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Geothermal energy potential of basement hot springs: Case study of Ulu Slim (Perak, Malaysia)

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Abstract: Interest in geothermal energy as a clean, renewable and stable source of energy is mounting as part of the strive towards carbon emissions reduction and transition away from fossil fuels. Hot springs occur in locations of active hydrothermal systems that may have exploitation potential and this paper assesses the potential of Ulu Slim hot-spring, the warmest of some 60 basement hot-springs reported across Peninsular Malaysia. Available data and analogue inferences i.e., hot-spring surface temperature and flowrate, applicable ranges in geothermal gradients, geothermometer indications of source temperature, hydraulic head differences related to surface topography, indicative and tentative fault and fracture dimensions, geometry and distribution, are summarized and supplemented by conceptual hydrodynamic- and thermodynamic-model calculations to bracket the possible range in key subsurface parameters like source depth and geometry and properties of the fracture system that control extractable heat. Results are then used in another mathematical model that simulates the heat-extraction and electric power potential of hypothetical wells drilled into the hot-spring source, supported by injector wells (re-injecting the cool waste stream from the powerplant). Model outcomes suggest that premature cooling due to fluid circulation through narrow fracture/fault corridors is a significant risk. Overall, study results suggest that utilizing the geothermal heat of hot springs like Ulu Slim for electric power generation may be not so straightforward. Maybe the search for attractive geothermal locations should be less guided by hot-spring locations but instead, driven by proximity to infrastructure and electricity demand.

Keywords: Hot springs, geothermal energy, fracture systems, data integration, thermodynamic model

INTRODUCTION

Hot springs occur in locations of active hydrothermal systems that may have potential for geothermal exploitation. At several locations worldwide (e.g., Iceland, Italy, Japan, New Zealand, Philippines, Turkey, US) hot springs have been successfully exploited for geothermal energy, initially for direct heating purpose and more recently for electrical power generation (e.g., Azhar *et al.*, 2022). As of 2020, some 20 countries used geothermal electricity generation with a total installed capacity around 16 GWe (gigawatts electrical) globally (Huttrer, 2021). Interest in geothermal energy as a clean, renewable and stable source of energy (independent of daily or seasonal weather variations) is mounting as part of the strive towards carbon emissions reduction and transition away from fossil fuels.

More than 60 hot springs have been discovered in Peninsular Malaysia (Bayoumi *et al.*, 2014) and it has been suggested that a number of them might have exploitation potential (Samsudin *et al.*, 1997). This paper assesses the geothermal energy-extraction potential of the Ulu Slim hot spring in Perak which has the highest reported surface-outflow temperature of all Malaysian hot springs (Samsudin *et al.*, 1997; Bayoumi *et al.*, 2014; Samuding *et al.*, 2016; Javino, 2016). The paper demonstrates how the integration of all available data and analogue inferences i.e., hot-spring temperature and flowrate, geothermometer indications of source temperature, applicable ranges in geothermal gradients, hydraulic head differences related to surface topography, indicative and tentative fault and fracture distribution etc. etc., no matter how sparse and tentative, can be supplemented by conceptual hydrodynamic- and thermodynamic-model calculations to bracket the possible range in key subsurface parameters like source depth and geometry and properties of the fracture system that control extractable heat. Results of this work are meant to illustrate the key uncertainties and challenges ahead for a potential exploitation of basement hot-springs (like Ulu Slim) to generate electricity.

GEOLOGICAL SETTING

The foothills of the Main Range Granite batholith of the Peninsular Malaysia contain more than 60 natural hot-springs of various sizes and temperatures (Samsudin *et al.*, 1997; Bayoumi *et al.*, 2014). In the area around Kampung Ulu Slim, located some 100 km north of Kuala Lumpur, more than 10 hot springs occur over a NE-SW trending

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area of about 8 by 2 km (Figure 1; Samuding *et al.*, 2016). The main Kampung Ulu Slim hot-spring where some 5 outflow points occur over an area of about 600 m^2, has a remarkably high and stable surface outflow of about 92°C brine temperature and volumetric flowrate (all outflow points combined) of about 27 litre per second (4-7 l/sec per outflow point; Samsudin *et al*., 1997; authors own observations). Conceptually, foothill hot-springs in granitic basement like the Ulu Slim system are believed to anchor to connected, fault-related fracture networks that allow surface discharge to percolate deep down into the granitic basement. Fluid flow is driven by hydraulic-head differences between the hot springs and recharge areas in the surrounding hills, supplemented by fluid-density differences induced by thermal heating of downward-moving fluid (Figure 2).

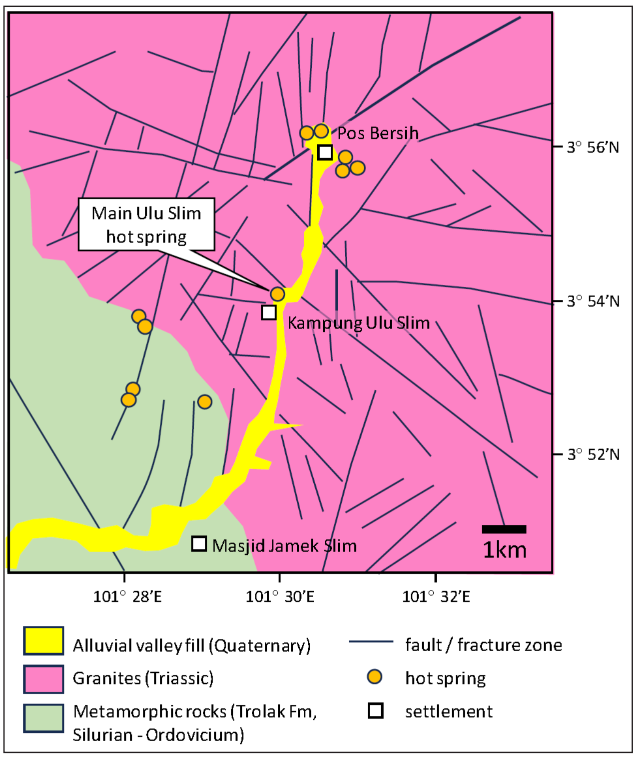


Figure 1: Geological map of Ulu Slim hot-spring and surroundings (modified after Samuding *et al.*, 2016).

