise this sector for installation of a 70 to 140 MW power plant.

Since commencement of exploitation of Olkaria geothermal field, performance has been encouraging and that has lead to additional installations being considered for the sectors. Although output from the production wells has been on the decline, it has been gradual and in line with the predictions of the numerical simulation studies carried out for the Olkaria reservoir (Bodvarsson and Pruess, 1981).

For instance, Olkaria I plant of capacity 45 MWe was commissioned in 1981. It has operated quite well and registered outstanding performance with the plant availability exceeding 90%. Around 2004, it was realized that the life of this plant was coming to an end and yet the Olkaria East reservoir still had great potential to supply steam. The total amount of steam available from the twenty-eight (28) wells that supplied the plant could support generation of 70 MWe, implying availability of excess steam equivalent to 25 MWe.

Similarly, Olkaria II plant of capacity 70 MWe was commissioned in 2003. It is supplied with steam from twenty (20) production wells. The total steam available from the North East production wells in 2004 could support generation of 98 MWe, implying availability of excess steam equivalent to 28 MWe. The total excess steam, which was available in the two fields, was equivalent to 53 MWe. Based on this fact, KenGen desired to install a third 35 MW unit at Olkaria II plant similar to the two units commissioned here the previous year.

However, it is known that Olkaria East, North East and Domes are interconnected. It was therefore necessary that any development in any part be considered in the light of the entire investment.

Therefore in 2004, KenGen contracted West Japan Engineering Consultants, Inc. to carry out Olkaria Optimization Study to find an optimal scheme for exploitation of Olkaria East, North East and Domes fields. The study is yet to be concluded but the results will provide a clear investment plan for KenGen now and in the future.

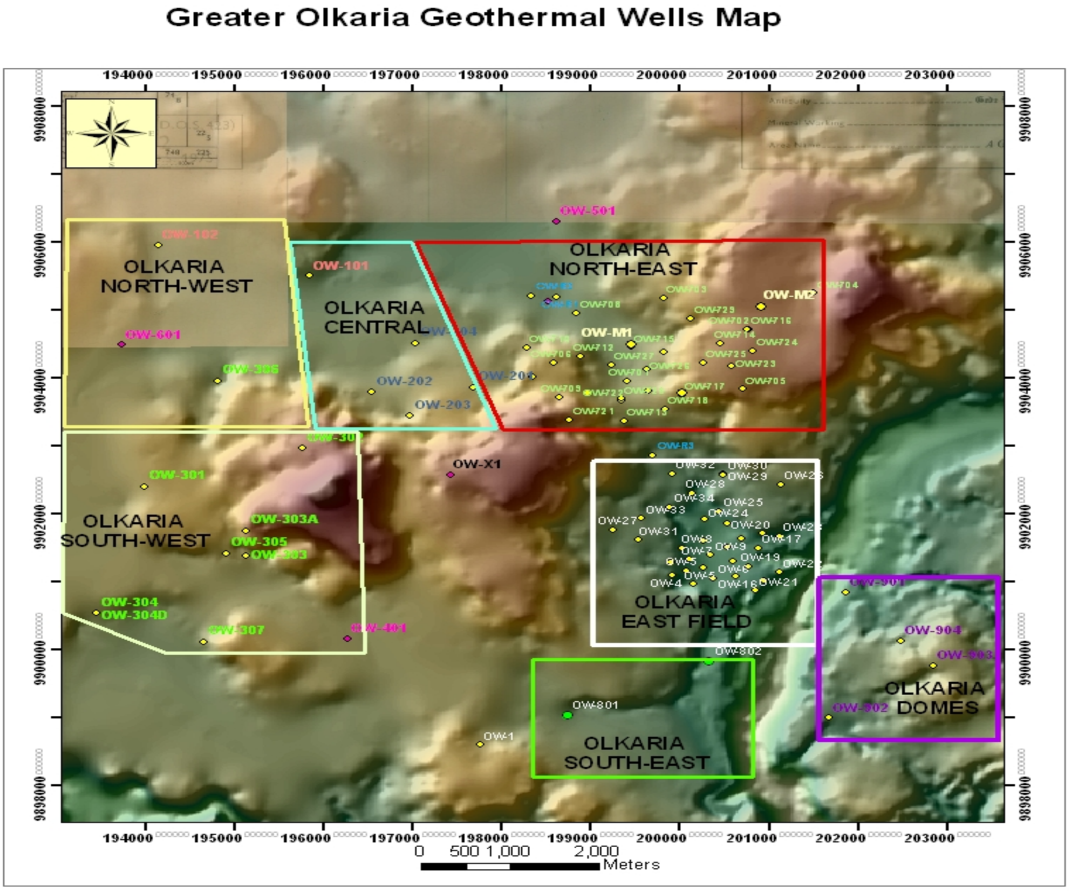


FIGURE 2: Geothermal Fields within the Greater Olkaria Geothermal Area

As part of reservoir management and assessment, Olkaria reservoir has been monitored for thermodynamic and chemical changes. Routine downhole temperature and pressure surveys have been carried out in production wells during well outages or plant shut downs. Regular output metering and geochemical sampling of the production wells have been conducted. The data collected during the above exercise is used to prepare the field bi-annual status reports on steam production. The decline in output of the wells has been compensated for jointly by drilling and connecting of make-up wells and in-field re-injection of effluent from the production wells.

The geothermal resource in Olkaria has mainly been utilized for electrical power production. Direct use has had little attention though it is well known that even after utilizing the steam part of the resource for electrical power production; a lot of energy is left in the water. Except for the binary plants in Olkaria South West and North West that utilize both steam and water, the condensing plants in Olkaria East, North East and North West only utilize the steam from the wells for electrical power production and separated water is rejected. However, there are wells with relatively lower enthalpy and produce more water than steam and hence if the energy in the water is rejected the result is very poor utilization of the resource. This paper discusses exploration and development of Olkaria geothermal field and management of the geothermal resource during exploitation.

## 2. EXPLORATION

Drilling of geothermal wells at Olkaria started in 1956 when shallow wells namely, X1 and X2 (Figure 3) were drilled without much success due to poor drilling experience. No information is available why the two wells were drilled at the location. Later Betty carried out some resistivity measurements in 1966 and found encouraging results of finding a geothermal resource.

