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Results of Well Production Test for Olkaria Domes Field, Olkaria Kenya

Eric Rop

P.O 785-2017, Naivasha, Kenya

Erop@kengen.co.ke

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ABSTRACT

A total of 29 wells have been drilled in the Olkaria Domes area to supply steam for the 140 MW_eOlkaria IV power plant. Production tests (discharge tests) were performed to obtain the discharge character of a well and to estimate its production capacity.

The wells were discharge tested using the lip pressure method. Well head pressure, lip pressure and water flow through the weir box were measured during the discharge tests. These well discharge parameters were then used in the calculation of total mass flow, steam fraction flow, water fraction flow, discharge enthalpy and power equivalent of steam.

Olkaria IV wells are high temperature two phase fluid wells with an average power equivalent of 7.1mw_e totaling 205mw_e which is capable of supporting a 140 mw_e conventional power plant with surplus steam for well head generation.

1. INTRODUCTION

The Greater Olkaria Geothermal Field is located in the Kenya Rift Valley, about 120km from Nairobi, covering an area of about 204km^2 as shown in**Error! Reference source not found.**.

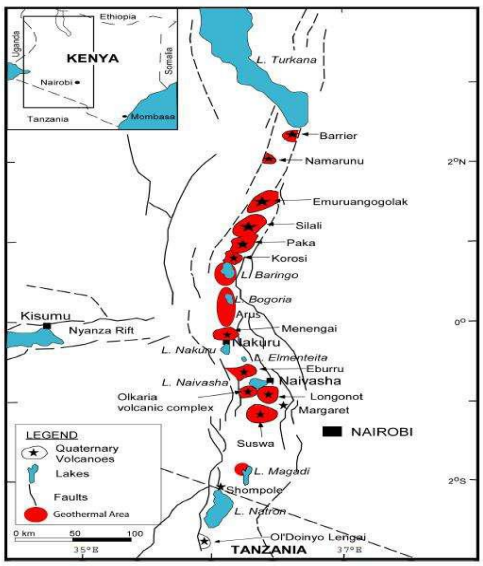

Figure 1: Map showing the location of the Greater Olkaria Geothermal Area within the Great Rift Valley of Kenya. Also shown are other volcanic and geothermal centers.

The geothermal field has been subdivided into `sectors that include Olkaria East, Olkaria South-East, Olkaria North-West, Olkaria South-West, Olkaria Central, Olkaria North-East and Olkaria Domes as shown in **Error! Reference source not found.**2.

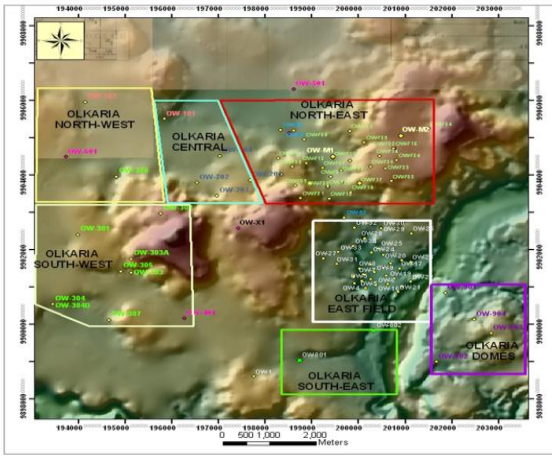

Figure 2: Greater Olkaria Geothermal Area divided into several sectors

Four power plants are currently installed and producing electricity in the field: Olkaria I with a capacity of 45 MW_e, Olkaria II with a capacity of 105 MW_e, Olkaria III with a capacity of 48 MW and Oserian with a 2 MW capacity.

The present optimization study estimates possible generating capacity of the whole 204km^2 field between 870 and 1120 MW (Table 1), of which a 280 MW power plant is on the implementation phase, a 140 MW expansion of Olkaria I and a 140 MW installation in Olkaria IV from the Olkaria Domes field.

Table 1: Electrical Generation Capacity Estimates for the Greater Olkaria Geothermal System Obtained during the Present Optimization Study.

