Heat Loss Assessment of Selected Kenyan Geothermal Prospects

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ABSTRACT

Kenya has identified several geothermal prospects which include 14 prospects within the Rift valley that transects the country from north to south and more recently discovered outside this region notably, Mwananyamala and Homa hills. Over the last two years exploration activities have been geared towards re-assessing previously explored prospects and assessing the hitherto unassessed prospect fields. This paper presents findings of heat loss surveys carried out on five geothermal prospect fields that include; Paka, Korosi-Chpechuk, Silali, Homa hills and Mwananyamala.

1. Introduction

Geothermal Development Company Limited (GDC) was set up as a Special Purpose Vehicle, wholly owned by the Government, to undertake integrated development of geothermal through initial exploration, drilling, resource assessment and promotion of direct utilization of geothermal. By undertaking the initial project activities, GDC is intended to absorb the attendant risks associated with geothermal development and therefore open up opportunities for both public and private participation.

GDC currently uses geological mapping, geophysical mapping, geochemical mapping environmental baseline surveys and heat loss surveys in carrying out detailed geo-scientific studies of identified prospect areas. Geothermal prospects recently studied using this approach include Silale, Homa hills, Mwananyamala, Korosi-Chepchuk and Paka, Kenya

The East African Rift together with the Ethiopian rift forms the larger East African Rift System (EARS). This is a region where tectonic plate activity resulted into faulting and subsequent rifting and formation of a graben. The rift formation process also resulted in previously deep seated hot rocks being brought closer to the surface and thus becoming a heat source while the faults serve as channels of leakage for heated subsurface fluids and form a geothermal system. Geothermal systems are thus associated with several heat loss features such as hot springs, geysers, mud pools, fumaroles, steaming grounds, hot grounds and altered grounds that transfer heat by either conduction or convection.

Geothermal resources in Kenya are estimated to have potential of over 10,000 MWe. The current installed geothermal capacity in the country is however 198 MWe (KenGen – 150 MWe and OrPower 4 – 48 MWe) from the Olkaria field. KenGen is implementing an additional 280 MWe scheduled for commissioning in 2013 in Olkaria and 2.5 MWe in Eburru. In the Menengai Field, GDC is drilling for Phase I of 400 MWe whilst initial project development activities have commenced for the development of 800 MWe in the Bogoria – Silali Block.

Heat loss surveys carried out in the identified geothermal prospects were aimed at estimating the amount of energy lost through heat transfer mechanisms, analyzing the distribution of heat loss features in the prospect area, deducing the extent of leakage through the capping and fracture zones, inferring on size of the reservoir, mapping out thermally active ground area within the prospect and where possible suggesting orientation of faults. Results from the surveys were also used as input in developing conceptual models for geothermal resources and providing information on the possible electrical energy potential of the prospect area.

2. Methodology

Natural heat loss occurs by one of the following mechanisms; conduction, convection or in rare cases radiation. Estimation of energy loss was done by obtaining temperature gradient from shallow 1 m depth holes drilled manually using 1 inch diameter by 1 m long spike. Temperature was then measured at the surface, 50 cm and 100 cm depths by a digital thermocouple. Locations of these holes were read from a portable hand held Global Positioning System (GPS). Holes were drilled at an interval of 100m – 1km in an area of high thermal activity and at 1 - 2km in an area of low thermal activity. The average earth surface temperature around this area is between 30 – 35°C. Thermally active areas were estimated with 40°C isotherm as a reference at 1 m depth. Areas with temperatures below 40°C were considered inactive and not factored in the overall heat loss calculation.