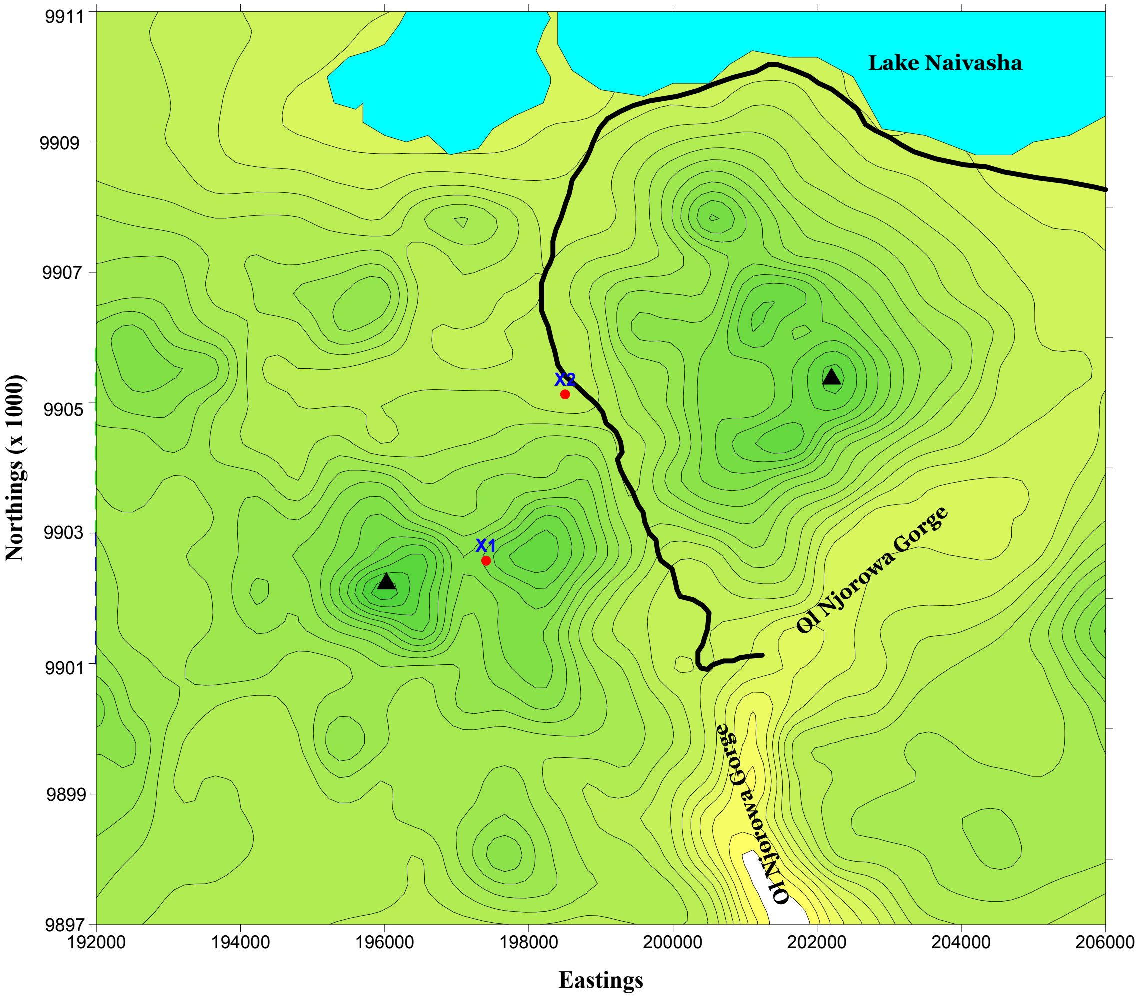


FIGURE 3: Location of OW-X1 and OW-X2

During the world oil crisis of 1970, UNDP and the Kenya Government carried out a reconnaissance survey along the Kenya rift that included Lake Magadi, Olkaria, Eburru and Lake Bogoria. Based on this reconnaissance survey more detailed work was done in Olkaria that included detailed geology, geophysics, geochemistry, heat flow measurements and hydrogeology. Although discharge of X2 was successful, it was not continuous.

Based on the scientific findings, the first well OW-1 (Figure 4) was drilled in 1973 to the south of the present Olkaria East in an area which had strong fumaroles. At 1000m, only 102 °C was realized. This area is now well established to be the outflow of the Olkaria geothermal system.

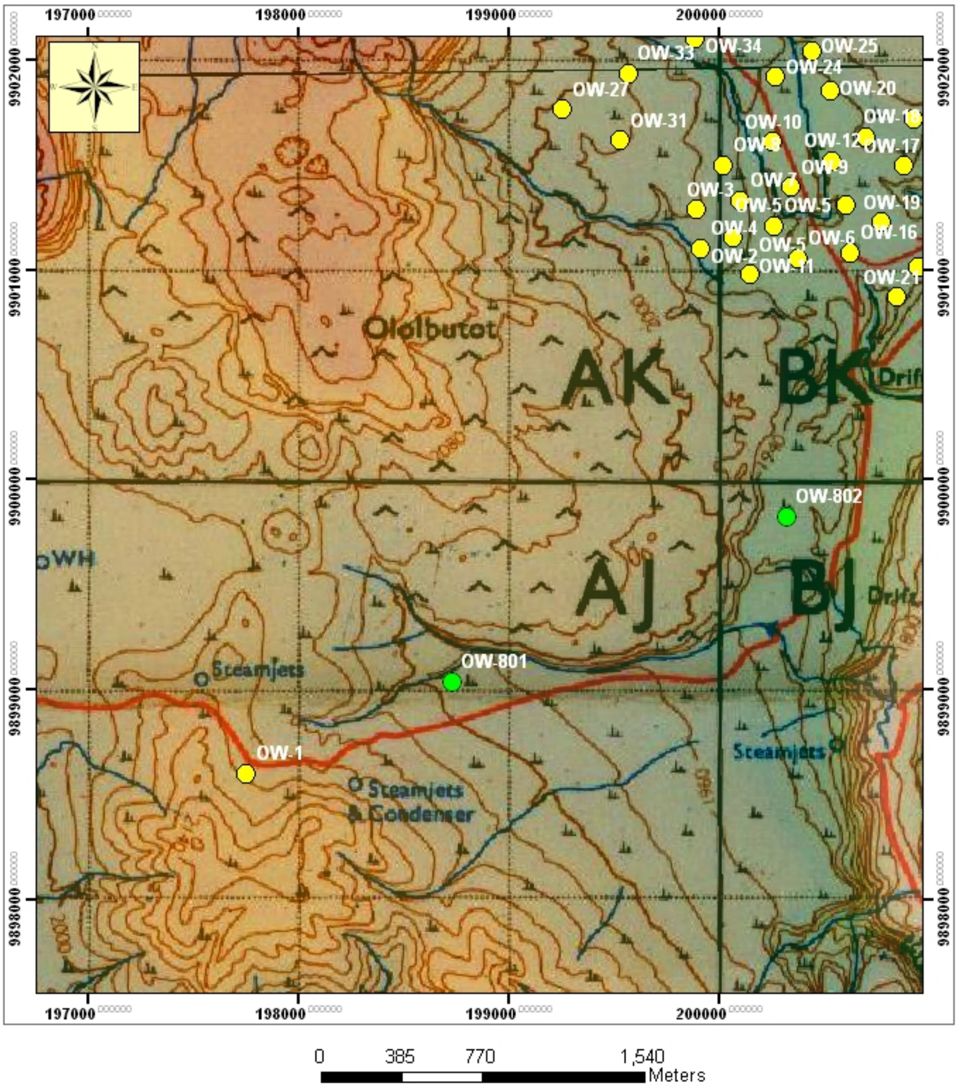

FIGURE 4: Location of OW-1 from Olkaria East sector

## 3. DEVELOPMENT

The scientific results were revaluated again and a decision was made to drill into the current Olkaria East area defined by a low resistivity. In 1974, OW-2 was drilled and because it proved steam, 5 other wells were drilled as step out wells by 1976. These wells proved the existence of an exploitable steam resource.

