Wellbore Simulation and Exergy Profile of Olkaria Domes

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ABSTRACT

This paper presents exergy in the wellbore. Exergy analysis is considered between the wellhead and the reservoir with geothermal brine at saturated conditions. The field data input parameters were wellhead pressure, mass flow rates of steam and brine, wellbore diameter, and the reservoir depths (deeper/2nd depth and shallow). The pressure-temperature (PT) profile was simulated using the developed wellbore model. The exergy profiles estimated feed zone depths for a directional well. The research investigated liquid-dominated Olkaria Domes wells, OW-908, OW-921 and OW-924.

The profiles predicted convective and conductive heat transfer points. For a range of wellhead temperatures, the reservoir temperatures and formation pressure from the wellbore simulator were calculated.

The thermodynamic parameters (temperature and pressure) from the wellbore simulator were input parameters in the (Engineers Equation Solver) EES code. The calculated values in EES were entropy, enthalpy, and specific exergy. Exergy wellbore simulation of the geothermal reservoir predicted the geological stratification of the geothermal field. The study demonstrates the importance of connecting the reservoir and wellhead via a wellbore simulation and exergy profiles.

1. INTRODUCTION

A geothermal system and utilisation mainly consist of a reservoir, wellbore, and surface facilities (steam gathering and power plant or direct use). The link between the reservoir and the surface is the wellbore, delivering the resource for utilization.

Energy is an essential aspect of life and exists in thermal, kinetic, mechanical, potential, or chemical forms. The first law of thermodynamics (energy can be transformed from one form to another) is based on energy conservation and its quantity. Available energy to be used is termed exergy based on the second law of thermodynamics (dealing with quality of energy, reversible work, entropy generation and exergy destruction) explained by Çengel and Boles (2006) in detail. Exergy is zero when the system and the surroundings reach equilibrium (Bett and Jalilinasrabady 2022; Jalilinasrabady et al. 2012; Jalilinasrabady et al. 2010; Çengel and Boles 2006; Ozturk et al. 2006).

In geothermal power plants, exergy analysis has been performed based on wellhead conditions. Liquid-dominated geothermal systems have fluid flowing in the wellbore from the reservoir as compressed water (Bett and Jalilinasrabady 2021). The application of geothermal energy mainly depends on the thermodynamic specification and geographical situation, resources' thermal energy. The evaluation point is at wellhead conditions for energy, exergy. Available reservoir simulators simplify the wellbore analysis for coupling the reservoir and the surface facilities (Hadgu, Zimmerman, and Bodvarsson 1993). The study to couple wellbore and reservoir simulator for steady and Darcy flow considered temperature, pressure, flow rates, and enthalpy in terms of time (Hadgu, Zimmerman, and Bodvarsson 1993).

The main representative parameters in geothermal energy are temperature and pressure. The wellbore simulator gives the two parameters for further interrogation in line with the research objectives. One of the objectives is to consider the coupling of the reservoir in Olkaria Domes with a wellbore simulator. Wellbore simulator gives pressure and temperature results close to the actual field flowing data for some wells in Olkaria Domes.

Exergy study has defined the potential sustainable size of the geothermal power plant by using numerical simulation to connect reservoir and surface facilities (Franco and Vaccaro 2020)

1.1 Olkaria domes geothermal field

Geothermal resources in Kenya are estimated to be water-dominated with high enthalpy. Pyroclastic and commendites are predominant within which there is minor interbedding of trachyte and basalt (Kibet et al. 2019). Olkaria volcanic formations are dominated with alternating thin tuffs, minor trachyte, and sporadic rhyolites. Volcanic centres and volcanic plugs are dominant features of volcanism associated with the geothermal systems. Prime geothermal systems are associated with volcanism, which is the main feature in Olkaria (Moeck 2014).

The were 180 geothermal wells in Olkaria (148 production and 32 injection wells) in 2020 (Nyandigisi 2020). Nyandigisi (2020) reported an 88% success rate of production wells. Well pads 904 and 921 have the most productive wells with OW 904 recording 363^{o}C. OW 921A is the most productive well, with an output of 24.7 MWe (Nyandigisi 2020).