With respective areas of hot grounds under each isotherm band and average temperature gradient known, conductive heat flow was then calculated using one dimensional heat conduction equation below.

$$Q = Ak \, {}^{dT}\!/_{dy} \qquad (1)$$

Where;

Q = Conductive heat flow (Watts),
A = Surface area of hot ground (m^2)
k = Thermal conductivity of rock taken as 2(w/m°C),
T = Temperature (°C)
y = Depth (m)

3.0 Paka Heat Loss Survey

Initial studies at Paka were first carried out in 2006 – 2007 by G. M. Mwawongo et al. Findings from this study were as follows; the prospect area was found to have high temperature gradients at shallow depths ranging from a mean value of 17°C/m in the coldest part to 23°C/m in the anomalously hot areas, Temperatures recorded at 1m depth ranged from 26.6°C in the coldest region to 93°C in the hottest part and total heat loss was found to be 2,855MW_t with a convective component of 10 MW_t. A recent study was carried out in February 2011 and the findings were as stated below. Presence of a geothermal system at Paka is manifested by the widespread fumarolic activity, hot grounds, sulfur deposits and hydrothermally altered rocks.

Results

Temperature readings from shallow holes were recorded in a field work book. A sample temperature log is shown in Table 1, notations are also explained,

where: PHs – Paka shallow hole
Ts – Surface temperature
T50 – Temperature at 50cm depth
T100 – Temperature at 1m

Table 1. Sample temperature logs.

Name	Eastings	Northing	Elevation	Ts	T50	T100	Comments
PHS-7	189413	96780	1195	26.1	33.4	34.8	
PHS-10	188003	99608	1382	51.5	53.3	51.4	
PHS-26	183117	100032	1078	34.3	38.9	39.2	
PHS-27	182010	100127	1008	35.0	39.5	39.9	
PHS-32	188521	101296	1563	28.0	77.2	81.1	Altered ground & fumaroles
PHS-35	187857	101098	1674	30.5	60.3	69.0	Altered ground
PHS-56	190868	106788	993	32.7	78.6	79.2	Hot altered ground
PHS-57	190898	106717	993	32.7	81.4	81.4	Hot ground & geothermal grass
PHS-64	187140	102315	1495	29.7	75.2	81.2	Hot ground
PHS-65	186744	102280	1504	30.2	80.3	83.2	Geothermal grass

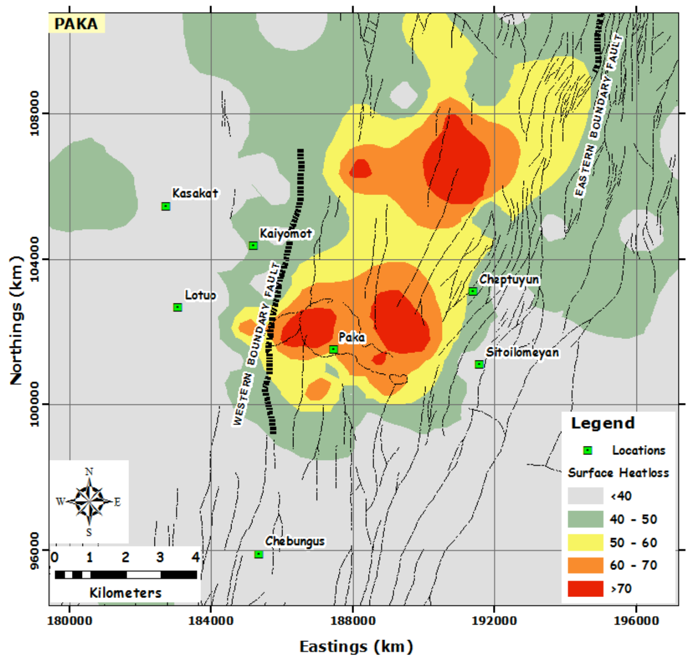

Figure 1. Temperature distribution at 1m depth over the prospect area.

The temperature distribution over Paka prospect was as shown in figure 1. Thermal contours were used to demarcate the temperature range areas.

Temperatures at 1m depth varied from 30.1°C to 84.3°C with areas recording high temperatures around the South Eastern part of the volcano, the South Eastern to Southern part of the caldera, the caldera floor, inside the Eastern crater and around the Orus area NNE of the volcano.