### 3.1 Olkaria East

Feasibility studies conducted by Virkir and Sweco (1976) recommended the development of a 2 x 15MW station. The construction of the power plant commenced in 1979 with World Bank funding and the first unit was commissioned in 1981. Production drilling was done while the power station was being constructed. By the time the second unit was commissioned in 1982, 25 wells had been drilled with more steam than the station could utilize. More knowledge of the reservoir was becoming available which indicated that the reservoir was progressively better northwards. A case was made to the World Bank and other financiers for the extension of the station by another third unit. The third unit was commissioned in 1985. The development of first power plant at Olkaria East therefore took about 15years. Performance of the reservoir in the last twenty-six years coupled with review of the earlier scientific data has suggested that this sector can support much more electrical power generation than 45 MW. Depending on the results of Olkaria Optimization Study it may be possible to add another 70 MW installation here.

### 3.2 Olkaria North East

In 1980, an experts' technical review meeting was held in Nairobi to deliberate on the next development stages of the greater Olkaria field (GENZL, 1980). In this meeting, the scientific and drilling results were reviewed. Several wells spread far apart were sited to test several scientific theories. Some of these theories were that faults and fractures were the major conduits of geothermal fluids, the main ones being Ololbutot fault, Olkaria fracture and Olkaria fault.

In 1984 another scientific review meeting was held to evaluate the drilling results (KRTA, 1985). It was concluded that the western part of Olkaria had a separate geothermal system upflow with high $CO_2$ content and that an area north of Olkaria East existed a field with similar fluid chemistry to Olkaria East. OW-701 was then sited to prove this with much success. By 1988 five additional appraisal wells had been drilled and the field was then committed for a 2 x 30 MW development.

In 1989 a consortium of four companies carried out a feasibility study for the power plant and a full EIA was undertaken between 1990 and 1994 (Sinclair knight and RPS, 1994). By 1993, the required 33 wells for production, re-injection and monitoring had been drilled. A numerical simulation study of the field performance under exploitation was completed in 1993. Although the power station designs were done between 1991 and 1994, they could not be approved until environmental issues were fully incorporated. These included use of water from Lake Naivasha.

In 1996, donors introduced energy sector reforms in Kenya some of which became conditional for further funding for the construction phase. The designs were reviewed in 1997, financing was approved in 1998 and a new supervising consultant, different from the designing one, was appointed. The tender documents prepared earlier by the previous consultant were revised and some design aspects changed to take into account changes in technology.

Construction of Olkaria II then commenced in September 2000 and commissioned at the end of 2003 after 3 years. Olkaria II power plant therefore took about 17 years to be realized. Following from the results of Phase I of the Olkaria Optimization Study a contract has been signed between KenGen and joint venture of Mitsubishi Corporation and Mitsubishi Heavy Industries for expansion of Olkaria II through installation of a third, 35 MW unit at the station.

### 3.3 Olkaria West

During the time exploration wells were spread far apart in the field to test several scientific theories in Olkaria, some wells were drilled in Olkaria West. Successful drilling results were also obtained in this part of the field. In the 1984 scientific review meeting held to evaluate the drilling results (KRTA, 1985), it was concluded that the western part of Olkaria had a separate geothermal system upflow with high $CO_2$ content. The southern portion (Olkaria South West) was acquired by an IPP (Ormat International) who installed 13 MW binary power plant in 2000. Ormat drilled more wells in this area since 2000 and following successful results the plant is being expanded to 48 MW generation capacity.

Some of the successful exploration wells drilled in the northern portion of Olkaria West are within Oserian Development Company land. Oserian has leased two of these wells, one for direct use in heating of green houses (OW-101) and another for electrical power generation (OW-306).

### 3.4 Olkaria Central

The first exploration well drilled in this sector had inverted temperatures and discharged medium enthalpy fluid. Another three wells (OW-202, OW-203 and OW-204) were drilled in this sector between 1994 and 1997 and only one of them (OW-202) was able to discharge. Steam from this well is to be utilized by Oserian Development Company to operate 2 MW condensing plant which is being commissioned. Three of the wells (OW-201, OW-203 and OW-204) are re-injection wells. OW-201 and OW-204 receive cooling tower blow-down from Olkaria II power station and OW-203 will receive brine from the separator at OW-202. This part of the field is considered an outflow zone and hence utilized for cold re-injection.

### 3.5 Olkaria South East

As a follow-up to the poor results obtained from drilling of OW-1 more geophysical work was carried out in this sector of Olkaria and OW-801 was drilled to confirm existence of the resource to the south of Olkaria East especially to the west of Ololbutot fault. Unfortunately, this well was unsuccessful and cannot discharge. The data was reviewed and OW-802 sited in this sector but has not been drilled.

### 3.6 Olkaria Domes

Detailed geo-scientific investigations were carried out in this sector between 1992 and 1997 involving geology, geophysics, geochemistry and heat flow measurements. Based on the scientific review of the data gathered from the surface investigations three explorations wells OW-901, OW-902 and OW-903 were sited and drilled between 1998 and 1999. All the three wells were successful and were able to discharge. By this time more advanced geophysical techniques, with better subsurface penetration capabilities than Schlumberger soundings used earlier, namely, Magneto telluric (MT) and Transient Electromagnetic (TEM), were available. The two techniques were applied to review the results of the previous geophysical surveys resulting in the high success achieved from drilling of the three exploration wells. Additional geophysical work was carried out using MT and TEM to have even better data spread hence gather more confidence in demarcation of the boundaries of the resource area.

This plus down-hole data from the three exploration wells were reviewed and the results are the basis for siting of the six appraisal wells currently being drilled in this sector. Two of the appraisal wells (OW-904A and OW-903A) have been drilled to completion and both have encountered very high temperatures (over 300 $^{o}$ C). OW-904A has been able to discharge and is capable of producing steam equivalent to over 6 MW of electrical power. The geophysical anomaly (Figure 5) is indicating a large resource area in this sector and if confirmed by drilling may support installation of up to 140 MW plant. However, the optimum installation in this sector will also depend on the results of the Olkaria Optimization Study.

Figure 6 represents the status of development in all the seven sectors of the Greater Olkaria geothermal field.

## 4. OLKARIA RESERVOIR MODEL

Development of the conceptual reservoir model of Olkaria geothermal field was initiated by Sweko and Virkir (United Nations – Government of Kenya, 1976). Since that time the model has been reviewed several times as additional information became available (KPC, 1980, 1982, 1985, 1986, 1997; KenGen, 1999; Bodvarsson, 1980; Bodvarsson and Pruess, 1981, 1984, 1988; Ewbank Preece – Virkir, 1989 and Virkir-Orkint and Bodvarsson, 1993). Over the years, the main concepts have remained more or less the same except that with more information, it has been possible to strengthen the model and add confidence to the understanding of the production characteristics of the reservoir.