DATA AND METHODS

Assessment of the geothermal energy potential of basement hot-springs involves consideration of a large number of parameters including hot-spring surface outflow temperature and flowrate, source temperature and depth, geothermal gradient, surface topography (driving hydraulic head), fracture network geometry and distribution, rock and fluid properties. Some of these parameters are much more difficult to estimate with some reasonable accuracy than others. The approach taken in this study is to start with those parameters that can be constrained to some extent from available data, and then deploy various types of modelling to force consistency across the dataset and assumptions and in the process, tentatively bracket the ranges in parameters for which little or no hard data is available.

Data on surface temperature and flow rates comes from site measurements made by the author: surface outflow-temperature was measured using a digital thermometer, volumetric flowrates were estimated by combining (for each of the surface discharge channels) estimated flow-velocity with measured channel cross-sectional area. Own observations were supplemented by open-domain reports (Samsudin *et al*., 1997; Bayoumi *et al.*, 2014; Samuding *et al.*, 2016; Javino, 2016). Geothermometer data that brackets the range in source temperatures (notably SiO_2 and chalcedony which are considered more reliable; Arifin, 2023 pers. comm.) were also sourced from these open-domain reports.

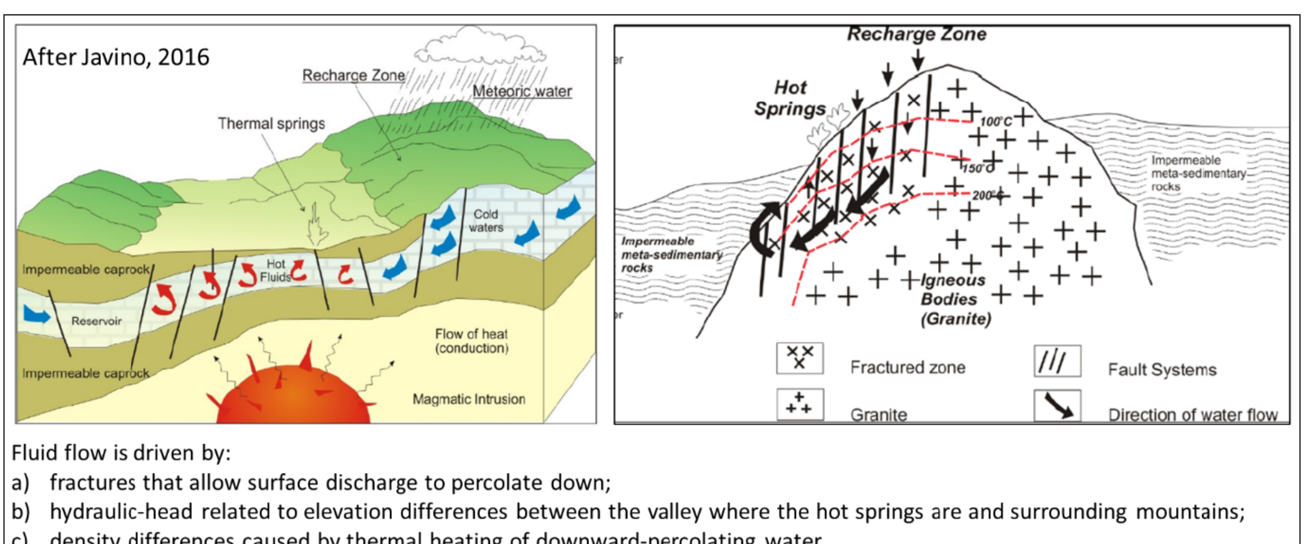


Figure 2: Conceptual model for fluid circulation in foothill hot-spring systems like Ulu Slim.

To estimate the anticipated range in geothermal gradients, geothermal gradients observed in petroleum wells around the Malay Peninsula (Madon & Jong, 2021; Jennings *et al.*, 2021) were correlated with isostatic gravity trend data (BGI, 2023) to extrapolate the trend across the peninsula itself (Figure 3).

Assumptions on fault zone / fracture corridor width and spacing of fractures within these corridors come from sparse outcrop observations in the region around Ulu Slim, similar analogues elsewhere in the region (Zhao *et al.*, 2001) and are compared to worldwide statistics on fracture corridors (de Joussineau, 2023).

Rock properties like density (2650 kg/m^3), thermal conductivity (3 W/(m*K)) and specific heat (800 J/(kg*K)) come from granite analogue data and rock trending studies (Chermak & Rybach, 1982; Cho *et al.*, 2009). Fluid properties like density (968 kg/m^3) and fluid specific heat (4273 J/(kg*K)) are based on the reported temperature and salinity of the hot-spring brine (Bayoumi *et al.*, 2014; Javino, 2016) combined with industry-standard correlations.

