Developing low temperature Geothermal projects in Indonesia using pumped well technology

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Abstract. Indonesia’s installed electrical-grade geothermal capacity is currently limited to developments at high temperature geothermal areas; however, survey data from Badan Geologi (Geological Agency of Indonesia) suggests that a large reserve of medium and low temperature geothermal resources also exists in the country. Using electric line shaft or submersible pumps, low to medium temperature geothermal fluids can be pumped from relatively shallow depths and electricity can be generated using binary power plant technology. This has been proven to be a commercially viable development approach for geothermal systems hosted in a range of geologic settings (e.g., structural/sedimentary basins, volcanic flanks, and metamorphic terranes), and are usually situated in regions of geologic structural complexity. The heat sources for these systems can be the conductive/advective heat transfer from a magmatic body or simply related to deep circulation of fluids in a non-magmatic setting. Lateral outflows of higher temperature geothermal systems are another category of low and medium temperature geothermal resources that may be attractive development targets, potentially allowing for the expansion of presently developed systems. This paper considers the utilization of pumped wells to exploit low and medium temperature resources considering recent trends internationally and with specific regard for the Indonesian context of this technology. As discussed herein, the commercial viability of pumped wells depends on the resource characteristics (namely temperature, depth, well productivity, and gas content) as well as a number of economic and development factors. We present results of modelling the potential productivity in terms of MW/well (net) for pumped wells over a range of permeability and temperature conditions and compare the results with typical high temperature self-flow wells.

1. Background
For electricity, geothermal production efforts have historically been focused on developing high temperature and high enthalpy resources utilising conventional steam (either dry steam or flashed steam) technology, and more recently binary and hybrid cycle plants (e.g., Ngatamariki, Olkaria III, Sarulla, and Cerro Pabellon). While low and medium temperature fields are common amongst newly developed projects internationally (e.g., Turkey, USA, and Honduras), none have yet been developed in Indonesia. Whether these can be commercially competitive against traditional higher temperature project options
is of significant interest given plans for increasing power generation from geothermal resources in Indonesia.

Most of Indonesia’s high temperature resources are associated with volcanic areas and have either been developed, are caught up in ‘red tape’ or are slow to move due to various financial or permitting issues. However, at least 2,000 MWe of low to medium temperature reserves are identified in Indonesia [2]. In fact, water-dominated systems with temperatures between 110 and 160°C are believed to be the most abundant geothermal energy resources globally [4]. Increasingly the projects being investigated in detail by Badan Geologi (Geological Agency of Indonesia) are reported to have modest temperatures and/or a higher degree of resource temperature uncertainty.

If Indonesia is to achieve its climate change commitments it will need to considerably increase the renewable energy contribution to the electricity grid. Given the importance of geothermal energy to Indonesia’s renewable energy portfolio, this will likely require a significant commitment to utilizing low and medium temperature geothermal resources for electricity generation.

In this paper we consider the viability of using pumped technology for developing geothermal systems in Indonesia with temperatures less than ~200°C.

2. International Trends
While most geothermal development has been at systems with resource characteristics that allow for self-flowing wells, the introduction of binary cycle plants over 35 years ago in the USA led to the development of several systems that were pumped and now have long operating history (e.g. East Mesa: 1980, Heber: 1985, Steamboat: 1986). The number of lower temperature (<210 °C) resources and pumped systems developed has been increasing in recent years so that now approximately 7 - 10% of all global geothermal generation comes from these types of systems, as documented in Figure 1.

![Figure 1](https://www.ThinkGeoEnergy.com)

**Figure 1.** Regions where <210°C geothermal reservoirs have been developed for power generation. Showing average reservoir temperature and net installed capacity (world basemap with highlighted geothermal regions from www.ThinkGeoEnergy.com).
Investigation of recently developed geothermal projects in the USA shows that the last known steam turbine plant in the country was commissioned in 2012. All nine projects developed since 2012 appear to be low temperature pumped projects and have tariffs lower than the final 50 MW steam turbine plant (USc/kWh 13), even when many have smaller units or stages (Table 1).