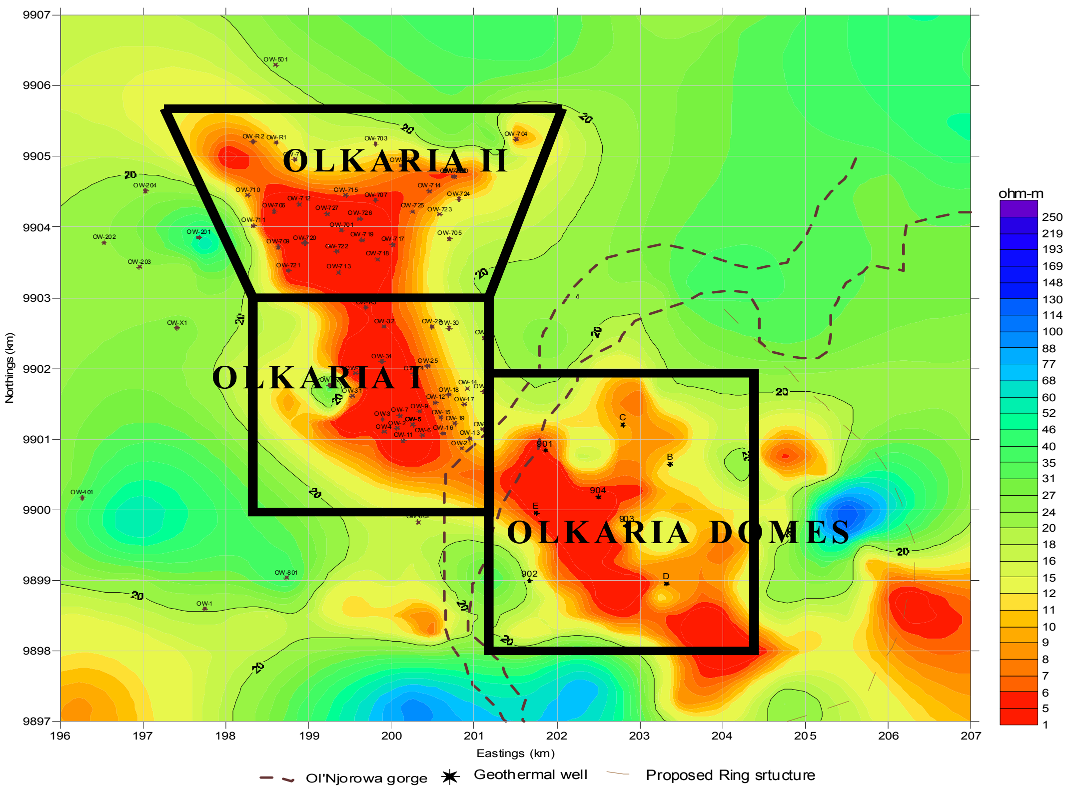


FIGURE 5: Potential resource areas for Olkaria East, North East and Domes

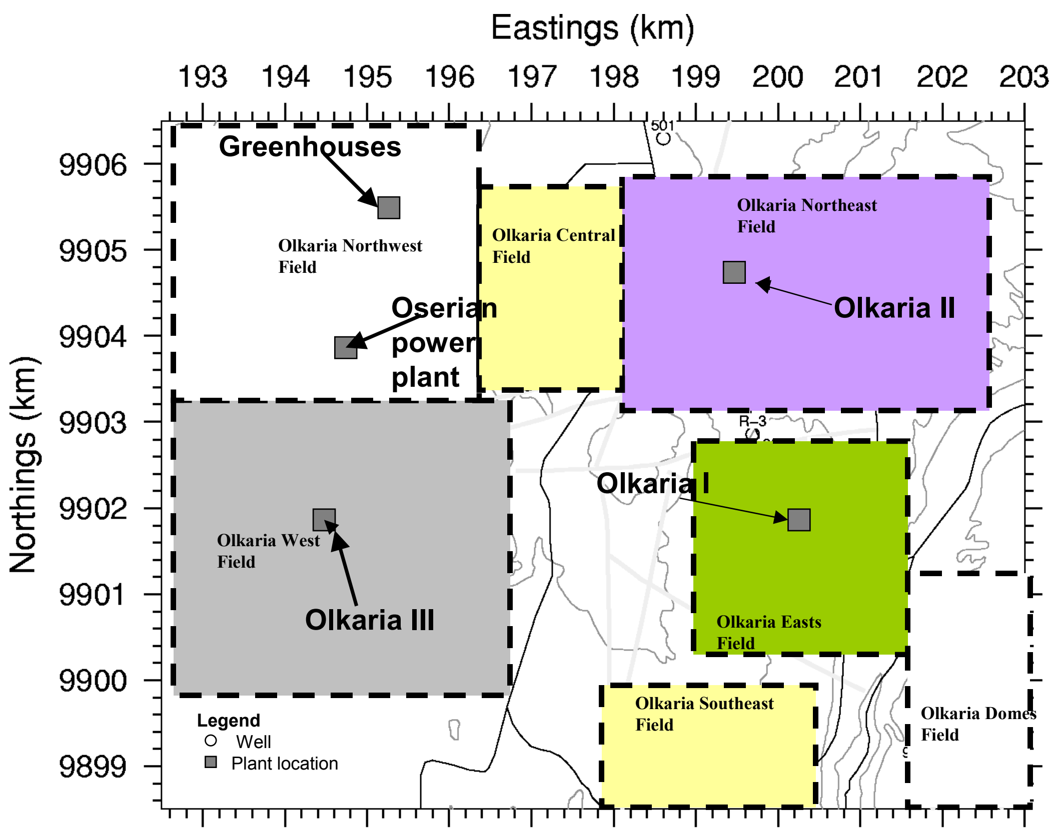


FIGURE 6: Present utilization of Olkaria Field area

The major hydrogeological features of the field, including two upflow zones of hot fluids in the general area of OW-301 and OW-716, large scale fluid movement in the field is dominated by major faults and fracture zones and large steam losses at the reservoir top, especially along the Ololbutot fault between wells OW-201 and OW-01, are established.

The Olkaria geothermal reservoir is associated with the Olkaria volcanic centre. It is considered that the reservoir is bounded by arcuate faults forming a ring or a caldera structure. The magmatic heat source is represented by intrusions at deep levels inside the ring structure. It is a two-phase liquid dominated one overlain by a thin steam dominated zone 100 to 200m thick at 240°C. This zone is widest in the south and thinnest in the north. Below the steam zone a two-phase system of boiling water exist. Above the steam zone, is a caprock that marks the top of the reservoir and is composed of impermeable basalt and trachytes, which lie 400 to 700m below the surface. The bulk of the reservoir rocks are mainly trachytic. The vertical extent of the reservoir is unestablished but it is believed to be of the order of several hundred meters (Bodvarsson, 1984). Temperatures intercepted by the wells are generally high, (250°C) with bottom hole temperature about 300°C (Figure 7).

The initial static water level varies but is between 400 and 700m. The initial pressure and temperature distribution in the field increases northwards while hydrological gradient indicated water movement was from North to South. This has been confirmed through drilling in the northern parts of the field where bottom-hole temperature in most wells exceed 310°C. The steam zone, that is present in the Olkaria East field, is replaced by a shallow two-phase zone in the Olkaria North East field (Ambusso and Ouma, 1991).