With the known outflow temperature and flowrate and estimated ranges in geothermal gradient, source temperature, fracture-corridor width, fracture spacing, thermal rock and fluid properties and estimated hydraulic head-related pressure, a mathematical thermodynamic model is deployed to bracket the ranges in two other important but difficult to estimate parameters: fracture-corridor length and fracture aperture. The model simulates the flowing-brine thermal gradient that evolves when fluid flows upward from the deepest point (the hot-spring thermal source) to the surface via one or more fracture corridors. On its way up, fluid travels through progressively cooler fractured rock and this results in conductive heat transfer from fluid to rock. In addition, flow velocities cause thermal in-equilibrium, i.e., a temperature difference across the fracture wall due to incomplete heat exchange.

Both these effects are captured in the thermodynamic model. The first step is to quantify the amount of thermal non-equilibrium by computing the convective heat-transfer coefficient on the fracture wall (h in W/[m^2*K]) as follows (Gaosheng Wang *et al.*, 2022):

$$h = 1.42 * 10^{-4} * (Re * Pr)^{1.12}$$

where Re is the Reynolds number, defined as $(\rho_{fl} * v_{fl} * W / 1000)/(\mu_{fl} / 1000)$

and Pr is the Prandl number, defined as $(C_w * (\mu_{fl} / 1000)) / \lambda_{fl}$

The heat-transfer coefficient is then used to estimate the heat exchange on the fracture wall (Q_h in kW_{th}) using the

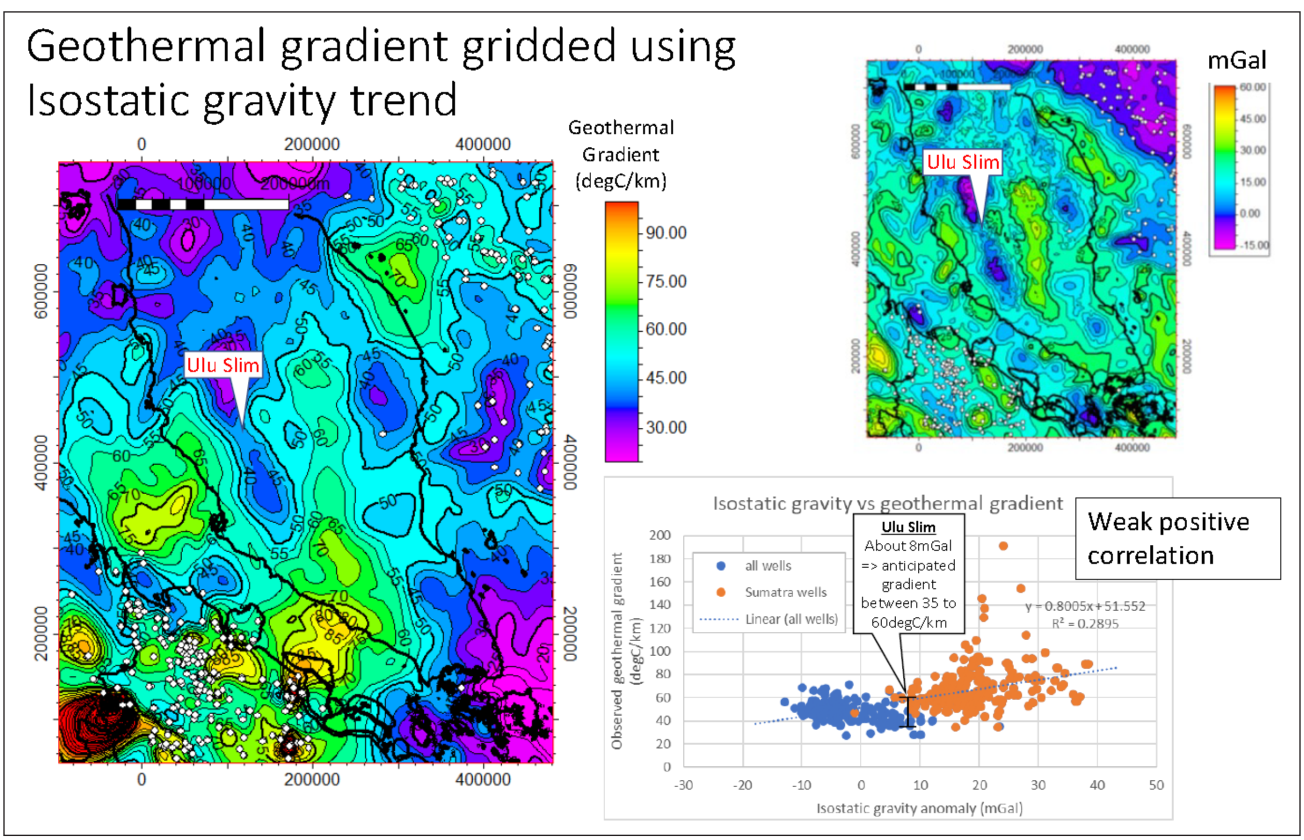


Figure 3: Geothermal gradient for Peninsular Malaysia and surroundings based on extrapolating the observed gradients in offshore wells (small circles) using the isostatic gradient map as a trend.

LTNE (Local Thermal Non-Equilibrium concept; Gaosheng Wang *et al.*, 2022), as follows:

$Q_h = h * A_{fr} * (T_r - T_{fl}) / 1000$

where h is the fracture-wall heat transfer coefficient, A is the fracture surface area, T_r is the temperature in the rock matrix away from the fracture wall and T_{fl} is the temperature of the fracture fluid-fill.

