Assessing the potential of low to intermediate temperature geothermal resources for direct use.

Ambunya M.[1], Wambua C[1], Mariita N.[3], Mariaria J.[1], Ako E[1], Ambusso W.[1] and Orozova-Bekkevold I.[2]

[1]Kenyatta University

[2]University of Copenhagen

[3]Dedan Kimathi University

maureen.ambunya@gmail.com

Keywords: *wellbore simulation, geothermal resources, low-to-medium enthalpy reservoirs*

ABSTRACT

Electricity generation by use of direct condensing conventional turbines or by organic Rankine binary systems remain the most viable options for exploiting geothermal resources. Wells used for the two power systems typically have adequate and consistent steam flow rates at relatively high pressure. However, with the development of geothermal fields, some of the many drilled wells may not meet the required steam and heat flow rates at the required well head pressures. Such marginal wells will probably have intercepted low-to-intermediate temperature formations or poor permeability zones. These wells are typically used for either re-injection of waste brine/blowdown or for monitoring temporal changes in reservoir conditions. With increased emphasis on green forms of energy, marginal wells have proved useful as source of heat, and their exploitation for direct use purposes. These uses are predominantly at local boiling conditions or below. However up-take of direct use at higher temperature above local boiling, and at large scale has been slow. Consequently, a need to design and develop direct use methodologies usable to applications that use intermediate temperature in the range, 100^{0}C to 140^{0}C. Temperatures in this range may be more usable for industrial applications leading to better utilization of geothermal resources. To justify the accompanying investment in the heat conveyance system from the source to the utilities, it is important to ensure a priori that the resources tapped by the wells can sustain production and usage of heat for long enough periods and at competitive costs compared to traditional sources of fuel. This paper looks at effect of the wellbore design on developing and exploitation of a geothermal resource at intermediate temperature for direct use. In addition, production sustenance through re-injection will need to be done differently from regular reservoirs. This paper addresses these aspects and proposes methods of assessing the energy potential of these reservoirs.

1. INTRODUCTION

This paper presents results of early studies on the utilization of low to medium enthalpy geothermal wells for energy generation and industrial heating applications as proposed by Nishith et. al (2022). In particular these results focus on well bore design for low to immediate enthalpy wells that intercept deep geothermal systems like Olkaria geothermal field, in Kenya. This study considers appropriate well design to be integral and important for sustained resource utilization as it directly affects fluid delivery from the reservoir to the surface where it can be processed and used in various ways. Other aspects of the framework proposed by Nishith et. al (2022) such as multi-generation will be subject of latter publications.

Even though direct use of geothermal energy has been going on for decades and some of its benefits are well known, a review of published literature reveals that only a limited number of large-scale facilities have been established for industrial applications. The Kawerau Pulp and Paper factory in New Zealand that has been in operation since 1950's, is among the first such large industrial scale applications for direct use and to date remains the largest direct-use facility in the world (Quinao et.al (2018), Bloomer (2015)). This facility uses high enthalpy wells at high temperature (>180^{0}C) to process pulp and other products using heat from the geothermal fluid.

On the other hand, use of low-to medium enthalpy wells worldwide has been limited to space heating and other activities that use geothermal fluids at local boiling conditions. Though usable at local saturation, use of these fluids at elevated temperature will not only expand the usage of fluids from geothermal wells to other activities but will also create higher level jobs demanded by industrial set ups. This study will target wells that are usually considered marginal and see how the fluids can be used in industry and agriculture where high energy throughput is expected and at temperatures elevated above local boiling. These are most likely to lower carbon emission by significant values.

The results presented here-in are based on review and analysis of the static and flowing temperature, pressure, and phase changes in the wellbore of a selected study well. Wellbore simulator was used to explore and suggest more efficient design for well usage. This enabled inclusion of effect of low permeability that is typically encountered in marginal wells. The selected well was provided by the Kenya Electricity Generation Company PLC.

2. OVERVIEW OF STUDY

Research on the use of low to medium temperature geothermal reservoirs must first seek to establish the amount of energy in place and establish what proportion of overall amounts of the energy that can be extracted and used most effectively. The well is an important conduit in this extraction and wellbore characteristics under different conditions need to be understood to inform developments downstream of the wellhead.

The need for industrialization is the primary focus of most development plans for the government of Kenya and other countries in East Africa. Besides, agriculture is an important economic activity for all countries in Eastern Africa and the focus of the use of geothermal energy should essentially target farm products and food processing.

A study framework that will address all issues pertaining to direct use of low-to-intermediate geothermal fields proposed by Nishith et.al (2022) intends to evaluate a practical single stream of geothermal field from fluid production from the reservoir to the wellhead and downstream where it is applied at large scale multi-generation projects and a prototype of a binary units.