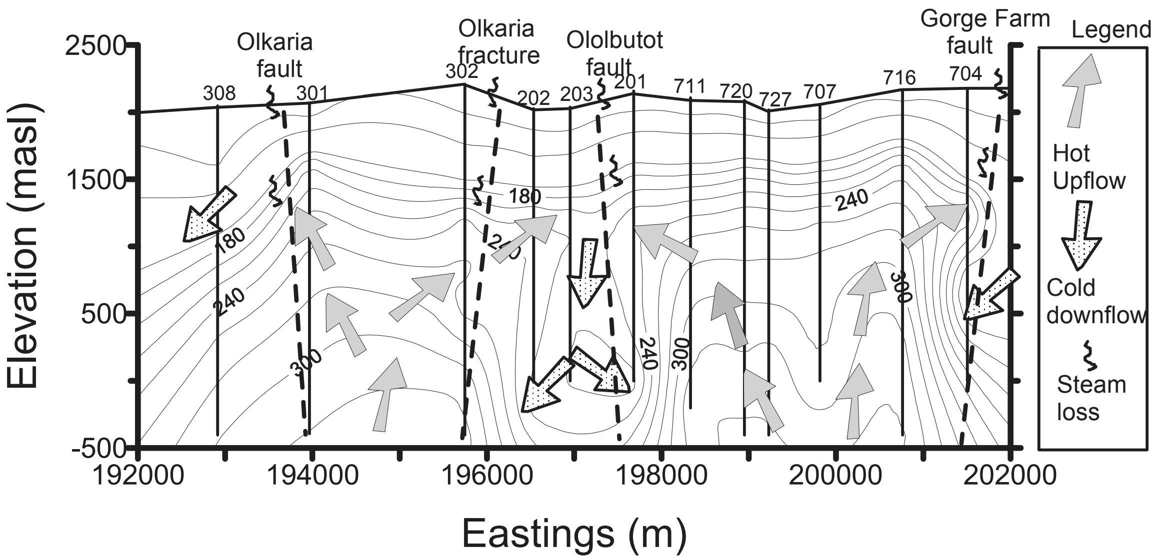


FIGURE 7: Conceptual model of Olkaria geothermal reservoir

## 5. RESERVOIR MANAGEMENT

The Olkaria reservoir has been under exploitation for the last twenty-six (26) years. Numerical studies of the generating capacity of Olkaria reservoir (Bodvarsson and Pruess, 1981) projected decline in deliverability of production wells with time and recommended monitoring of the production wells to determine the decline rate. The decline rate in the deliverability of the Olkaria wells would have major economical effects on the development plan for the field. However, the history match and performance predictions for Olkaria geothermal field (Bodvarsson and Pruess, 1984) indicated that injection of water into the geothermal reservoir would significantly increase the economic life time of production wells and thus save on the drilling of make-up wells. Therefore, as part of reservoir management requirement and general performance assessment, the reservoir has regularly been monitored for thermodynamic and chemical changes.

### 5.1 Temperature and pressure

Routine down-hole temperature and pressure logs have been carried out in production wells during well outages or plant shutdowns. Availability of wells for down-hole logs has been very limited due to the high steam demand hence limited information is available on the changes in reservoir temperature and pressure across the field. However, from the available data, the most significant change in this field over the last twenty-six (26) years of production is pressure decline (Figure 8). The figure shows that minimal pressure drawdown of about 22 bars has occurred in the liquid reservoir. This pressure drop recovers pretty fast when production rate is decreased as seen after the year 2003 when unit I in Olkaria East was out of service for a long time for major overhaul followed by unit III.

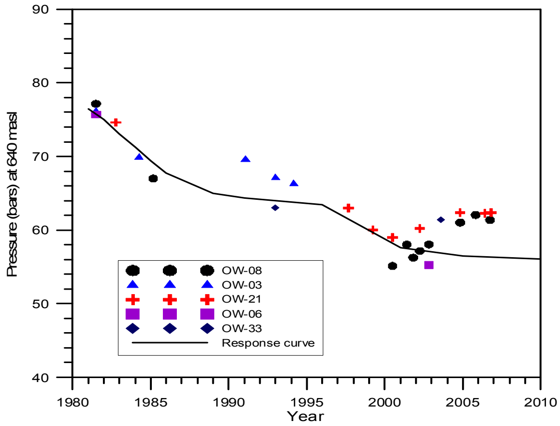


FIGURE 8: Pressure decline trends

The response curve fit suggests that the reservoir has a good recharge so that after a certain time constant (of about 7 years), it reaches a steady state. This is actually evident by the fact that we now have almost zero decline rate in output from the field. Increasing production under these circumstances will not therefore adversely affect performance of the production wells.

Downhole temperature and pressure logs show that wells located at the central and western parts of Olkaria East field are almost dry (Figures 9) while those in the south show temperature inversion at the bottom, indicating incursion of cooling fluid (Figure 10).