Table 2. Sample calculation for conductive heat loss.

Name	Easting (km)	Northing (km)	T_S (°C)	T_{50} (°C)	T_{100} (°C)	$Grad_{50}$ (°C)	$Grad_{100}$ (°0C)	Mean (°C)	Area (m^2)	Heat Flow (MW_t)
PHS-32	188521	101296	28.0	77.2	81.1	49.2	53.1	41.64	3000000	249.84
PHS-33	188350	101707	30.9	53	56.0	22.1	25.1			
PHS-34	188096	102416	32.1	35	-	2.9	-			
PHS-35	187857	101098	30.5	60.3	69.0	29.8	38.5			
PHS-63	186869	102777	29.7	65	68.2	35.3	38.5			
PHS-65	186744	102280	30.2	80.3	83.2	50.1	53.0			
PHS-66	186405	103305	30.9	34.1	-	3.2	-			

Conductive Heat Loss Calculations

Areas considered to be anomalous are enclosed by the 40°C isotherm at 1m depth highlighted by the lemon green color. From figure 4, it is observed that thermal active ground at Paka covers an area of about 89.75km^2 with an orientation in a NE-SW direction. A hot ground occurs west of Kasakat with an orientation not well defined hence appears almost as an isolated circular spot.

T_s, T_{50} and T_{100} refer to temperature at the surface, 50 cm and 100 cm depth. Grad refers to temperature gradient in (°C/m) while PH_S refers to Paka shallow hole.

Discussion

Fresh lava flow cover posed a challenge in making holes, in such zones temperature gradients have been extrapolated from temperature contours. For practical purposes this gives satisfactory accuracy for field measurements.

Heat loss features in Paka especially the fumaroles in the eastern crater are bigger and more active when compared to those found at Korosi and Chepchuk prospects. Occurrence of sulfur deposits' suggests less sealing of the flow paths at Paka (Mwawongo, 2007).

Hot grounds at Paka geothermal prospect seem to occur in the caldera floor and the eastern crater. A NE-SW trend of the thermal features is evident and seems to correspond to a similar trend exhibited by structures mainly the Eastern and Western boundary faults and several fissures.

In computing temperature gradients, temperature fluctuations due to periodic heating by sun and cooling at night was not factored as it was considered to have negligible effect on temperature readings at 1m depth (Mwawongo, 2006)

An estimated 3,406.7 MW_t of heat loss occurs at Paka geothermal prospect most of it through conduction and about 10 MW_t through convection.

4.0 Korosi – Chepchuk Heat Loss Survey

Initial heat loss survey of this area was carried out in 2006 (Mwawongo et al.). Conductive heat loss was found to be 2,135 MW_t and 546 MW_t at Korosi and Chepchuk respectively, heat loss features at Korosi were found to be controlled by NE-SW and NW-SE fault zones, recharge to the resource area being from east to west and outflow towards the flow and estimated reservoir temperature at 1km depth of over 200ºC. Recently in January, 2011 heat loss studies were carried out in this area and findings are stated below. The surface manifestations were in form of hot grounds, altered grounds, steaming grounds and fumaroles. Two major faults occur in this prospect area; the Nakaporon and Nagoreti faults.

Results

From results obtained, temperature reversals were observed in some instances. Typically the temperature was expected to increase with depth. These temperature reversals were attributed to surface soil falling into the bored hole as opposed to geothermal sources. Surface temperature was measured in a shaded spot that was not affected by direct sunlight. However an area with bare ground or thin vegetation presented a challenge in measuring this temperature. In this case a temperature higher than the actual surface temperature was measured.

Temperature distribution within the prospect area was as shown in figure 2. The map indicates the extent of thermally active ground hence help define respective temperature range contours.