It is expected that the outcome of these studies shall lead to practical applications to increase the usage of geothermal energy, for example by utilizing wells that were previously considered noncommercial.

2.1 Geological set-up

The Greater Olkaria Geothermal field is characterized by numerous volcanic centres of Quaternary age. The presence of a ring of volcanic domes in the east and south, and southwest has been used to invoke the presence of a buried caldera (Naylor, 1972, Mungania, 1992). The drilled lithological column of OW-927A is composed of unconsolidated pyroclastics that occur at the shallow levels overlying a volcanic sequence whose lithological composition is dominated by rhyolite, trachyte and basalt.

Trachyte is the most dominant rock encountered in this well and occurs from 698 m to the bottom of the well (Munyiri, 2015). The hydrothermal alteration mineral assemblage found in this well include calcite, chlorite, haematite, epidote, pyrite and sphene (Browne, 1978).

3. STATIC AND FLOWING PROFILES FOR OW-927A

The Kenyan central rift system contains several geothermal fields with high temperatures, including Olkaria (Lagat et al 2004).

Figure 1 shows the location of OW-927A, the well used for this study. The well is in the Domes area of the greater Olkaria Geothermal field.

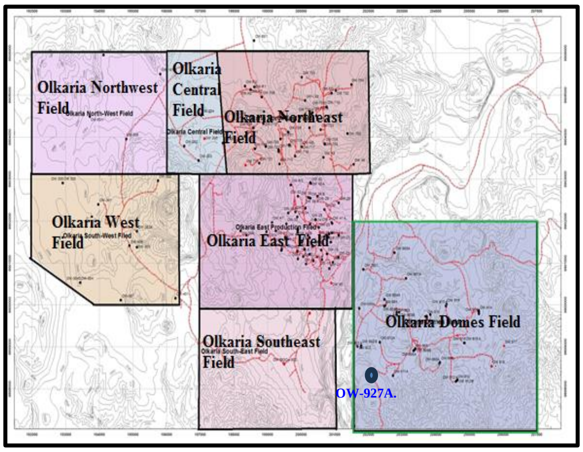

Figure 1: Map of Greater Olkaria geothermal field subsections (Modified: Ambunya, 2014)

Although most of the wells are drilled in high-temperature zones, some wells intercept low-to-medium-temperature zones (more than 10 wells) Most of those wells have been either shut-in and used for reservoir monitoring or used for purposes of fluid reinjection.

Well geometry and the location and number of feed zones are major factors influencing well performance in low-to-moderate temperature geothermal resource.

OW-927A well was used for this study. The well is in the Domes area of the greater Olkaria Geothermal field. The well data were provided by the Kenya Electricity Generating Company PLC

3.1 Well geometry

OW-927A is a directional well drilled in 2015. A 9 5/8” production casing was set at 910 mMD (measured depth) and 7” perforated liner running to 3000 mMD. The well deviates by a 20° inclination from the vertical below 400 mMD as a KOP (kick off point) and is drilled to a depth of about 3000 meters (2817.8 m TVD).

3.2 Well test data

After a long period of shut-in after the last flow test and downhole survey in 2016, OW-927A was recently, May-July 2023, surveyed and retested as part of this study. The static and flowing temperature and pressure profiles are shown in Figure 2.

The well is cased to 910m and has a perforated liner in the open hole from the casing shoe to the total drilled to a depth of about 3000 meters.

The profiles indicate that static down hole temperatures are lower than most wells in Olkaria geothermal field and even within the domes area. Except for a short part of below the casing shoe that shows two phase characteristics, the water column in the well is hydrostatic at the prevailing temperature conditions.

The well does not flow by itself and requires stimulation by compression to induce discharge. The well was tested using the Russel James’ tube method and results are as summarized in Table 1.

Table 1: Summery of flow output data

Pipe	WHP (bara)	Enthalpy (kJ/kg)	Water (t/hr)	Steam (t/hr)	Total mass (t/hr)
8”	4.3	1034.5	70.2	18.1	88.37
6”	4.9	983.2	61.4	13.3	74.73
5”	4.9	964.0	49.1	10.0	56.87
4”	3.4	1016.0	21.5	5.2	26.70

The flow rates are very marginal and are partially cyclic, which is typical of wells that intercept low permeability formations. Also notable is the higher downhole temperature for most parts of the well above 2400m during the discharge test. With the bottom hole temperature remaining constant and at lower temperature than the rest of the well below casing shoe. These profiles indicate that the well had an internal flow during shut-in with the lower temperatures at the well bottom masking the upper part.