Area/Sector	Assessment method	Generation capacity (MW)	Classification	Comments[1)]
Heavily explored part	Volumetric method	520-670	Proven reserve	Includes plants in operation with 150mw$_e$ capacity
	Lumped model	600[2)]		
	Numerical model	580		
Peripheral zone	Volumetric method	50-150	Probable reserve	
Less explored part	Volumetric method	>300	Inferred resource	To be confirmed by surface exploration and exploration/ appraisal drilling
Total		**870-1120**		

1) Australian geothermal code committee (2008)
2) Assuming a generation capacity for the Domes approximately equaling the average of the capacities of the Eastern and Northeast production fields estimated through lumped parameter modeling.

Results of discharge testing of Olkaria Domes field wells for the 140 MW$_e$Olkaria IV power plant are described in this paper.

2. OLKARIA DOMES FIELD DEVELOPMENT

Detailed geo-scientific investigations were carried out in this sector by KenGen between 1992 and 1997 involving geology, geophysics, geochemistry and heat flow measurements. Based on the scientific review of the data gathered, three exploration wells namely, OW-901, OW-902 and OW-903 were sited and drilled between 1998 and 1999. All the three wells were successful and able to discharge steam. Down-hole data from the drilled wells was reviewed and additional geophysical surveys carried out with MT and TEM. After the successful drilling of three exploration wells, six appraisal wells were to be drilled for the development of Olkaria IV (Olkaria Domes) plant but it was known that the fields under Olkaria I, II and IV developments were interconnected. It was therefore necessary to consider development in any part in the light of the entire investment.

In 2004, KenGen approached the World Bank for funding to carry out a study on optimal schemes for the exploitation of Olkaria East, North East and Domes fields.The World Bank approved the funding and the study now known as "1st Olkaria Optimization Study" was tendered out for bidding. The tender was won by West Japan Engineering Consultants, Inc. with services subcontracted to Global Synergy Link Ltd. (Kenya). Six appraisal wells were sited and the drilling contract was signed between GWDC of China and KenGen to drill the six appraisal wells (OW-903A, OW-904A, OW-905A, OW-906A, OW-907A and OW-908) and production wells OW-908A, OW-903B, OW-904B, OW-909 and OW-910A.

The study reviewed Olkaria Conceptual Reservoir Model and repeated numerical simulations based on the revised model established that Olkaria domes field can support generation of 140 MW. Production drilling was then carried out to completion. Table 2 presents the drilled well parameters

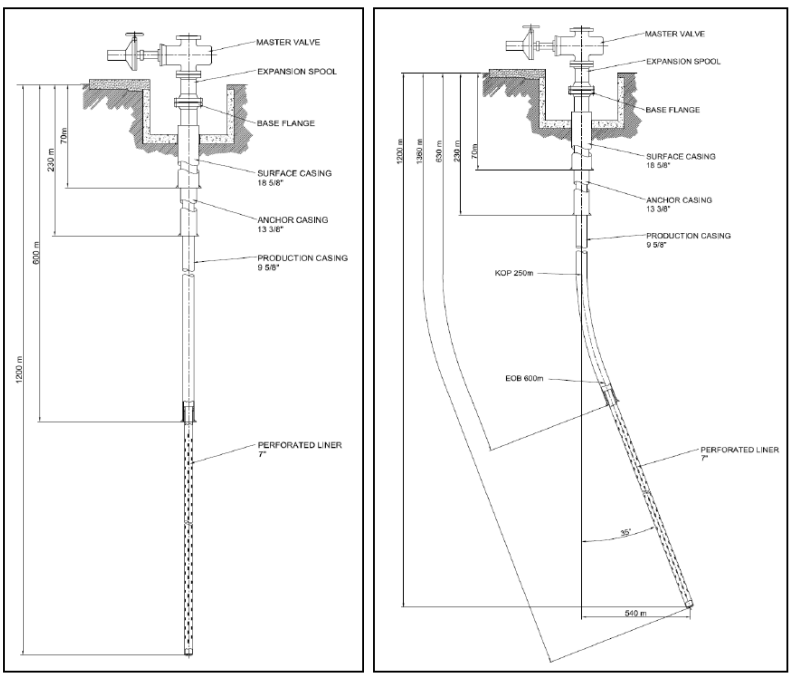

Figure 3: Olkaria wells general design for a vertical (left) and directionally (right) drilled regular diameter production well.