1.2 Olkaria domes geothermal field

Wellbore flows and modelling affect isotherm plots constructed using temperature log data in geothermal field simulation to obtain reliable results (O'Sullivan et al. 2000; Marcolini, Battistelli, and Consultant 2014). Simulation of the flow in geothermal fields is the first step in coupling a reservoir with well-flowing data. In wellbore temperature calculations, it is assumed that heat losses between the wellhead and downhole conditions can be ignored (Grant, Donaldson, and Bixley 1988).

Flashing in the wellbore is the driving force that uplifts the geothermal fluid due to expansion and reduction in hydrostatic pressure (Grant, Donaldson, and Bixley 1988).

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Wellbore simulation is applied in matching the available down-log data sets. The downhole measurements are analysed before matching the analysis of the measured parameters and simulated estimates (temperature and pressure). The wellbore is a unifying feature for geothermal reservoir analysis (Watson 2013). The vital parameter governing wellbore flow in geothermal wells is the reservoir temperature (Ortiz-Ramirez 1983).

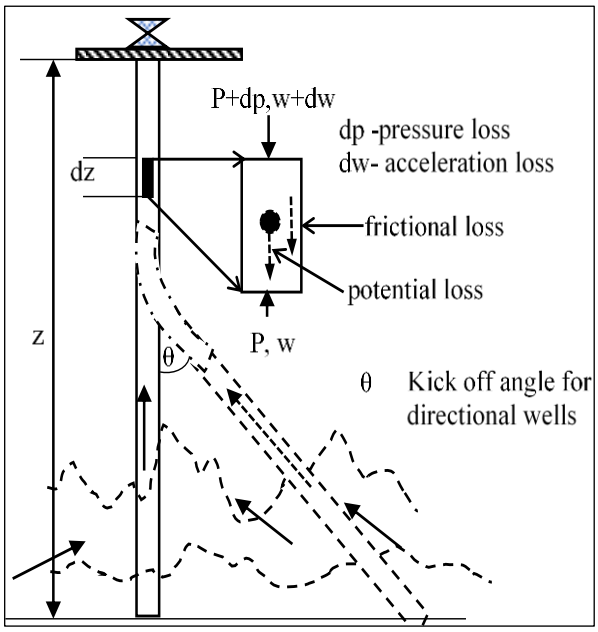


Figure 1; Basic wellbore model showing fluid flow from the reservoir up to wellhead (Itoi et al. 1988)**.**

Error! Reference source not found. shows a simplified mathematical model of a typical geothermal well.

The mass, momentum and energy equations (1), (2), and (3), respectively, are the main foundational equations applied in wellbore analysis (Itoi et al. 1988).

$$w = \frac{\dot{m}v}{A} \tag{1}$$

$$\mathrm{dp} + \frac{\mathrm{dw}^2}{2\mathrm{v}} + \frac{\lambda \mathrm{w}^2}{2\mathrm{Dv}}\mathrm{dz} + \mathrm{gdz} = 0 \tag{2}$$

$$\mathrm{di} + \frac{\mathrm{dw}^2}{2} + \mathrm{gdz} = \mathrm{dq} \tag{3}$$

where A is the well cross-sectional area (m^2), $\dot{m}$ is the geothermal fluid flow rate (kg/s), D is the wellbore diameter (m), z is the well true vertical depth (m), p is the pressure in (Pa), w is the velocity (m/s), v is the specific volume ($\frac{m^3}{kg}$), λ is the frictional factor (-), i is the specific enthalpy (J/kg) and q is the heat energy (J/kg) (Bett and Jalilinasrabady 2022).

2. RESULTS

The presented study projected the link between wellhead and reservoir by exergy profile. Feed zones were predicted by using a wellbore simulator for wells in Olkaria Domes.

This paper investigated liquid-dominated Olkaria Domes wells, OW-908, OW-921, and OW-924.

Wellbore simulation profiles represent well-flowing data under steady-state conditions and can be used to couple reservoir and wellhead. Exergy profiles of geothermal wells predict some subsurface behavior of geothermal reservoirs. The estimated cap-rock depth of the subsurface is in the hypothesis of the study.