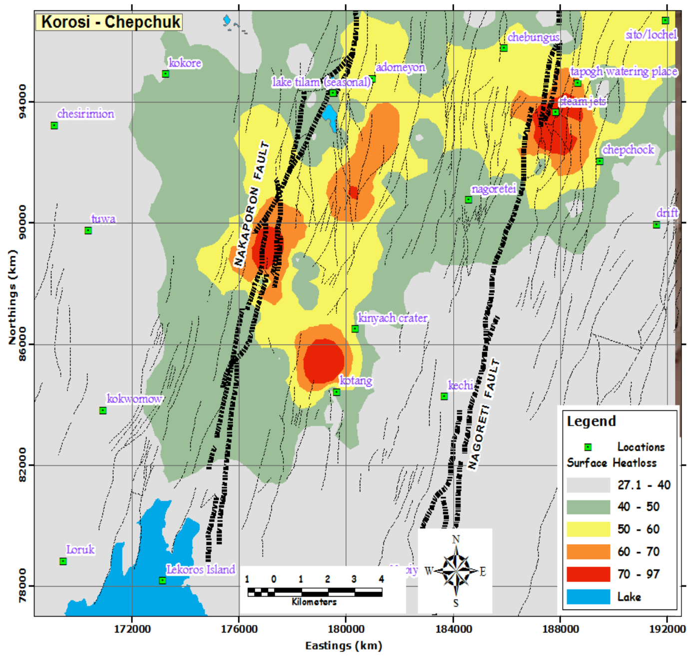

Figure 2. Temperature contours at 1 m depth in Korosi-Chepchuk.

Conductive Heat Loss Calculations

For the purpose of determining the size of the exploitable geothermal resource, areas with temperatures in excess of 40°C were considered to be associated with the heat source. Using this criterion the area delineated by the 40°C isotherm was determined, Eqn. 1 above was then used to determine the amount of heat lost.

Discussion

Temperatures recorded from the data obtained ranged from 27°C in the coldest region to 97°C in the hottest part.

Heat loss at Korosi and Chepchuk was estimated to be 2,120MW_t and 747 MW_t respectively. Cumulative heat loss for the two prospects was estimated at 2,867 MW_t. This represented a 7% increase from the previous estimate. The increase in the projected thermal power of the prospect was attributed to the additional hot grounds encountered during infill work. Three fumaroles with the highest temperature recorded being 59°C, were discovered north of Kinyach crater.

5.0 Silali Heat Loss Survey

Silali volcano is located 70km north of Lake Baringo in the northern section of the Kenya Rift. Detailed heat assessment studies of this volcano are limited and could be attributed to the rugged terrain limiting its access. The first heat loss survey of Silali was carried out between May and June 2010 as part of GDC's geoscientific exploration of Kenyan geothermal prospects.

Results

Temperatures at 1m varied from lowest 27.7°C to highest 96.2°C, with areas recording high temperatures confined to the SE part of the caldera and Eastern and SE part of caldera rim. High temperatures are also recorded to the western side with a cold divide evident in the center between the western part and the eastern part.

Conductive Heat Loss Calculations

Temperature gradients ranged from a mean value of 1.2°C/m to 66.9°C/m in the anomalous hot area. Areas exhibiting temperatures in excess of 40°C at 1m depth are considered to be associated with heat loss areas. Hot ground indicated by 40°C isotherm covered approximately 32 km^2.

Discussion

The estimated conductive heat loss could be lower as this area (southern edge outside the caldera rim) is covered by a thick pyroclastic layer ash which could be an insulating cover.

Heat loss features in the prospect are active especially at Kapedo hot Springs and inside the caldera suggesting good recharge.

Total conductive heat loss from the prospect was estimated at 1,127 MW_t.

6.0 Homa Hills Heat Loss Survey

The prospect measures an estimated 153 km^2 and has several hot springs located at Bala, Abundu, Rakombe, Kokulo, Ongoro and Ayoma that all drain into Lake Victoria.