**Table 1.** Recent pumped geothermal projects in the USA and Honduras (partially derived from [6]).

| Field Name       | Development Name                      | MW (net) | Average Temp (°C) | Typical well depth (m) | Average MW/well (MW net) | Price (US¢ /kWh) | Power Provider       | Contract Start Date |
|------------------|---------------------------------------|----------|-------------------|------------------------|--------------------------|------------------|----------------------|---------------------|
| Jersey Valley    | Jersey Valley Plant                   | 10       | 165               | 950                    | 3.5                      | 6.6              | Ormat                | 2012                |
| Neal Hot Springs | Neal Hot Springs Plant                | 22       | 137               | 700-1100               | -                        | 9.6              | US Geothermal        | 2012                |
| San Emidio       | San Emidio Plant                      | 8.6      | 138               | 700-1000               | -                        | 8.9              | US Geothermal        | 2012                |
| Lightning Dock   | Lightning Dock Plant                  | 10       | 155               | -                      | -                        | 9.8              | Cyrq                 | 2013                |
| Cove Fort-Sulphurdale | Cove Fort Binary Plant (OEC-1, 2) | 25       | 150               | 1000-2300              | 4                        | 7.9              | Enel Green Power     | 2013                |
| Wild Rose        | Don A Campbell 1                      | 16.2     | 128               | 450-600                | 4                        | 9.9              | Ormat                | 2014                |
| McGinness Hills  | McGinness Hills - Phase 1, McGinness Hills - Phase 2 | 63.7     | 165               | 600-1000               | 6.5                      | 8.6              | Ormat                | 2015                |
| Wild Rose        | Don A Campbell 2                      | 19       | 128               | 450-600                | -                        | 8.13             | Ormat                | 2015                |
| Platanares       | Platanares 1                          | 30       | 177               | 650                    | 7.5                      | 10-13            | Ormat                | 2017                |

From this data, it is apparent that not only are pumped projects proving to be both technically and financially feasible, but also in some circumstances they may even have a lower cost than conventional flash plants. An important consideration is that developed case studies indicate that the average net MWe/well achieved are reasonable (even after a subtraction of the parasitic well pump load).

Many of these developments are producing from quite shallow reservoirs (<1000 m), which reduces the cost of drilling compared to conventional higher temperature systems. Some pumped developments utilize very shallow wells of less than 300 m depth (Salt wells: 150m, Mammoth: 200m) that are outflows from some upflow area, but that the outflow has proven most economical to develop.

While there will be geological and market cost differences between the US and Indonesia, the recent development history for pumped systems in the USA and other countries is indication that such systems may be feasible to develop in Indonesia, especially in the higher tariff regions.
3. Features of pumped well systems

Wellfield design of low temperature pumped systems are somewhat similar to conventional, higher temperature developments; they have production and injection wells separated by enough distance so that cool injection fluid will not unduly affect the temperature of the production wells, while being having enough hydrologic connection to offer pressure support. Injection is important to maintain pressure in production areas of low temperature fields, because any pressure drawdown will increase the amount of parasitic pumping power needed to lift the fluid and hence result in a reduction of the net power from the project. High permeability is also necessary in the reservoir to reduce the drawdown seen at the production pumps.

A typical pumped system is shown schematically in Figure 2. The production well(s) each have a downhole pump installed such that it stays below the water level under producing conditions (the amount that the water level drops under pumped conditions is related to its productivity index). The pump lifts fluid through a “riser” pipe above the pump, that is installed inside the well casing. Production wells need to have sufficient diameter to install the pumps, and will typically have production casing diameters of 13 3/8” or larger. The pumps normally also have to be installed in a vertical upper section of the well, even if the deeper part that accesses the reservoir is deviated.