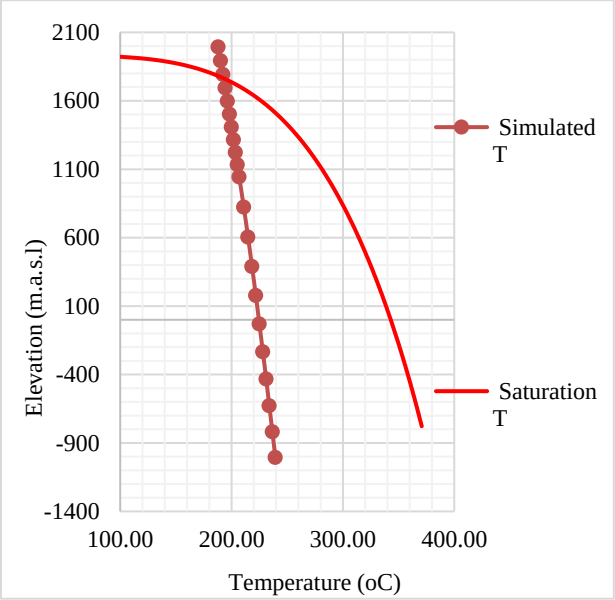


Figure 2; OW -908 simulated temperature profile and the boiling curve of water.

From the exergy profiles, with gain and losses with depth, are used to conceptualize the sub-surface structure to interpret the likely scenario in the reservoir using specific exergy.

The exergy and flow rates diagrams (as a possible scenario) consider a multi-feed zone between the well bottom and production casing depth.

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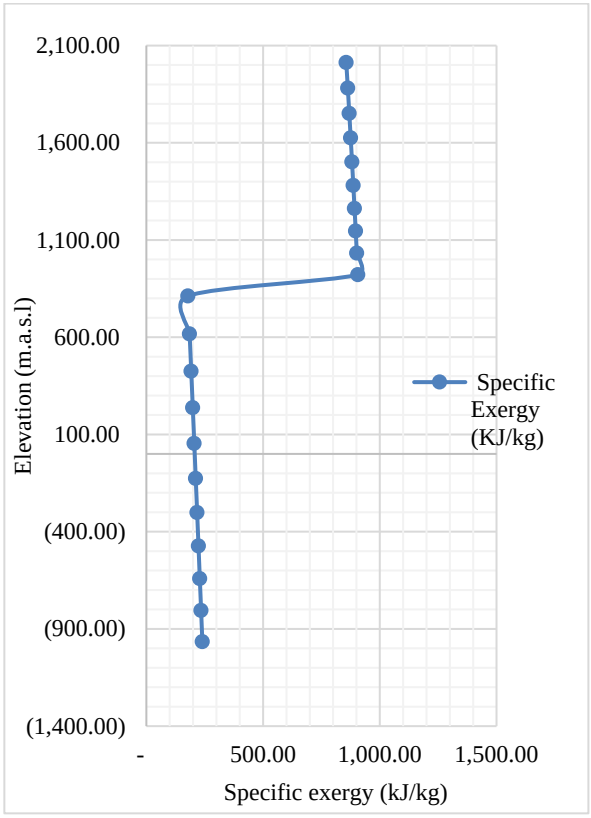


Figure 3: Exergy profiles of well OW-908.

Table 1: Results of simulated temperature and pressure of wells in Olkaria Domes.

Well	Wellhead			Steam	Water	Simulated	
	P (kPa)	T (ºC)	Enthalpy (kJ/kg)	flow rate (t/hr)		Bottom T (ºC)	Formation P (kPa)
OW-908	1,200	188		25.9	130	239	3,307
OW-921	1,184	187.36	1,698.20	48.7	58.5	267.52	5,295.1
OW-924	1,174	187		12.6	31.4	285	6,900