Table 2: Drilled Well Parameters in Olkaria Domes Wells.

Well no.	Eastings (m)	Northings (m)	Completion depth (RKB) (m)	Production casing depth (m)
ow-901	201857.6	9900843	2204	764.17
ow-902	201682	9899012.8	2206	653.28
ow-903	202839.2	9899769.9	2207	702.08
ow-903A	202834	9899824.5	2810	1197
ow-903B	202932.4	9899825.5	2800	1190
ow-904	202481.8	9900131.6	3000	1204
ow-904A	202506.9	9899989	2799	1250
ow-904B	202512.5	9899989	2820	1204
ow-905A	202778	9901245	2800	1269
ow-906A	201724.7	9899916.9	2804	1259
ow-907A	203113	9900635.8	2581	1250
ow-908	203378.2	9898929.2	2988	1201
ow-908A	203377.9	9898929	3000	950
ow-908B	203404.2	9898951.8	2877	958
ow-909	204138.1	9898631.7	3000	1205
ow-909A	204115.9	9898603.9	3008	903
ow-910	203733.2	9899737.6	3000	950
ow-910A	203848	9899774.4	2882	956
ow-910B	203745.9	9899703.4	3000	948.94
ow-911A	202736.1	9898315.2	3007	951
ow-912	204602.4	9898181.7	3010	856
ow-912A	204634.3	9898198.3	2989.7	856
ow-912B	204656.4	9898215.9	3000	858
ow-913A	202341.9	9899117.5	3010	1200
ow-914	205290.8	9899836.9	3000	952
ow-914A	205293.7	9899790.2	3000	858.53
ow-914B	205278.2	9899865.6	3000	754.49
ow-915	204308.6	9899979	3010	808
ow-915A	204327.4	9900010.1	2960	1020
ow-916	204858.8	9899094.3	2993	956
ow-916A	204879.2	9899063.8	3000	956.72

2.1 Discharge Test

The discharge test measurements were conducted using James' lip pressure method (James 1962) in which the two phase (steam-water) mixture was discharged through appropriately sized lip pipes (different throttling conditions were achieved by changing lip pressure pipes) into a silencer at atmospheric pressure. The lip pressure was measured at the extreme end of the (6mm-diameter hole centered at 6mm from the end of the pipe) discharge pipe using a liquid-filled gauge to damp out pressure fluctuations. Water flow from the silencer was measured using a sharp-edged V-notch weir near the silencer outlet.

The well output was then calculated using James' empirical formula. The wellhead pressure was monitored during discharge using a pressure recorder with chart paper. At the time of changing the recorder paper, the general condition of the discharge set-up was checked and necessary adjustments made by the measurement crew on site.

Readings of the wellhead pressure, lip pressure and water flow were recorded. The repetitiveness in the well head pressure profile over the 24-hour period, as indicated on the chart paper, formed the basis for establishing that the well output on certain throttle conditions had become stable.

Once the well output on certain throttle conditions became stable and the output was established to be satisfactorily steady over a 24-hour period, the output was monitored over a period of 10-20 min and the computed average result taken as representative.

After the representative output was obtained for the five throttle conditions, depending on the targeted discharge well-head pressures, which were above 5 bara, and flow stability, the well was shut-in to pave way for pressure recovery surveys. Also, down-hole flowing profiles were undertaken to ascertain the down-hole thermodynamic conditions that prevailed during discharge. Table 3 below presents the well test parameters for Olkaria Domes wells.