The total heat transfer per residence period (E_h in MJ_{th}) is then computed:

$E_h = n_{fr} * Q_h * t_{res} / 1000$

And used to compute the temperature difference across the fracture wall (T_{LTNE} in °C):

$T_{LTNE} = E_h * 10^6 / (C_w * q * t_{res} * \rho_{fl} / 1000)$

Note that this estimate of fracture-wall temperature difference assumes infinitely perfect conductive heat-transfer where the rock adjacent to the fracture wall is as hot as it is away from the fracture. In reality, conductive heat transfer will build a temperature gradient in the rock surrounding the fracture and therefore the rock adjacent to the fracture wall will be less hot than away from the fractures. To quantify this effect, the model computes conductive heat exchange in the rock surrounding the fractures (Q_c, in kW_{th}) using the non-equilibrium temperature difference on the fracture wall as a starting point:

$Q_c = k_r * A_{fr} * T_{LTNE} / d_z / 1000$

The total conductive heat transfer per residence period (E_c in MJ_{th}) is then computed:

$E_c = n_{fr} * Q_c * t_{res} / 1000$

And used to compute the final fracture-wall temperature:

$T_{LTNE\_final} = E_c * 10^6 / (C_w * q * t_{res} * \rho_{fl} / 1000)$

All computations of heat transfer and temperature are done at 10 m depth increments (hence, d_z is 10 m).

Some of the key parameters in the above equations are the Fracture surface area (A_{fr}), residence time (t_{res}) and the fracture volumetric flowrate (q). Volumetric flowrate at surface is known (27 l/sec measured at the hot spring) and used to estimate velocity in the fractures for a given set of assumptions on the fracture-cluster geometry (cluster length, cluster width, fracture spacing, fracture aperture) using relationships derived from cubic law assuming fractures as parallel plates (e.g., Snow, 1965; Lucia, 1983). Porosity of the fracture cluster (PhiF in fractions, assuming the host rock itself is tight) is:

$PHI_f = W / Z$ where W is fracture aperture and Z is fracture spacing

Fracture permeability (k, in D) equals:

$k_f = 84.4 * 10^5 * W^3 / Z$

Flow velocity in the fracture corridor (v_{fl}, in m/sec) equals:

$v_{fl} = (q/1000)/(l * w * PHI_f)$ where l and w are length and width of the fracture corridor.

Residence time per depth increment (dz, in sec) equals:

$T_{res} = dz / v_{fl}$

Finally, fracture surface area per depth increment (A_{fr}) equals:

$A_{fr} = 2 * l * dz$

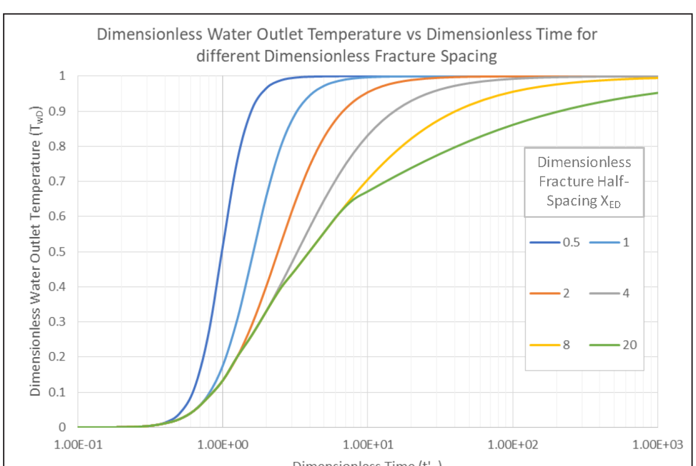
Table 1 gives a full listing of the parameters used in the model equations and their respective units.

Deployment of the thermodynamic model is as follows. For every realization (= set of input parameters), the model constructs a flowing-brine temperature gradient, starting from the (known) outflow temperature down into the subsurface until it finds the point where the brine gradient crosses the geothermal gradient (Figure 5). Whilst conductive heat transfer is highly sensitive to the fracture surface-area, the fracture-wall convective heat-transfer coefficient and also flowrate are mostly sensitive to the fracture aperture. These peculiarities are exploited to find best-match estimates of fracture-corridor length and fracture aperture, for each Low/Mid/High combination of the tighter-constrained parameters (source temperature, geothermal gradient, fracture-corridor width, fracture spacing; altogether $3^4 = 81$ cases; Figure 6). As to pressure in the model, hills around Ulu Slim reach altitudes of up to 1100 m some 16 km to the NNE of the hot spring (which is at 60 m above SL). Assuming frequent discharge (rain) would maintain a groundwater table not far below the surface topography, hydraulic-head could translate to a differential pressure around 10mPa (1500psi) at the hot-spring outflow point. In the thermodynamic model, this pressure is used as the driving force behind fluid flow and fracture parameters, notably aperture, adjusted to match the observed outflow rate at the surface.

With source temperature and depth, corridor length and fracture aperture ranges constrained, the next step of the assessment is to estimate the thermal energy-yield of a hypothetical producer-well targeting at source-depth. For this purpose, another mathematical model (for hot fractured rock, first developed by Gringarten *et al.* (1975) is deployed. The model assumes a box of fractured reservoir rock where water is injected at the bottom and then flows upward through the fractures to a producer well and it predicts the evolution of produced-water temperature with time (Everts, 2023, Figure 4). Besides the rock and fluid parameters listed in Table 1, additional key parameters used in the model are Q_d, the volumetric per fracture per unit of thickness (which

Table 1: Listing of parameters and respective units as used in the thermodynamic model equations.