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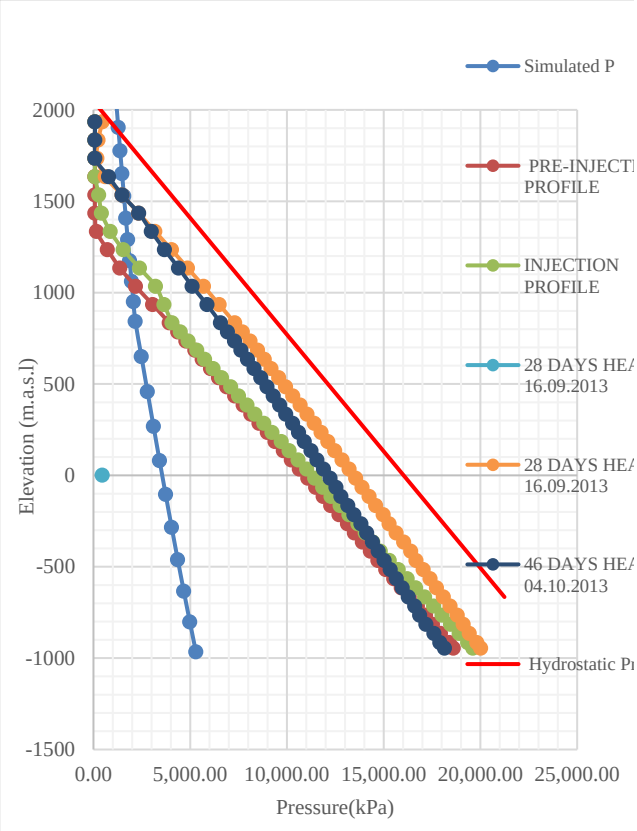


Figure 4: Pressure profiles of OW-921.

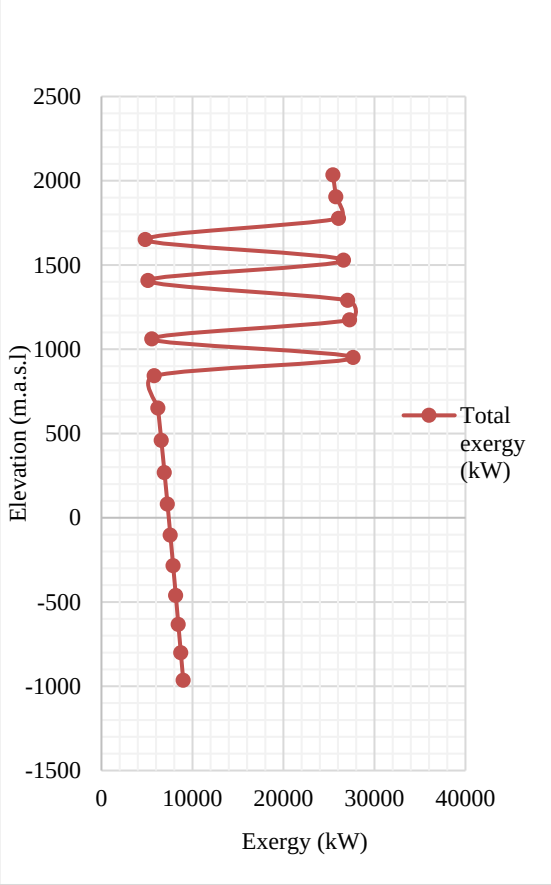


Figure 5: OW -921 exergy profile.

Figs 3, 5 and 7 shows the exergy profiles. The exergy profiles vary for each well and vary with depth because of the different thermodynamic parameters simulated. At differentpoints the enthalpy values are different because different pressures an temperatures.