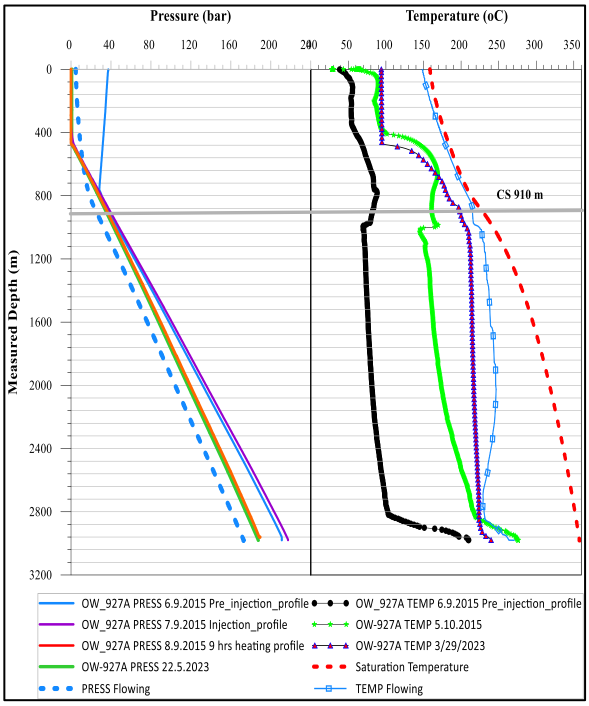

Figure 2: OW-927A Temperature and Pressure profiles

The saturation curve for the flowing pressure also shows that the pressure column is largely hydrostatic for measured temperature below the casing, but two-phase conditions prevail upwards of the casing shoe to the wellhead. The marginal difference between saturation and measured temperature could be due to low gas concentrations that tend to induce premature boiling (Lowenstern, 2001).

Spinner logs are shown on Figure 3 alongside the flowing temperature and pressure profile. The spinner readings are largely the same in the well bore over the interval below the casing shoe. The logs, however, reveal interesting features within the casing. The high spin rates begin right at the casing shoe and increase rapidly towards the well head. This increased spin indicates continued flushing with the steam fraction in the flow increasing with reducing pressure. The well head temperature. ~150^{0}C, are high. This is acceptable for the proposed study which targets temperatures below this value.

The chemistry of the discharged fluid is an equally important piece of well data. Other than indicating temperatures through different geo-thermometers, brine chemistry can have a strong impact on the design of downstream facilities and even the production pressure if risks of scaling are high. Table 2 gives the chemistry data collected during the discharge tests in 2016. The table shows the low and benign levels of silica and TDS are low and for high PH scaling is unlikely.

Table 2. Chemistry of OW-927A

Date	Enth (j/g)	Cond (µΩ/cm)	TDS (ppm)	pH/ 20°C	CO_2 (pp)	H_2S (pm)
5/21	1012	1045	524	9.752	278.9	0.54
6/21	1061	1223	611	9.658	326.4	1.53

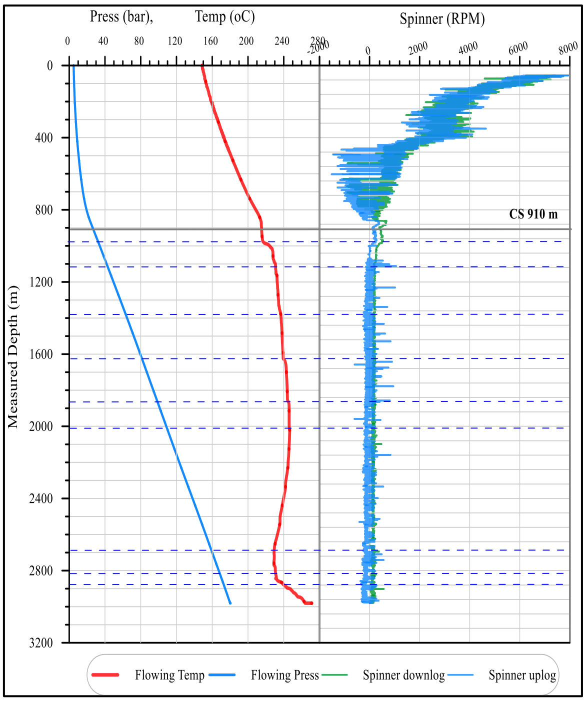

Figure 3: OW-927AFlowing Profile

4. WELLBORE SIMULATION

To simulate the downhole pressure and temperature profiles an application WellSim Version 4.16.11.30 developed by GSDS was used (Anderson, 2006). WellSim is a flexible wellbore simulator and can be used to obtain and refine formation parameters based on well head flow rates or can be used in reverse to provide expected flowrates given wellbore and formation properties.