Parameter	Description	Units
A_{fr}	Fracture surface area per depth increment	m^2
C_w	Fluid specific heat	J/(kg/K)
C_r	Rock specific heat	J/(kg/K)
d_z	Depth increment	m
E_c	Total conductive heat transfer per residence period	MJ_{th}
E_h	Heat transfer per residence period from LTNE	MJ_{th}
h	Fracture-wall convective heat transfer coefficient	W / (m^2*K)
k_f	Fracture permeability	D
k_e	Rock thermal conductivity	W / (m*K)
l	Fracture cluster length	m
λ_{fl}	Fluid thermal conductivity	W / (m*K)
μ_{fl}	Fluid viscosity	Cp
n_{fr}	Number of fractures in the cluster	
Qc	Conductive heat exchange in the rock surrounding the fractures	kW_{th}
Q_h	Heat exchange on the fracture wall from LTNE	kW_{th}
q	Volumetric flowrate	l/sec
ρ_{fl}	Density of fluid	kg/m^3
ρ_r	Density of rock	kg/m^3
T_{ro}	Host-rock temperature away from fractures	°C
T_{fl}	Fluid temperature	°C
T_{LTNE}	Fracture wall temperature difference from LTNE	°C
$T_{LTNE_}$final	Fracture wall temperature difference considering LTNE and conductive heat-transfer	°C
t_{res}	Residence time per depth increment	sec
v_{fl}	Flow velocity in fracture corridor	m/sec
W	Fracture aperture	cm
w	Fracture corridor width	m
Z	Fracture spacing in corridor	cm



Analytical solution proposed by Gringarten et al (1975) to predict the temperature T_w at time t' in a producer well a distance *z* above an injector well, in a fractured, hot- and dry-rock geothermal reservoir where:

Dimensionless Fracture Half-Spacing $X_{ED} = (\rho_w * C_w) / K_r * (Q_d/z) * X_E$

Dimensionless Time $t'_D = (\rho_w * C_w)^2 / (K_r * \rho_r * C_r) * (Q_d/z)^2 * t'$

Dimensionless Water Outlet Temperature $T_{wD} = (T_r - T_w) / (T_r - T_i)$

Figure 4: Mathematical model for heat extraction from hot-dry-rock by Gringarten *et al.* (1975).

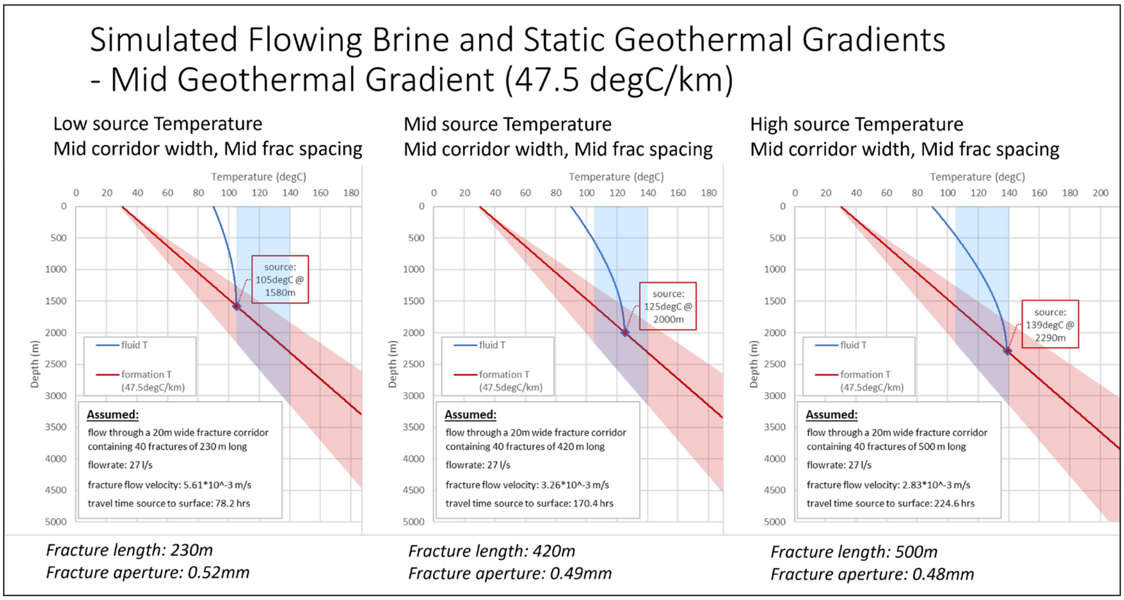


Figure 5: Example of flowing-brine thermal gradients computed with a thermodynamic model, for different assumptions of geothermal source-temperature contained within the range of geothermometer indications (blue envelope). All simulations are contained within the anticipated range in geothermal gradients (red envelope) and anchored to the observed surface-outflow temperature (92°C) and flowrate (27l/s).