Table 3: Summary of Well Test Results in Olkaria Domes Wells

Well no.	Whp (bara)	Mass(t/h)	Enthalpy (kj/kg)	Water (t/h)	Steam (t/h)	dryness fraction	Power (mwe)	Remarks
OW-904A	6.46	142	1223	91.3	39.3	0.28	5.5	directional
OW-903A	10.5	64.3	1700	27.8	32.3	0.50	4.5	directional
OW-907A	-	-	-	-	-	-	-	directional
OW-906A	-	-	-	-	-	-	-	directional
OW-907A	5.28	105.3	1801	40.7	58.3	0.55	8	directional
OW-908	11.1	33.95	2331	5.2	27.2	0.80	4	vertical
OW-903B	5.0	150.7	1193	98.9	39.4	0.26	6	directional
OW-904B	7.28	153.4	1161	102.9	39.9	0.26	5	directional
OW-909	7.3	143.9	1950	46.4	89.6	0.62	12.5	vertical
OW-908A	6.0	143.7	1332	85.5	47.1	0.33	6.5	directional
OW-910A	9.1	125.1	2215	25.5	93.5	0.75	13	directional
OW-911A	3.6	77.2	1192	50.7	20.2	0.26	-	directional
OW-912	5.1	91.1	1496	46.7	35.0	0.38	5.1	vertical
OW-913A	5.3	48.8	1374	28.1	17	0.35	2.4	directional
OW-909A	6.7	127.1	1867	45.4	74.00	0.58	10.2	directional
OW-904	6.52	133.6	1225	85.9	37.1	0.28	5.2	vertical
OW-914	7.8	138.6	2007	41.1	89.9	0.65	12.5	vertical
OW-910	6.2	62.5	1755	25.5	33.1	0.53	4.6	vertical
OW-915A	6.87	112.4	2389	14.2	93.2	0.83	13	directional
OW-916	11.7	130.8	2499	10.2	115.2	0.88	16	vertical
OW-912A	7.14	65.8	2461	6.2	56.8	0.86	7.9	directional
OW-908B	5.6	91.6	1972	28.6	57.9	0.63	8	vertical
OW-910B	12.1	270.5	1455	146.2	104.6	0.39	14.5	directional
OW-914A	5.21	99.1	1864	35.6	57.5	0.58	8	directional
OW-916A	9.7	65.2	2281	11.4	50.7	0.78	7.1	directional

Well no.	Whp (bara)	Mass(t/h)	Enthalpy (kj/kg)	Water (t/h)	Steam (t/h)	dryness fraction	Power (mwe)	Remarks
OW-915	5.1	86.7	1885	30.4	51.2	0.59	7.1	vertical
OW-914B	5.4	79.5	2057	21.8	53.4	0.67	7.4	directional
OW-915B							11.6	directional
Average	**7.12**	**109.7**	**1787**	**46.08**	**56.53**	**0.54**	**7.09**	
Total		**2742**		**1152**	**1413**		**205.6**	

3. DISCUSSIONS

The discharge test results indicate that Olkaria Domes wells are two phase fluid high enthalpy wells. The total discharge per well varies from 33 tonnes per hour to 270 tonnes per hour with an average of 107 tonnes per hour. Olkaria domes wells indicate an average dryness fraction of 0.54. This means that Olkaria domes wells are not dry wells and therefore they have a longer life time. The average steam output per well is 56.53 tonnes/hour with an average water output of 46.08 tonnes per hour. The total steam output in Olkaria domes is 1413 tonnes per hour.

It is often claimed that directionally drilled wells should in general be more productive, especially due to their greater chance of intersecting near-vertical permeable structures. This has been difficult to validate and an analysis of the Olkaria Domes wells presented in Table 4 below demonstrates that this is not the case. However, directionally drilled have the following advantages:

- Drillings pads can be overlapping and several wells drilled from the same drill site. Constructions and installations on the surface can be common for several wells, including roads, water supply for drilling and steam pipelines, in addition to the drill pads.
- Directional drilling allows for targets to be reached with more accuracy, including when specific faults or other structures are being targeted.
- Targets that can't be reached vertically from above, due to landscape or other access restrictions, can be reached from the side by directional drilling.