In this study the simulations were conducted to determine the rates of discharge of fluid from the various permeable intervals in the well. These were latter used to investigate effect of change in wellbore design and how these parameters would have on the rates of discharge.

The input parameters for WellSim is the wellbore dimension and geometry. This includes well total depth, depth and size of the production casing, and dimension of open hole or well bore linear. Well deviation is also an important parameter. The fluid chemistry that includes brine salinity and gas levels also need to be specified, though pure water properties can be used.

In general, matching the temperature/pressure profile is not always unique as combination of several formation flowrates in different proportions can still give the same output. However, by integrating all the information known about the well and incorporating balance of mass, energy, and momentum, reliable results can be obtained. In this case the recovery, static and flowing temperatures and pressure provided the vital information (Figure 3).

4.1 Productivity index; matching flowing profiles.

As stated, a spinner log was taken alongside the downhole pressure and temperature surveys. The well was flowing on a 6-inch James' tube. The deepest logged depth was 2980 meters. The well was flowing at 97.5 t/hr mass flow rate at

Proceedings 45th New Zealand Geothermal Workshop
15-17 November, 2023
Auckland, New Zealand
ISSN 2703-4275

wellhead pressure of 4.5 bara. The highest temperature measured at the well bottom was 265^{0}C.

Matching the flowing profile is usually the first task in the use of WELLSIM software. This requires identifying feed zones and assigning productivity index and fluid properties. Results that best fit the observed curve are normally adopted for any forward studies and investigations. Skin effects were ignored in this study. In addition, pure water properties were assumed because of low concentrations of dissolved salts and non-condensable gases.

The simulation used six feed zones for OW-927A: 1040, 1400, 1660-, 1900-, 2040- and 2820-meters MD depth. The main producer from the enthalpy at the wellhead would be below the casing shoe where Minor contributions were also found at 1080 m, 1160 m, 1360 m, 1620 m, 1860 m, 2640 m, and 2780 m MD depths.

In the actual simulation the feed zones listed above had to be corrected for wellbore geometry. The production casing is 9 5/8", and the liner is 7" running from 889 m to 3000 m MD. The well deviates by a 20° inclination from the vertical below 400 m.

Table 3 gives a summary of results that gave best fit. The temperature and pressure of the profiles are plotted in Figure 4.

Table 3: Feed points constraint properties

Feed Depth [m]	Enthalpy [kJ/kg]	Mass Flow [t/hr.]
1040	780	36.00
1400	920	16.00
1660	980	14.00
1900	1040	14.00
2040	1060	16.00
2820	975	1.50

4.2 Simulation results, analysis and discussion

In general, the simulation results gave a good match to the flowing profiles. While the pressure profile was picture perfect all through the wellbore to the wellhead, only a small deviation was seen in the match for temperature profile from 2000 meters to the bottom hole. This implies that production from this depth, which is at a lower temperature, is probably less than the value assumed in the simulation.

The well bore properties derived from the matching were used to simulate production from a larger (13") production casing and a 9" open hole. This was intended to determine whether better production can be achieved. The outcome was that the production would indeed improve but not in a significant manner (Figure 4). However, a marginally higher wellhead pressure would be realized. This result is within what is expected due to reduced friction even with increased flushing (Barnett, 1989).

Simulations were also extended to investigate flow from a smaller wellbore; 6-inch production casing and 4-inch open hole below the casing. Slim holes are less expensive and would low overall costs of direct use projects. The results were somewhat disappointing.

This time there was no flushing in any part of the well and the well was not able to flow. This result is largely expected given the depth of the fluid rest level and the low productivity.