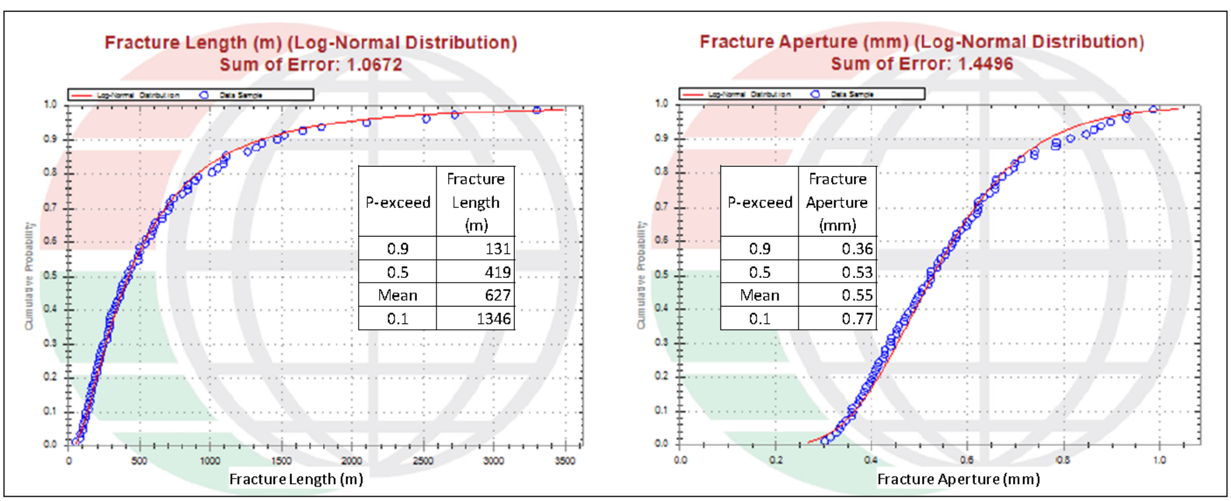


Figure 6: Multi-realization mathematical model-inferred ranges in length (left) and fracture aperture (right) of the fracture corridor through which fluids are believed to flow, upwards from the source to the surface location of the hot-spring.

is equal to the total volumetric flowrate divided by the number of fractures times the fracture length), T_w which is the outlet temperature of a geothermal well and T_i which is the temperature of the re-injected wastewater. A detailed description of this mathematical model goes beyond the scope of this paper and the reader is referred to Gringarten *et al.* (1975) original paper.

This model was run for the full range in outcomes of source temperature/depth, fracture spacing and corridor width and assuming an injector-producer well distance equivalent to the long end of the range in fracture corridor-length.

The final step was tentative estimation of the electric power potential of hypothetical producer wells. This combines prediction of produced-water temperature and thermal energy at the wellhead over time, with estimates of electric powerplant conversion-efficiency from analogues worldwide (Zarrouk & Moon, 2014).

RESULTS

Inferences on source temperature, depth and fracture system layout/properties

Geothermometer indicators from water-chemistry analysis suggest that the main Kampung Ulu Slim hot-spring complex (water flowing out at surface at 92°C from multiple outlets with a combined rate of 27l/sec) has a source-temperature between 105 to 140°C. Combined with the 35 to 60°C/km range in geothermal gradients anticipated for the Ulu Slim region from all available data (Figure 3), it follows that the depth of the hot-spring thermal source-point (the deepest point the percolating water reaches prior to flowing to surface) must be located somewhere between 1,250 to 3,140 m below surface (the area of overlap between the blue and red polygons in Figure 5).

The layout of the fracture system that presumably forms the flow path for water to percolate down from the recharge area to the source depth and then back up to the hot-spring outflow point at the surface, remains very speculative as the area is densely vegetated and there are no outcrops near the hot spring. Geological maps of the area (Figure 1; Samuding *et al.*, 2016) suggest the subsurface consists of granites with a network of tentative WNW-ESE and NE-SW trending fault/fracture lineaments (interpreted from surface topography). Interpretation of these lineaments remains rather speculative and sense of displacement (if any) is different to observe or verify due to difficult to assess terrain, intense vegetation and lack of consistent lithological contrast in the granite. Fault-related fracture corridors between 8 to 40 m wide are interpreted from inverted resistivity 2D images near Ulu Slim (Anukwu *et al.*, 2020), sparse outcrops in the wider vicinity of Ulu Slim as well as from granite outcrops and wells in similar settings elsewhere in the peninsula (Zhao *et al*., 2001). Fracture spacing within these corridors appears to range between 30 cm to 1 m. These inferences are reasonably consistent with fracture-corridor sizes reported from analogues elsewhere in the world (de Joussineau, 2023).

The thermodynamic model was then set up and run for each Low/Mid/High combination of source temperature, geothermal gradient, fracture-corridor width and fracture spacing, to yield the fracture-corridor length and fracture aperture that matches the source temperature and surface outflow rate. Figure 5 shows temperature-depth plots for three of the 81 simulations whilst Figure 6 shows the expectation curves for fracture-corridor length and fracture aperture from all 81 simulations. Note that the range in fracture-corridor length (about 130 to 1350 m, average 630 m) only refers to the corridor that makes the flow path from source to surface. Other fracture corridors which could be of similar or different lengths, presumably make the flow path from the recharge area in the surrounding hills to the hot-spring thermal source-point (at maximum depth).

Thermal energy potential for hypothetical geothermal wells

Estimation of thermal-energy potential of the 92°C / 27 l/s surface outflow at Kampung Ulu Slim can be done via straightforward multiplication of measured flow rate and temperature with estimated fluid density and fluid specific-heat. If the combined flow from all individual (4-6l/s) outlets could be routed to a binary heat exchanger of a power plant, the total thermal-power supply would be around 10,100 kWth (kilowatt thermal). Unfortunately, temperatures below 100°C are at the borderline of usability for binary powerplants when anticipated conversion-efficiency is very low (around 2%; Zarrouk & Moon, 2014). Hence, the tentative electric power-potential of the 27 l/s surface stream of Ulu Slim is only around 200 kWe (kilowatt electrical).