The reservoir water is kept pressurised to avoid any flashing (to maintain original temperature and avoid calcite scaling) and pumped to a binary power plant where the heat is transferred to a closed-cycle working fluid (with a lower flash point temperature) that flashes and passes through a turbine, which drives an electric generator. The cooled geothermal fluid is then reinjected and the working fluid is
cycled through an air- or water-cooled condenser. Lower temperature binary developments typically utilize a production to injection well ratio of roughly 1:1.

The key resource performance indicators for pumped well systems are temperature, well productivity index and inter-well permeability. The well productivity index has a direct bearing on how hard the pump has to work for a required flow and as such dictates the parasitic power lost in driving the system.

The pump impeller must be set below the dynamic water level and this dictates the pump setting depth for reliable operation.

Equipment performance indicators include the mean time between failures (MTBF) of the pump. Fluid chemistry has a significant influence on the MTBF, as outlined in the experience of [12] at the Soultz EGS site in France.

The two main types of downhole pumps in use are lineshaft vertical turbine pumps (LSP) and electrical submersible pumps (ESP), distinguishable by the location of the motor. The former have been utilized extensively in USA since the 1970s (refer Figure 3), the latter are less widely used in geothermal applications but have been used in France, USA and Germany (refer Figure 4).

Both types have typical flow rate limitations related to well/pump diameter, motor power and temperature. Until recently, the typical flow limits for LSPs were about 150 kg/s, however, larger diameter LSPs capable of pumping >225 kg/s have recently been manufactured and installed at a few projects in the USA and Central America. Pumped geothermal wells are not presently used in Indonesia, but some of the companies that develop these projects in the USA and Europe are actively seeking or developing projects in Indonesia. It is reasonable to assume that they can bring or attract the services required for this type of production if they see the development opportunities pumped systems in the country.

There are relative advantages and disadvantages between the two types of well pumps as outlined in Table 2 (adapted from [1]), and these aspects can be the basis in selecting which pump type is preferred for a particular system.
Table 2. Lineshaft vs electrical submersible pumps

|                           | Lineshaft Pumps | Electrical Submersible Pumps |
|---------------------------|-----------------|-----------------------------|
| Max well depth            | Limited to ~730m| Relatively deeper > 1km     |
| Well deviation            | Production casing must be vertical | Deviated production casing possible |
| Time installation         | Time consuming  | Quick                       |
| Motor driver location     | At surface      | Down hole                   |
| Temperature capability    | High ~215°C     | Limited to ~160°C (higher claimed by vendors) |
| Pump and motor efficiency | Higher          | Lower                       |
| Wear prone                | Less (lower speed) | More (higher speed)          |
| Capital and O&M Cost      | Less expensive  | More expensive              |
| Maintenance schedule      | Predictable     | Routine inspection          |
| Flow rates                | Less (~150 kg/s) | More (~250 kg/s)            |
| Delivery pressures        | Up to 7 MPa     | Up to 7.5 MPa               |
| Environmental Impact      | Oil lubrication system used for shaft bearings | None |

The ESP temperature limit arises because the pump motor is submerged and the geothermal brine acts as a cooling fluid. Vendors have claimed pumps can operate higher than 160°C but this can translate into derating of the motor output and/or reduced MTBF.

4. Potential Resources in Indonesia

Potential geothermal settings for pumped well developments primarily include:

1. Hot sedimentary or naturally fractured aquifers in a variety of non-volcanic, but most ideally, high heat flow basinal settings. These are typically extensive in horizontal directions and can occur at any depth, but deeper is likely to be hotter.