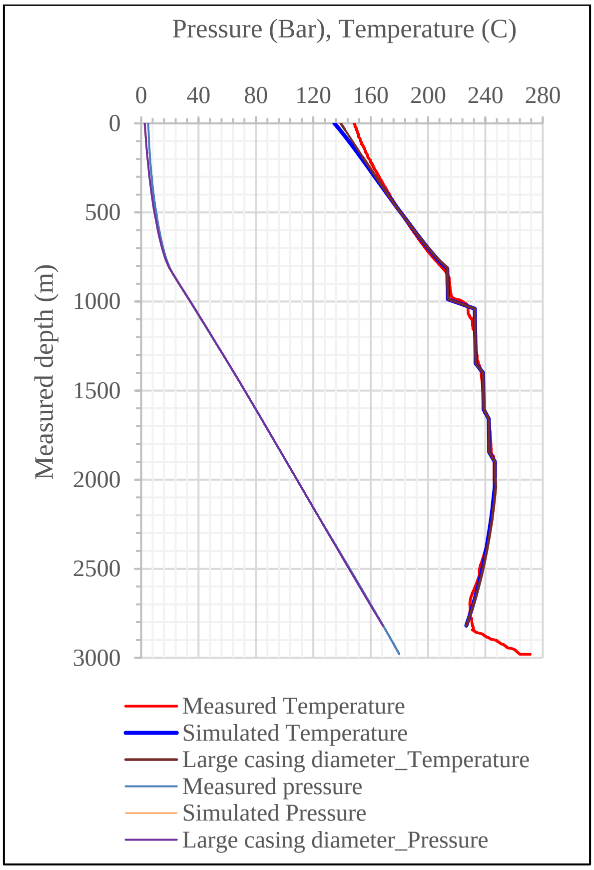

Figure 4: Simulation match: A comparison between conventional casing and larger diameter casing.

5. CONCLUSION AND RECOMENDATION

The results obtained from the well tests and simulation as presented here are crucial for further planning of the rest of the study on multi-generation using wells with low to intermediate enthalpy. Most significant is that the fluid flow rate for the selected well is considered adequate for a multi-generation. The well head temperatures are also acceptable as they enable use fluid beyond local atmospheric saturation conditions for varies direct use applications.

Furthermore, the wellbore simulations have shown that results are reproducible and that larger production casing while leading to better well head pressure and by extension higher temperature, will not impact the fluid flow rates significantly.

Though not part of the intended study the temperature inversion observed in the flowing profile should be subjected to further investigation. Being present in well that has been on thermal recovery for over six (6) years this could represent a significant aspect of the regional hydrology or outflow features not previously reported or factored in field studies. However, the measured temperature is still high enough for direct use.

ACKNOWLEDGEMENTS

The research presented in this paper was developed within the project "Widespread use of geothermal energy in East Africa" (File No. 20-06-DTU), funded by the Ministry of Foreign Affairs of Denmark and administrated by Danida Fellowship Centre (DFC). The financial support is gratefully acknowledged.

The well used for the study together with the well testing equipment and the tools for measuring pressure, temperature and spinner are owned by the Kenya Electricity Generating Company (KenGen). This gracious support, and the permission to use the data in this publication is greatly acknowledged.

REFERENCES

Ambunya, M.N. 2014: Natural-state model update of Olkaria Domes geothermal field. report 7 in: Geothermal training programme 2014. UNUGTP, Iceland.

Anderson, E.: GSDS Geodata (2006). *Webpage: https://www.gsds.co.nz/wellsim/*

Barnett, B.: A Theoretical Study of the Effect of Bore Diameter on Well Outputs. Proc. 11th New Zealand Workshop, Auckland, New Zealand. pp. 181-187. (1989).

Bloomer, A.: Kawerau Industrial Direct Heat Use: Recent Developments. Proceedings World Geothermal Congress 2015 Melbourne, Australia, 19-25 (2015)

Browne, P.R.L.: Hydrothermal Alteration in Active Geothermal Fields: Annual Review of Earth and Planetary Sciences, v. 6, no. 1, p. 229–248. (1978)

Lagat, J. K. E., Arnorsson, S., & Franzson, H.: Geology, hydrothermal alteration and fluid inclusion studies of Olkaria Domes geothermal field, Kenya. Háskóli Íslands, jarð-og landfræðiskor. (2004).

Lowenstern, J.B.: Carbon dioxide in magmas and implications for hydrothermal systems. Min Dep 36, 490–502 (2001).

Mungania, J.: Surface geology of Olkaria- Domes field. Kenya Power Company, unpublished internal report. (1992)

Munyiri, S.: Borehole geology of OW-927A. Kenya Electricity Generating Company, unpublished internal report. (2015)

Naylor, W.I.: The Geology of the Eburru and Olkaria Geothermal Projects. United Nations Development Programme, Report No. 01, 52 p. (1972)

Nishith B. Desai1*, Ivanka M. Orozova-Bekkevold, Meseret T. Zemedkun, Willis Ambusso, Nicholas O. Mariita5, Cuthbert Kimambo, Fredrik Haglind.: Utilisation of low to medium temperature geothermal resources in East Africa., Proceedings, 9th African Rift Geothermal Conference Djibouti, 3rd November – 5th November 2022

Quinao. J., Watt, R., McClintock, S.: Updates from New Zealand's Kawerau Industrial Complex: Home to the World's Largest Industrial Geothermal Direct Use Operations. GRC Transactions, Vol. 42, (2018)