For the purpose of electric power generation, both the flowrate and temperature of the brine must be substantially higher than the Ulu Slim surface outflow. A well drilled towards the suspected source point could potentially achieve this. However, if such a well is produced at flowrates substantially higher than the initial surface outflow-rate of the hot spring, rapid pressure depletion of the hydrothermal system and eventual reduction in flowrates may result (as observed e.g. at Geysers in US; Gunasekera *et al*., 2003). To mitigate this risk and to dispose the plant waste-water outflow in an environmentally sound manner, reinjection of produced water may be required. The development concept would hence involve one or more injector-producer well pairs.

To estimate the thermal performance of a hypothetical injector-producer pair drilled into Ulu Slim hot-spring, I use the Gringarten *et al.* (1975) mathematical model for hot-dry-rock as explained in the Methods section. In the model, the producer and injector both intersect the same fracture corridor but some 1100 m apart, near the long end of the corridor-length range (Figure 6). The larger the distance, the more cold-water breakthrough will be delayed. However, too large a distance has the risk of injecting into a different fracture corridor which means, pressure and flowrate in the producer may not be maintained.

Some 27 model runs were made covering the anticipated range in key subsurface parameters (fracture corridor width, fracture spacing, source temperature). Additional sensitivities tests were made with regard to corridor length and rock thermal properties (thermal conductivity and specific heat). The well mass-flow rate was set at 60kg/s (about 62 l/s) and a 30-year project duration was assumed. Figure 7 shows

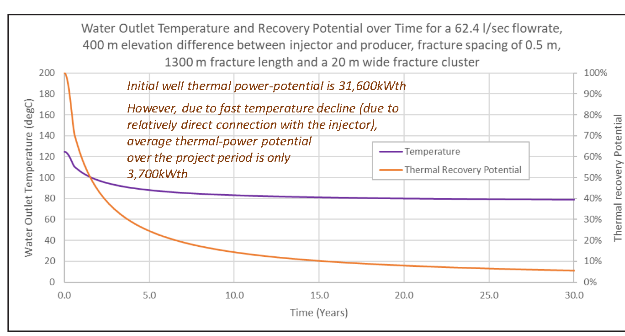


Figure 7: Predicted evolution over time of produced-water temperature in a hypothetical Ulu Slim geothermal producer. The well is targeted at source depth/temperature (about 2 km depth / 125°C), producing at a mass-flow rate of 60kg/sec (62.4 l/sec) and supported by a hypothetical injector drilled 1300 m away and 400 m deeper.

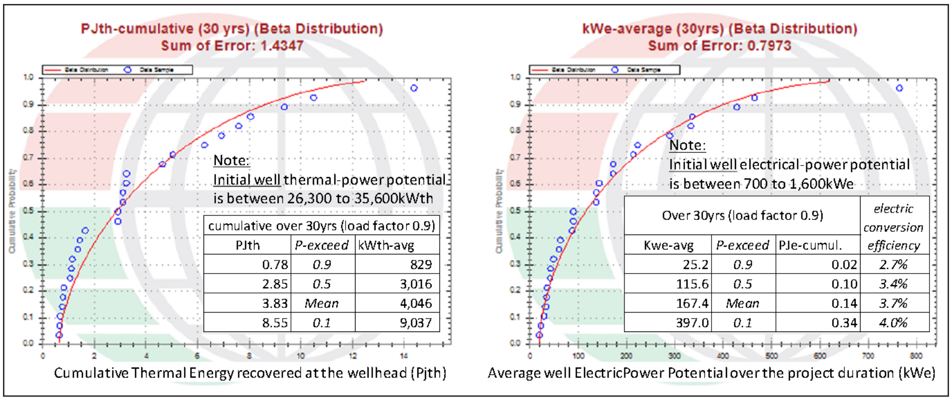


Figure 8: Cumulative exceedance probability for project-cumulative Thermal Energy (in PJth, left) and project-average Electric Power Potential (kWe, right) for a hypothetical geothermal producer-drilled to Ulu Slim geothermal source, assuming a 30 years project duration.

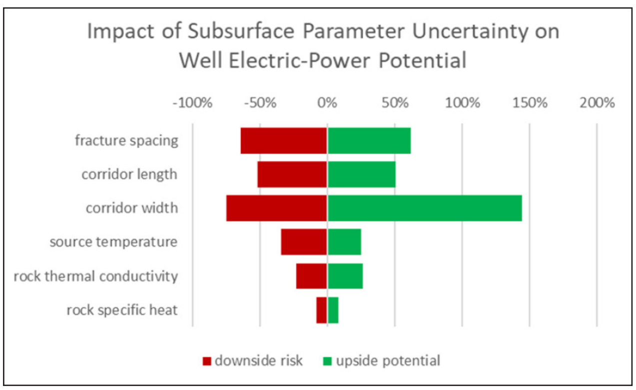


Figure 9: Sensitivity of Well Electric Power Potential to uncertainty in various subsurface parameters.

an example of recovered water temperature and thermal recovery potential over time simulated in the model.

Figure 8 shows the ranges in energy recovered over the assumed project-duration from the various model runs: probability curves for the total Thermal Energy recovered from the well (left-hand graph) and Electric Power Potential based on the model results combined with the electrical plant conversion-efficiency relationships by Zarrouk & Moon (2014; right-hand graph).