2. Structural controlled systems that also may be in non-volcanic but most ideally high heat flow settings. Zones of structural complexity and associated steeply-dipping fault and fracture networks bring fluids that have been heated by deep circulation to shallower levels where they can be tapped by drilling into the fracture zone or perhaps into adjacent shallower aquifers being fed by the parent fault system. Examples of these types of systems occur along the Great Sumatran Fault system, commonly associated with extensional bends and pull-apart basins (Figure 5).
3. Lateral outflows from geothermal systems developed on the flanks of central volcanoes. Some high temperature convecting geothermal systems have considerable hot fluid outflows at shallow levels (often with strong lithologic influence), which is sometimes manifested as hot springs occurring kilometers away from a central volcanic edifice. A conceptual illustration of this type of system is provided in Figure 6.

Figure 5. Muraoka [11] noted the relationship of geothermal systems with major structures in Sumatra.

Figure 6. High temperature systems can have lower temperature outflows that may be developable with pumped wells.
While the “quality” of these resources in terms of temperature and resource capacity is often less than high temperature systems, the structural (2) and volcanic outflow (3) type systems can occur at relatively shallow depth and are likely to be in much more accessible terrain than many of the high temperature systems that have been developed to date in Indonesia. These important characteristics may make them more commercially viable than deep and remote high temperature systems in some regions.

While Indonesia has considerable surface volcanic activity, regionally elevated mantle heat flow and co-located major geological structures (such as the Great Sumatra Fault System) also provide favorable host settings for low and medium temperature geothermal systems. The results of Badan Geologi’s efforts to explore Indonesia’s geothermal resources reveal that many of the identified geothermal systems are lower temperature. Thus, further efforts to understand these systems in terms of their reservoir characteristics plus how they can be produced and developed for power generation is warranted.

Some examples of lower temperature systems and regions in Indonesia include:

- Ulubelu in South Sumatra is presented as example of a volcanic outflow system is noted by [7]. Although much of this system is higher temperature where it is presently feeding two power plants, it has downstream areas with lower temperature. Typically, such lower temperature outflows have been ignored as not being useful for power generation.
- Riogilang [13] note that two wells drilled into sediments and limestones hosting an outflow of Kotamobagu in North Sulawesi found temperatures of about 160°C and so would not flow naturally.
- Muraoka [11] note the presence of many geothermal systems particularly associated with 13 identified pull-apart basins along the Sumatra Fault Zone. There are often volcanic features in proximity to these systems because some of the magmatism is also influenced by these structures. However, many of the fields along the Great Sumatran Fault System appear to be dominantly structurally-controlled, rather than directly associated with central volcanoes.
- Herdianita [5] describe the low temperature system at Cisolok-Cisukaram in Java which may have once been a hotter convective system, but which now may be a ~160°C outflow system associated with permeable limestones.
- Humaedi [9] describe wells that have drilled a highly permeable outflow with temperature about 200°C from a hotter part of the Rantau Dedap system in Sumatra. This thick and permeable outflow is an example of the strong outflows that can occur from volcanic systems. If targeted at low elevations, these sorts of resources could present an attractive development target in some fields.

On the basis of temperature, an estimate of the potential resource for utilizing pumped wells for power generation can be inferred from [2] classification of geothermal resources in Indonesia, as shown in Table 3.

| Classification      | Temperature range | MWe  |
|---------------------|-------------------|------|
| Low enthalpy        | <100°C            | 850  |
|                     | 100°C to <150°C   | 2,660|
|                     | 150°C to 190°C    | 4,175|
| High enthalpy       | >190°C            | 16,134|
5. Well Productivity

[8] and [3] showed that the economic feasibility of a pumped well development depends on resource extent and temperature, permeability (in terms of well productivity), drilling depth and parasitic load, and pump reliability. For a case in Indonesia with reasonably positive parameters they estimated that a levelized cost of electricity could be around 10 to 12.5 US¢/kWh. This estimate was calculated making some assumptions regarding well productivity. We have conducted further analysis to determine what range of well productivity may be achieved in the Indonesian context.