The survey involved carrying out shallow holes temperature measurements and measuring hot water temperature and flow rates from hot springs at suitable locations.

Results

Nine shallow gradient holes were measured with the highest recorded temperature being 32.5°C. The temperature range recorded did not indicate any anomaly.

Convective Heat Loss Calculations

The convective component of the total heat loss was estimated by measuring hot water temperature and flow rates from hot springs. Flow rate was obtained by placing a V-notch across a stream channel emanating from the hot springs and the height of water over the V measured. The height of water was measured using a steel rule after attaining steady flow. With the temperature of the hot springs known, other fluid parameters; density and enthalpy were obtained from steam tables. Mass flow rates and heat flow was then calculated using the following equation;

$$Q = 0.824h^{2.5} \quad (2)$$

Where; Q is volumetric flow rate (l/min); h (cm) is the height above the V-notch.

$$Q_{conv} = m_f h_f \quad (3)$$

$$m = Q\rho \quad (4)$$

Where Q_{conv} is convective heat flow (watts) and h_f is enthalpy of water at the corresponding source temperature (kJ/kg), ρ is density of water (kg/m^3) and m_f is the mass flow rate of the hot spring (kg/s).

Six hot springs were identified in Homa hills prospect area. Flows were metered at nine points using the v-notch weir. The volumetric flow rates ranged between 12.8 l/min and 437 l/min. The highest recorded temperature was 88.8°C at Abundu hot springs.

Discussion

The convective heat lost from the area could be higher than the estimated amount since the temperatures used for computation were average temperatures from a number of small hot springs. The total convective heat transferred from the hot springs in the prospect area is 3.55MW_t.

7.0 Mwananyamala Heat Loss Survey

Mwananyamala geothermal prospect is located in Kwale County. The prospect has an approximate area of 44km^2 and lies between Jombo and Mrima Hills. Locals refer to it as Maji Moto (A place of hot water). Prior to this survey, little work has been done on the prospect except for a few surveys by academicians and scientists and its geothermal potential was not well known.

Studies by Tole (1990) in relation to geothermal indicated existence of hot springs that discharge slightly alkaline $NaCl{-}NaHCO_3$ waters from underground, suggesting the springs are controlled underneath by a still active igneous. Temperature measurements carried out at that time record maximum hot spring discharge range of between 56 – 76°C.

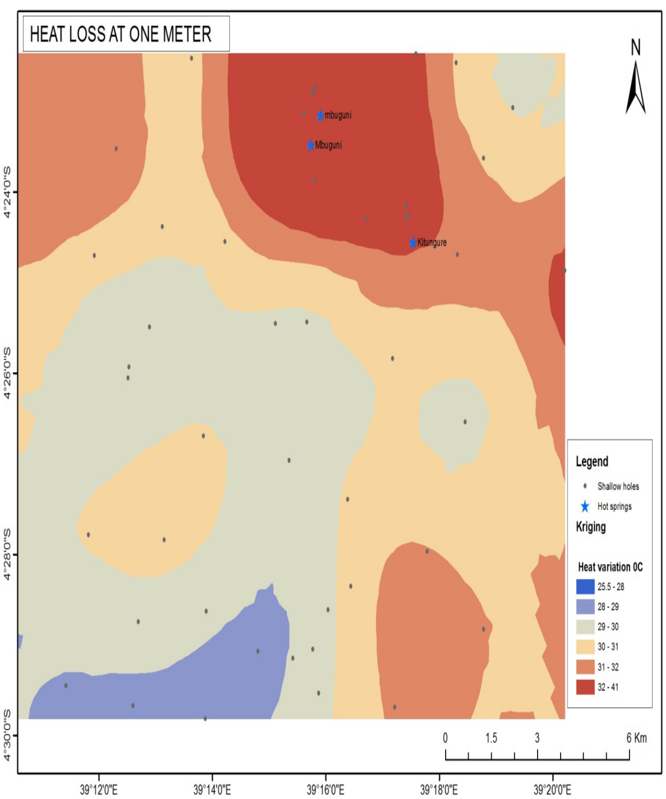

Figure 3. Shallow holes distribution and hot springs location in Mwananyamala.