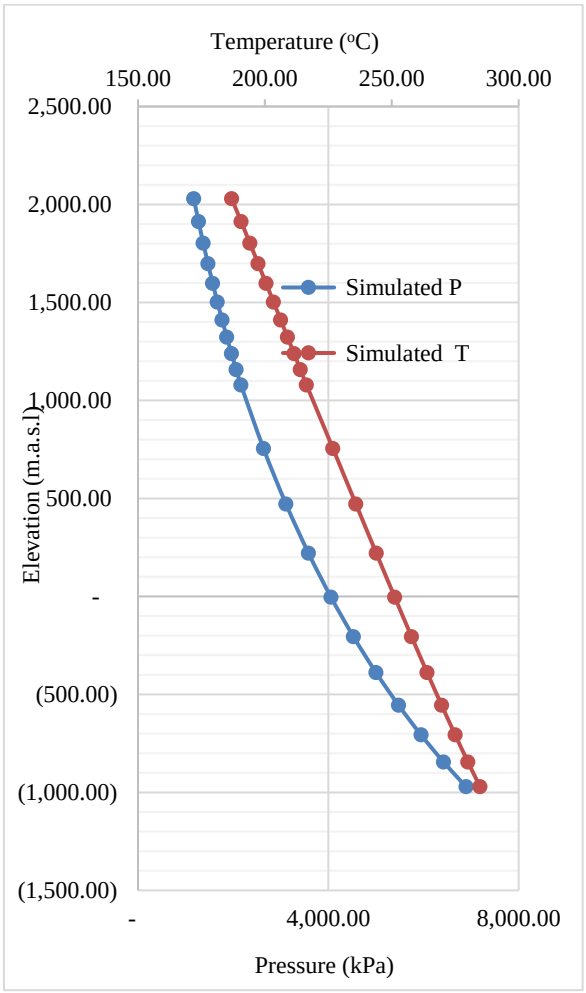


Figure 6: Well, OW-924 wellbore simulated temperature and pressure profiles.

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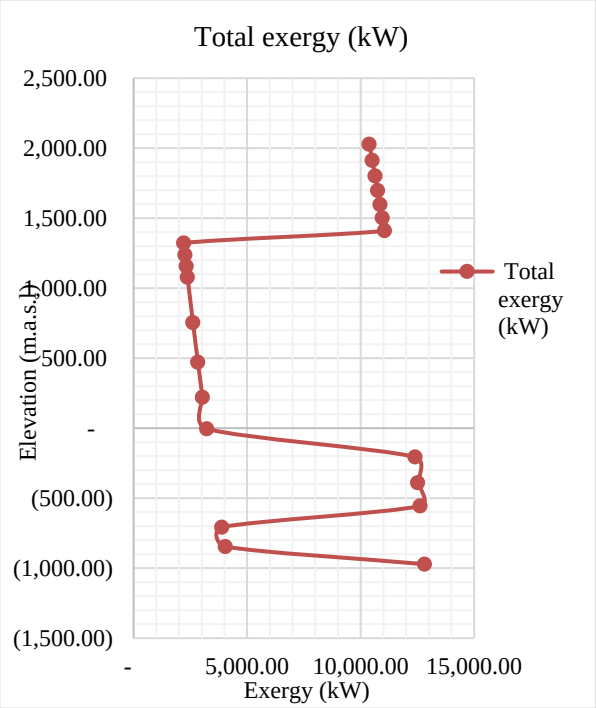


Figure 7: Well, OW-924 exergy profile.

For well OW-924, no downhole data was available to locate the feed zones or heat transfer zones.. The simulated exergy profiles show that the feeds zones are at different depths regions. The elevations 1,500-0 m.a.s.l is predicted to be the reservoir and convective heat transfer section from Fig.7.

For wells the OW-908 OW-921 and OW-924, the exergy profiles in the proposed reservoir section have negative gradients. The region loses the exergy as the fluid moves up the wellbore, indicating the heat or fluid is cooling with depth. The exergy profile with depth tool links the reservoir and wellbore as a function of enthalpy and entropy with reference to ambient conditions at the wellhead.

3. CONCLUSION

To link the surface and sub-surface more investigations on geothermal wellbore simulators need to be considered, and two-phase or geothermal steam resources can be analysed.

Exergy is a powerful tool to optimise geothermal energy, especially at surface facilities. The surface and sub-surface were linked using the exergy concept, the wellbore simulator.

A wellbore simulator was used to obtain temperature and pressure profiles of water-dominated geothermal wells in Olkaria Domes geothermal field. The exergy at any depth within the well was calculated in EES code using wellbore simulator results. Exergy profile with depth identified exergy losses and gains interpreted or predicted as either convective or conductive heat transfer zones.

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