Table 4: Vertical and Directional Wells Average Power per Well

Well type	Number of wells	Average capacity (Mw_e)
Vertical	8	8.4
Directional	21	6.6

The Olkaria Domes field is a high enthalpy field as shown in Figure 4. The down-hole temperature profiles indicate that the field is a high temperature field. It ranges from 200 to 360^{0}c at -500m above sea level.

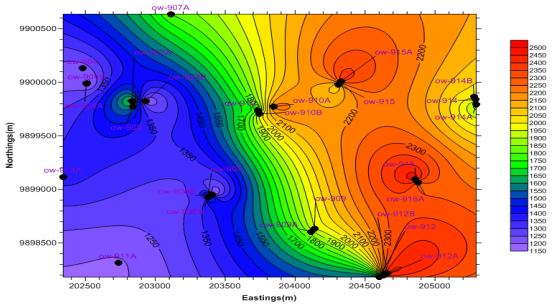

Figure 4: Enthalpy contour maps in Olkaria Domes field

Figure 5 shows the temperature contour map of Olkaria Domes field. The down-hole temperature profiles indicate that the field is a high temperature field. It ranges from 200 to 360^{0}c at -500m above sea level.

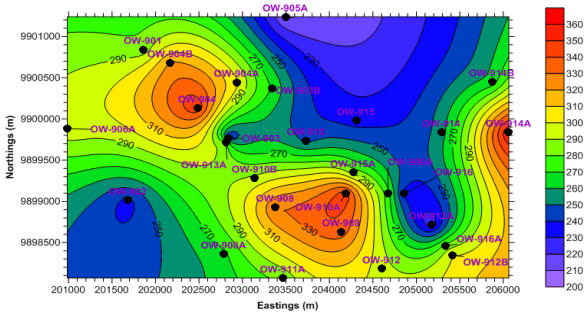

Figure 5: Temperature contour maps in Olkaria Domes wells at -500 m.a.s.

The corresponding pressures ranges from 45 to 195 bar absolute at -500 m above sea level. This shows that the field is a high pressure field. Figure 6 shows the pressure contour map of Olkaria Domes field.

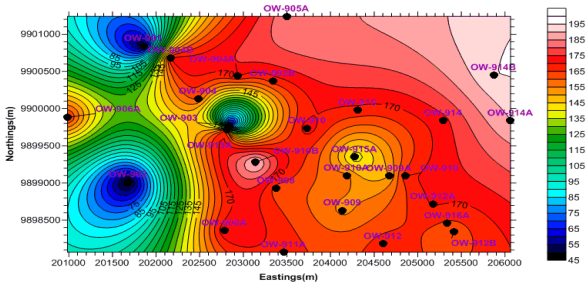

Figure 6: Pressure contour maps in Olkaria Domes wells at -500 m.a.s

Some of the wells in the field are cyclic for example ow-916A. The possible explanation for the cyclic nature of the

wells is that it must have penetrated zones of different permeability.

The average power per well in Olkaria Domes is 7.1 MW_e with the highest power of 16 MW_e recorded in OW-916. The target average power in the field was 5 MW_e.

4. CONCLUSIONS

This report presents the results of well discharge test for Olkaria Domes wells.

Reliable well test data of geothermal systems are the key to their successful development and particularly vital during expansion of geothermal operations and power plant design.

The main aspects of the Olkaria Domes field presented here are the following:

- Olkaria Domes field is a high enthalpy and pressure field with a two phase fluid.
- The average power per well in the field is 7.1 MW_e which exceeded the target value of 5 MW_e per well. This can be attributed to deep drilling of wells as well as targeting more permeable zones during drilling.
- The drilling of wells in Olkaria Domes field was a great success with power equivalent in excess of 205MW_e capable of running a 140 MW_e power plant and excess steam for well head generation.
- The eastern part of the field looks promising and further studies should be carried out to explore the extend of the geothermal resource.
- Higher average production achieved on vertical wells shows that it is not always the case that directional wells intersect multiple fractures. However directional drilling remains a very useful drilling technique as it allows accessibility of remote areas as well as reduction in drilling support infrastructure.

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