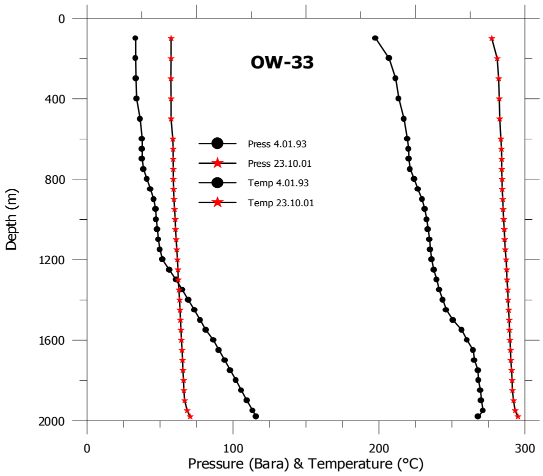


FIGURE 9: Downhole profiles in OW-33

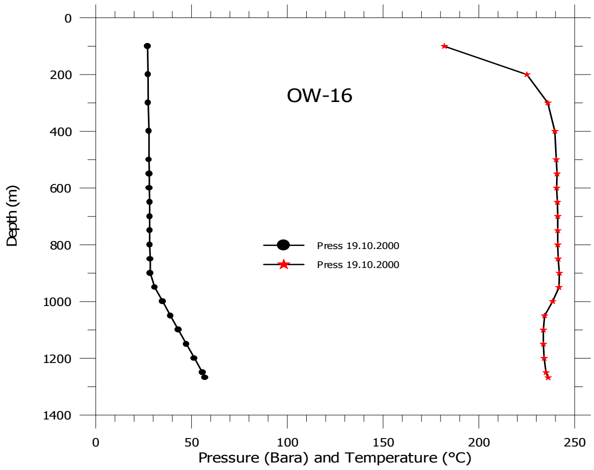


FIGURE 10: Downhole profiles in OW-16

### 5.2 Wells deliverability

From the time the third unit was commissioned in 1985 at Olkaria East, the field has experienced pressure drawdown and hence decline in output from the wells resulting into decline in steam supply to Olkaria I plant. The decline in pressure has also introduced severe cyclicity in some of the wells in Olkaria East (Ouma, 1992). The field has shown various regimes of annual steam decline from an initial 5-6% decline to the current near zero. From 1981 to 1988 the average steam decline was about 5.5 % per annum (Ambusso and Karingithi, 1993). This led to the connection of OW-26 in 1986 raising the steam output by about 35 t/hr. The decline rate between 1988 and 1992 was about 4% per annum that reduced to less than 4% between 1993 and 1998 with some wells experiencing almost no decline while others experienced an increase (Ouma and Karingithi, 1998). Six make-up wells were connected between 1993 and 1998 raising the output by about 230 t/hr. In 1998, the steam decline was 4.6% (Ofwona and Wambugu, 1999) whereas between 1999 and 2000 Olkaria East field experienced steam increase of about 1% instead of a decline (Kariuki and Opondo, 2001). The trend of steam increase continued with a value of about 3.7% increase being observed in 2001. After connection of make-up wells OW-32 and OW-34, the total steam available became 730 t/hr equivalent to about 73 $MW_e$ (Kariuki and Opondo, 2002). Except for the problem with well OW-34 (Ofwona and Opondo, 2003) the total steam available in Olkaria East field has remained at about 707 t/hr between 2002 and 2004 (Karingithi and Mburu, 2005). Generally it has been observed that steam deliverability from Olkaria East field has a significantly reduced decline rate compared to what was predicted by the numerical simulation models (Figure 11).

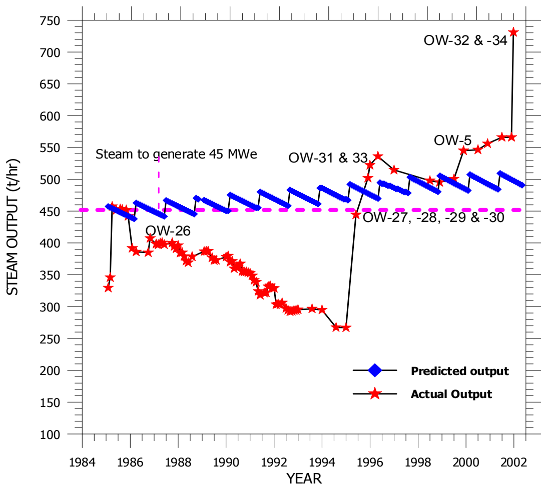


FIGURE 11: Steam decline trend at Olkaria East field

From 1992 to 2004, discharge enthalpy for the centrally located wells in Olkaria East field has increased with as high as 600 kJ/kg. This is mainly due to large reservoir pressure drawdown leading to drying up of wells as a result of boiling. Peripheral wells unlike the centre ones have had a decrease in discharge enthalpy (Maximum 400kJ/kg). This is caused by cold water incursion at the bottom of the wells as demonstrated by down-hole temperature logs.

### 5.3 Fluid chemistry

Chemical changes in this field have been diverse and vary both in type and degree across the field. The cyclic nature of most wells and multiple production zones make the data interpretation complicated. However, for a number of wells, the extent of variation has been minimal and such wells have been used to infer the changes in the reservoir. These changes have been evaluated in terms of concentration of reservoir chloride, silica, sulphate, discharge enthalpy, calculated geothermometer temperatures and variation in gas composition of the discharge fluids. Gases considered include nitrogen, hydrogen, hydrogen sulphide and carbon dioxide in the steam. Wells located at the centre of the field have shown a gradual increase in concentration of dissolved constituent like chloride. Some peripheral wells have shown stable or decline in chloride concentration (Figures 12).

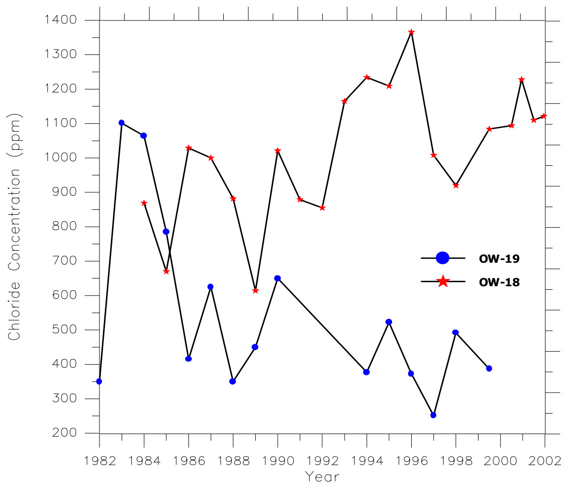


FIGURE 12: Chloride concentration for OW-18 and OW-19

### 5.4 Re-injection

Numerical simulation studies suggested that re-injection into this field would reduce well deliverability decline rate and hence reduce the number of make-up wells requirement (Bodvarsson and Pruess, 1984; Bodvarsson, 1993). This was considered economically favourable and hence cold and hot re-injection has been implemented in Olkaria geothermal field. Cold re-injection was carried out in OW-12 from July 1996 to August 1997 with a total of 136,886 tonnes of water being re-injected. Accompanying tracer test showed that OW-12 has hydrological communication with wells OW-15, OW-18 and OW-19. Monitoring of these wells indicated improved mass output but enthalpy drop due to cold re-injection and therefore was discontinued before the affected wells started recovering (Figure 13). Hot re-injection of separated brine from OW-27, OW-31 and OW-33 into OW-3 has been going on since May 1995. A total of 1,750,000 tonnes of brine has been re-injected into this well resulting in improved output in wells OW-2, OW-6, OW-8 and OW-11 without causing excessive decline in enthalpy (Figure 14). Currently, about 5% of the total brine generated from Olkaria East field is being re-injected hot into OW-3 and plans are underway to increase this amount. Recently cold re-injection of condensate from Olkaria I plant into OW-6 was commissioned in which about 13% of the condensate generated is re-injected.

In Olkaria North East field we have 100% re-injection of effluent generated by the production wells. Hot brine is re-injected into wells OW-R2, OW-R3, OW-703 and OW-708 whereas cold condensate is re-injected into well OW-201 or OW-204. Tracer was introduced into the re-injected fluid at OW-708 with returns reported in OW-706 and OW-712 and at OW-R3 with returns reported in OW-25 and OW-32.