Figure 9 summarizes results of the sensitivity tests made with the model. Uncertainty in the geometry of the fracture system (especially fracture-corridor width) has by far the largest impact on the simulation outcome. The impact of thermal rock properties is less significant.

DISCUSSION

Whilst initial Electric Power Potential from the model-simulated wells (700 to 1,600 kWe) are considerably higher than the electric power equivalent of the Ulu Slim surface outflow (200 kWe), the simulated well average power potential over a 30 year project barely matches 200 kWe and in many simulation outcomes it is even lower. The reason for these disappointing results is, the fracture corridors assumed in the model (which, in turn, are based on matching the outflow data from the hot spring) are relatively narrow. Therefore injector-producer connection is rather direct and the volume of rock from which heat is extracted by the circulating water, is relatively small.

Spacing producers and injectors further apart might delay cooling of the produced water stream but as said, such a strategy is not without risk. Injecting into a different fracture corridor than the one its paired producer is drilled into, has the risk that pressure and flowrate in the producer may not be adequately maintained. Also, re-injected water could inadvertently break through to surface giving increased outflow at existing hot springs or creating new ones. The production history of Geysers in US (e.g., Gunasekera *et al.*, 2003) illustrate the complexity of withdrawal and re-injection management of a geothermal system.

Another option could be to drill deviated or horizontal wells that intercept multiple fracture corridors. In such a scenario, it would however become very difficult to understand and optimize injector-producer connectivity, i.e., the flowrate per fracture corridor. If one, relatively narrow corridor would dominate flow (like is often the case in complex fractured reservoirs), it might again lead to premature cooling.

What is clear, both from the sensitivity analysis results (Figure 9) and from above discussion, is that insight into geometry and distribution of the fracture network is critical to a successful exploitation of basement hot-springs like Ulu Slim. To maximize flowrates whilst minimizing the risk of premature cooling, producers and injectors should target parts of the fracture system that have good permeability but which are diffuse, i.e., avoiding direct pathways from injector to producer. Subsurface data required to deliver suchs insights may include resistivity or magnetotelluric surveys and/or seismic (preferably 3D) to better image faults in the granite, borehole image data in wells drilled to image the actual fracture intersections in a well and microseismic to detect fracture connectivity away from wells.

Acquiring such data could be involved and costly. Hence, utilizing the geothermal heat of basement hot-springs like Kampung Ulu Slim for electric power generation may not be so straightforward. Traditional hot-dry rock exploitation where hydraulic fractures are created in fresh granite around a producer well, with microseismic and other monitoring in place (to determine geometry and extent of the hydraulic fractures such that subsequent injector placement can be optimised), might actually be easier, more effective and less risky. Compared to attempts to exploit an permeable and connected but difficult-to-map fracture system with surface outlets like in a basement hot-spring system.

Maybe the search for attractive locations to harvest geothermal energy in Peninsular Malaysia should not be driven by hot-spring locations (in fact, avoiding them to not invoke the risk of the inadvertent flow of re-injected waste streams to the surface during exploitation) but instead, driven by proximity to infrastructure and electricity demand.

CONCLUSIONS

This case study assessing the geothermal potential of Ulu Slim hot-spring in Perak (Peninsular Malaysia), demonstrates how the integration of all available data supplemented by analogue inferences and findings from conceptual hydrodynamic- and thermodynamic-model calculations can lead to a better understanding of the range in plausible subsurface parameters and possible outcomes in terms of extractable heat. Hard data from Ulu Slim are limited to the observed fluid flow to surface (27l/sec from multiple outlets combined with an outflow temperature of 92°C) and estimated source temperature (105 to 140°C from geothermometer data). Other relevant parameters like rock properties, fracture geometry, spacing and aperture come from indirect inferences and/or analogues and have wide uncertainty ranges. Using a thermodynamical model, the range of depth of the hot-spring thermal source-point (the deepest point the percolating water reaches prior to flowing to surface) is inferred to range between 1,250 to 3,140 m below surface. Length of the fracture corridor that facilitates fluid-flow to surface is estimated to range between 130 to 1350 m (average 630 m). Aperture of the fractures is estimated to range between 0.36 to 0.77 mm (average 0.55 mm).

The 92°C surface outflow-temperature of Ulu Slim hot-spring is too low for efficient electrical-power generation using existing (binary) plant technology. Results of a mathematical hot-dry rock model simulating the performance of a producer-injector pair drilled towards the hot-spring source indicate an initial Electric Power Potential of 700 to 1,600 kWe, considerably higher than the electric power equivalent of the Ulu Slim surface outflow (200 kWe). However, the simulated well average power potential over a 30 year period barely matches 200 kWe and in many simulation outcomes, it is even lower. Rapid decline in simulated brine-temperature and hence, disappointing long-term energy yield is because fracture corridors assumed in the model (which, in turn, are based on matching the outflow data from the hot spring) are relatively narrow. Therefore injector-producer connection is rather direct and the volume of rock from which heat is extracted by the circulating water, is relatively small. Exploiting an obviously permeable and connected but difficult-to-map fracture system with surface outlets like a hot-springs system for electric power generation, may not be so straightforward. Hot-dry rock exploitation away from hot springs where hydraulic fractures are created in fresh granite around a producer well, with monitoring in place to help optimise injector placement, might actually be easier, more effective and less risky.

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CONFLICT OF INTEREST

The author has no conflicts of interest to declare.

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