Results

A total of 86 shallow holes were bored and measured within the prospect area. There was no hot ground encountered in these shallow 1m holes. All the holes recorded an inverse with ambient temperature attributed to very lose sandy surface soil that kept falling into bored holes.

Convective Heat Loss Calculations

Three hot springs were identified in Mwananyamala prospect area. Flows were metered at four (4) points using the v-notch weir. Volumetric flow rates ranged between 223.23 l/min and 541.6 l/min. The highest recorded temperature was 75.6 °C at Mbunguni.

Discussion

Mwananyamala prospect recorded an average ambient temperature of 34°C. Temperatures of 32°c was recorded during early mornings and varied to 38°C at hottest times during early afternoons. All surface temperatures were taken in areas not affected by direct sunlight thus were cooler compared to the open surfaces affected by direct sunlight. Early morning surface temperature readings were lower compared to readings obtained at late mornings and early afternoons. Most of 1m meter holes were dug at open grounds and where possible in shaded areas. Elevated temperatures at 50m compared to surface temperatures could have been due to the effect of sunlight. At 1m temperatures are seen to be either similar to that at 50m or are lower. This means that there is no effect of conduction in the areas surveyed. Temperature gradient recorded close to the hot springs could be as a result of hot water conduction mechanism. Total convective heat transferred from the hot springs in the prospect area is estimated at $5.54MW_t$.

8.0 Conclusion

Heat loss features at Paka are controlled by NE-SW trending faults and fissures. An isolated hot ground occurs west of Kasakat whose orientation is not well defined. An estimated $3{,}406.7\ MW_t$ is naturally lost at Paka geothermal prospect and seems mostly centered around the caldera and eastern crater.

Features at Korosi associated with NE-SW and NW-SE trending faults. Thermally active zones occur where faults intersect. In Chepchuk the trend is not well defined. An estimated $2{,}867MW_t$ is lost naturally at the Korosi and Chepchuk prospects mainly through conduction. There is a positive indication of a heat source between Nakaporon and Nagoreti major faults within the prospect area.

The total conductive heat loss from the other prospects: Silali, Homa hills and Mwananyamala is estimated at $1{,}127MW_t$, $3.55MW_t$ and $5.54MW_t$ respectively.

References

Dunkely, P. N., et al, 1993. “The Geothermal Activity and Geology of the Northern Sector of the Kenya Rift Valley.” British Geological Survey Research Report, SC/93/1.

Mungania J, and J. Wambugu, et al, 2007. “Geo-Scientific Evaluation of the Paka Geothermal Prospect.” Geothermal Resource Assessment Report.

Mwawongo G. M., 2006. “Heat Loss Assessment of Korosi and Chepchuck Geothermal Prospects.” Kengen Internal Report.

Ofwona C., P. A. Omenda, N. Mariita, J. Wambugu, G. Mwawongo, and B. Kubo, 2006. “Geothermal Exploration of Korosi and Chepchuk Prospects.” KenGen Internal Report.

Simiyu M. S., 2008. “Status of Goethermal Exploration in Kenya and Future Plans for its Development.” United Nations University Geothermal Training Program 30th Anniversary Workshop, p. 1–9.

Sutter J., E. Kipyego, and D. Mutai, 2012. “The Use of Portable Geothermal Wellhead Generators as Small Power Plants to Accelerate Geothermal Development and Power Generation in Kenya.” 37th Stanford Geothermal Workshop Proceedings, SGP-TR-194.

Tole M. P., 1990. “Present Day Ore Deposition in the Geothermal Systems of Kenya: The Mwananyamala Hot Springs North East of Jumbo Hill, Coast Province.” Geothermics, vol. 19, p. 233 - 239.