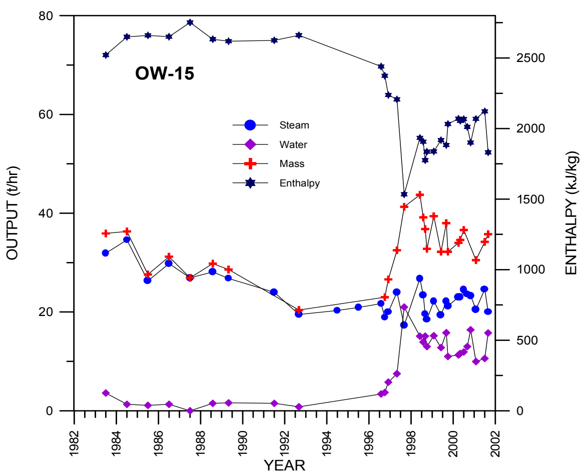


FIGURE 13: Effects of cold re-injection in well OW-15

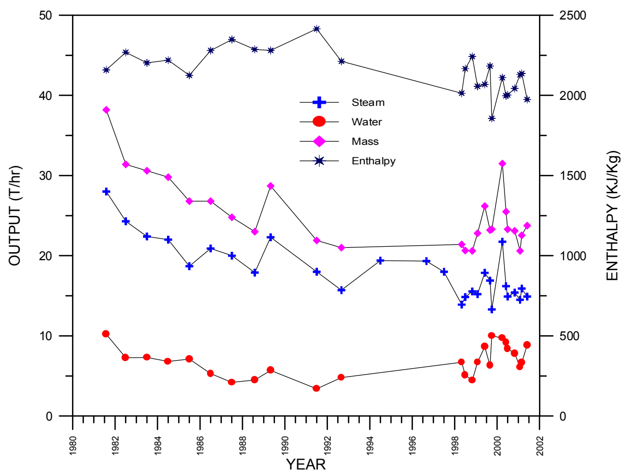


FIGURE 14: Effects of hot re-injection into well OW-2

## 6. POWER PRODUCTION

Olkaria reservoir produces two-phase mixture of steam and water in general proportion of 85% steam and 15% water. However, there are a few wells that produce near dry steam or mostly hot water with very little steam. Thus the resource is suitable for electrical power generation. Two types of power generation plants operate in Olkaria namely, the Ormat binary plants and the Mitsubishi condensing plants. In all there are four power plants, two owned by KenGen and one each owned by Ormat International and Oserian Development Company Ltd (ODCL). The total installed power generation capacity of the four plants is 129 $MW_e$. Thus geothermal power installation constitutes about 12% of the national power installation and the plants operate as base load.

### 6.1 Olkaria I plant

It is the oldest plant in Olkaria and has been in operation since 1981 (24 years) with an installed power generation capacity of 45 $MW_e$. It consists of three (3) Mitsubishi condensing units each of capacity 15 $MW_e$. The plant has achieved an overall load factor of 81.9% and availability factor of 92.5% and continuous operation of up to ten months in one year has been realized. The steam conversion rate has been maintained at 9.2 t/hr per $MW_e$ (Figure 15).

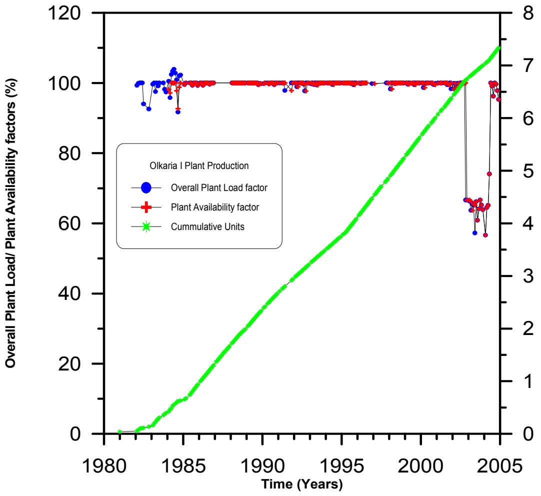


FIGURE 15: Olkaria I Plant Production

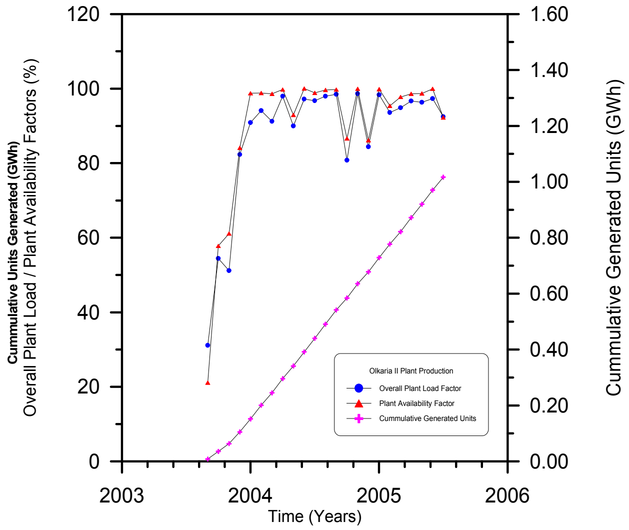


FIGURE 16: Olkaria II Plant Production

### 6.2 Olkaria II plant

It is the second geothermal plant installed by KenGen in Olkaria and has been in operation since October 2003 (2 years) with an installed power generation capacity of 70 $MW_e$. It is similar to Olkaria I plant but consists of two (2) Mitsubishi condensing turbo-generating units each of capacity 35 $MW_e$. The plant has achieved an overall load factor of 80% and availability factor of 83% in the last two years it has been in operation. This plant has steam conversion rate of 7.3 t/hr per $MW_e$, which is better than that of Olkaria I plant (Figure 16).

### 6.3 Ormat type binary plants

These were installed one each by Ormat International (Orpower 4) and Oserian Development Company Ltd. (ODCL) at Olkaria South and North West sectors. They utilize both steam and water phases of the discharge from the wells for electrical power generation.

The Orpower 4 plant with an installed capacity of 12 $MW_e$ has been in operation since 2000 (5 years). It was installed as a pilot to test the performance of that sector of Olkaria reservoir, utilizing some of the exploration wells that had been drilled in the eighties plus the first drilled appraisal and production wells, ahead of the bigger plant planned for Olkaria South West.

The Oserian plant with an installed capacity of 2.0 $MW_e$ has been in operation since 2004 (1 year). It utilizes discharge from one well (OW-306) that was drilled as an exploration well in Olkaria North West sector but which falls within the land owned by ODCL. The electrical power generated from this plant is all consumed by ODCL and supplements the electrical power supply from The Kenya Power and Lighting Company Ltd.

**6.4 Energy utilization**

Geothermal energy in Olkaria has mainly been utilized for electrical power production. Direct use has received little attention though it is well known that even after utilizing the energy for electrical power production, a lot of energy is still left in the water. Whereas the Ormat binary plants installed at Olkaria South and North West utilize both steam and water parts of the discharge from wells for electrical energy production, the Mitsubishi condensing plants installed by KenGen in Olkaria East and North East only utilize the steam part. Furthermore, there are wells with relatively lower enthalpy and hence produce more water than steam and if energy in the water for such wells is rejected can imply very poor energy utilization. For instance Olkaria I plant in Olkaria East field generates 45 MW of electrical power from steam but rejects 46 MW of thermal power in the water. Similarly, Olkaria II plant in Olkaria North East field generates 70 MW of electrical power from steam but rejects 142 MW of thermal power in the water.

Recently Oserian Development Company Ltd (ODCL) leased OW-101 from KenGen for direct use in horticultural farming. OW-101 is one of the exploration wells drilled in Olkaria North West in the early eighties and is capable of supporting generation of only 1 MW of electrical power. However, it has proved capable of supplying up to 10 MW of thermal power to ODCL for direct use in flower farming. With geothermal energy from OW-101 ODCL is able to heat approximately 30 Ha of green houses.

There are wells in Olkaria with extreme cyclic discharge characteristics and hence cannot operate with the other wells supplying steam to the power plants. Such wells, in the past, have either been turned to re-injection wells or simply rendered useless and yet are capable of supplying a lot of geothermal power for direct use. KenGen is looking at the possibility of economically selling geothermal energy from such wells to direct users either for recreational purposes or space heating. One such well is OW-724 drilled in Olkaria North East field. It is productive but because of its cyclic discharge characteristics, was found unsuitable to connect to the Olkaria II power plant. It was also found unsuitable for re-injection and hence so far no use has been found for it. However, this well is capable of providing 15 MW of thermal power for direct use and is being considered for supply of thermal power to interested direct users.

**7. DISCUSSION**

Initial scientific investigations for Olkaria geothermal field were unable to demarcate the resource accurately because limitations of the techniques used. Geophysical studies at the time did not give a good representation of the subsurface structure due to limited depth of penetration (less than 700m). The data spread was also sparse and therefore could not demarcate the boundaries of the resource area. In addition, the drilling technology was poor and that contributed to the initially low drilling success rate. With more advanced techniques applied in the later part of exploration especially geophysical techniques with more subsurface penetration capabilities, it became possible to demarcate the resource more accurately and hence the drilling success rate remarkably improved. For instance in Olkaria Domes MT and TEM were applied and the data coverage improved and that has contributed significantly in the excellent drilling success rate registered so far.

Development of Olkaria resource has been slow mainly due to funding and the best example is Olkaria North East case where funding delayed the Olkaria II plant construction by over a decade. After exploiting Olkaria East sector for twenty-six years it has been realized that this sector can support more that the 45 MW installed but decision to expand the power installation has been delayed because the financiers are insisting on the results of Olkaria Optimization Study before availing the funds. The study has already delayed the decision by three years while results from analysis of the data gathered over the twenty-six years of operating the field are strongly supporting additional installation.

The geothermal resource has mainly been used for electrical power production utilizing the steam portion of the discharge from wells. The water portion of the resource has mostly been sent to waste either through surface rejection or re-injected back into the reservoir. This has resulted into very poor utilization of the resource and KenGen is exploring the possibility of economically selling energy contained in the water part of the resource to neighbouring flower farms and hotels for direct use.

## 8. CONCLUSION

Improvement in technology and approach to scientific investigations has contributed to the high drilling success rate for exploration wells. Availability of funding can accelerate the development of Olkaria geothermal resource. Olkaria reservoir has performed well and should be developed further to realize its full potential. Energy utilization of the Olkaria resource will remain low unless some use is found for the energy contained in the water portion.

## REFERENCES

Ambusso W.J and Karingithi C.W., 1993. Response of Olkaria east geothermal field to production. GRC Transactions Vol 17.

Ambusso W.J and Ouma P.A., 1991. Thermodynamic and permeability structure of Olkaria North East field. GRC Transactions Vol 15.

Bodvarsson, G.S., 1980. Report on Preliminary Studies of the Reservoir Behaviour of the Olkaria Geothermal Field. Report presented to Virkir, Nov. 1980.

Bodvarsson G.S and Pruess K., 1981. Olkaria Geothermal Field Numerical Studies of the Generating Capacity of the Reservoir. A report prepared for the Kenya Power Company Ltd. Olkaria Geothermal Project, Kenya.

Bodvarsson G.S. and Pruess K., 1984. History Match and Performance Predictions for the Olkaria Geothermal Field. A report prepared for the Kenya Power Company Ltd., Olkaria Geothermal Project, Kenya.

Bodvarsson G.S., Pruess K., Stefansson V., Bjornsson S., and Ojiambo S.B 1984. The East Olkaria Geothermal Field Kenya: Predictions of Well Performance and Reservoir Depletion. A report prepared for the Kenya Power Company Ltd. Olkaria Geothermal Project, Kenya.

Bodvarsson G.S. and Pruess K. 1988. Numerical Simulation Studies of the Olkaria Geothermal Field. A report prepared for the Kenya Power Company Ltd., Olkaria Geothermal Project, Kenya.

Ewbank Preece – Virkir., 1989. Feasibility Study for a Geothermal Power Station at North East Olkaria. Report prepared for the Kenya Power Company Ltd.

GENZL, 1980. Scientific Review of Olkaria Geothermal Reservoir. A KPC report prepared by GENZL.

Glover, R.B., 1972. Chemical Characteristics and Steam Discharges in the Rift Valley of Kenya. UNDP report.

Karigithi, C.W. and Mburu, M.N., 2005. Status Report on Steam Production and Reservoir Assessment of Olkaria East Field (Second Half of 2004), KenGen Internal Report.

Kariuki M.N. and Opondo K.M., 2002. Status Report on Steam Production and Reservoir Assessment of Olkaria East Field (Second Half of 2000), KenGen Internal Report.

Kariuki M.N. and Opondo K.M., 2001. Status Report on Steam Production and Reservoir Assessment of Olkaria East Field (Second Half of 2000), KenGen Internal Report.

Kenya Electricity Generating Company Ltd., 1999. Update of the Conceptual Model of Greater Olkaria Geothermal Field. KenGen Internal Report.

Kenya Power Company Ltd., 1980. Scientific Review of Olkaria Geothermal Reservoir. Report prepared for the Scientific Review Meeting by GENZL, Nov. 1980.

Kenya Power Company Ltd., 1982. Status Report on Steam Production. Prepared by Merz and McLellan and Virkir, May 1982.

Kenya Power Company Ltd., 1985. Proceedings of the Scientific and Technical Review Meeting 19-24 November 1984. Prepared by KRTA, Feb 1985.

Kenya Power Company Ltd., 1986. Olkaria Scientific Review Report. Report prepared by GENZL, Nov. 1986.

Kenya Power Company Ltd., 1997. Conceptualized Model of Greater Olkaria Geothermal Field. KPC Internal Report.

Kenya Power Company, 1988. Proceedings of the Scientific Review Meeting 15-18May 1988.

Ofwona, C. O. and Wambugu, J. M., 1999. Status Report on Steam Production (First Half of 1999), KenGen Internal Report.

Ouma, P. A. and Karingithi, C. W., 1998. Status Report on Steam Production (First Half of 1998), KenGen Internal Report.

Ouma, P. A., 1992. Performance of East Olkaria Geothermal Field during ten years of production. A paper presented at an international conference on Industrial Uses of Geothermal Energy at Reykjavik, Iceland, 2-4 September 1992.

Sinclair Knight and RPS International, 1994. Environmental Assessment Final Report. North East Olkaria Development Project. A report for KPC.

Sweko – Virkir, 1976. Feasibility Report for the Olkaria Geothermal Project. United Nations – Government of Kenya report.

Virkir – Orkint and Bodvarsson, G.S., 1993. Update of the Numerical Simulation Model for the North East Olkaria Geothermal Field. A report prepared for Company Ltd., Olkaria Geothermal Project, Kenya.