It has long been recognized that self-flowing wells tend to have greater capacity at high temperatures than at lower temperatures. This is because the higher energy content at high temperatures helps drive the well flow (driven by fluid flashing and volume expansion) and also the reservoir fluid itself has more energy per unit mass. The result is that resources with reservoir temperatures <210°C typically cannot be developed using self-flowing wells as the obtainable flow rates are too low – exceptions are systems with elevated gas contexts (e.g., systems in the Menderes Graben, Turkey) and systems with shallow or artesian piezometric surfaces (e.g., Beowawe, USA).

Further to this, modelling of lower temperature self-flowing wells has highlighted that they can achieve useful production where water levels are high and good reservoir permeability is encountered. The implication is that lower temperature projects with self-flowing wells need to be developed in low elevations close to the hydrostatic water level of the reservoir, and not be designed to have wellpads on the ridgelines of steep terrain, for example.

Modelling of pumped and self-discharge well flows reported in the IFC report “Success of Geothermal Wells: A Global Study” from 2013 (Figure 7) was based on earlier work but showed a step change in well capacity as temperature increases and pumps reach their temperature limit (then identified at 190°C) and the production from self-flow wells was lower than pumped wells in the middle region around 200°C.

That work assumed a maximum pump set depth of 457 m and a maximum pump flowrate of 2,500 gpm (about 150 kg/s). This tended to limit the maximum capacity of any pumped wells to about 7.3 MW (net excluding pumped power – the IFC report is not clear about this distinction). Subsequently,
it is now common to set pumps deeper and also some manufacturers are working towards about 50% greater flows. Also, ambient conditions in Indonesia are somewhat different to the US (affecting the efficiency of the condensing cycle in the binary plant), so we have conducted some modelling to update these estimates of capacity for application in Indonesia.

5.1. Pumped Well Model
Jacobs has developed a model to analyse the performance of pumped low temperature geothermal wells feeding a binary plant. This models the process of extracting fluid from the reservoir, up the well, through the pumps, to the power plant and then back into injection wells and the reservoir. It will calculate the required pump setting depth for given assumptions of reservoir water levels, productivity index (PI), pressure drops in the wells and piping and for given boiling point and gas breakout pressure of the reservoir fluid. It can calculate the pumping power and net power from a modelled power plant including allowance for pumping power.

For this modelling, we have assumed one production well and one injection well in order to normalize the simulations in terms of MW/well. We have run this model for a range of flows and identified when the pump set depth or mass flow gets beyond assumed typical practical limits; for this work we have assumed that 150 kg/s is still a practical limit and a maximum set depth is 600m. These limits are both being exceeded now, but they have been utilized herein to provide a conservative assessment of the applicability of pumped well developments in Indonesia.

An ambient temperature average of 25°C has been assumed. The well depth assumed with this modelling was 1,200 m, however, this resulting MW/well of this modelling has a low sensitivity to well depth.

5.2. Model Results
The results are summarized in Figure 8.

**Figure 8.** Productivity of pumped wells as a function of temperature and productivity index (PI). This assumes a water level in the reservoir that is in hydrostatic equilibrium with the surface.
The MW presented are net after power plant parasitic power and pumping power are deducted from the gross generation of a typical binary plant.

These results differ from the [10] results as some of the deeper limits in terms of pump set depth are increased allowing for more generation at high temperatures, and at lower temperatures, the higher ambient temperature in Indonesia curtails the net generation compared to the IFC work based on US conditions (we assume). We note that two of the largest projects in the US and Honduras (see Table 1) are exceeding the MW/well results with an average of 6.5 MW/well at McGinness Hills (165°C) and 7.5 MW/well average at Plataanies (177°C). This indicates that the modelling done here is reasonably conservative and does not rely on particularly optimistic assumptions.

The results of this modelling are plotted over the [10] results (see Figure 9). The assumed average successful well MW/well numbers used in recent tariff modelling by GT Management are also included for reference. As a working guideline, 4 MW/well can be expected from 160°C systems and 6 MW/well from 180°C systems. It can be seen that the MW/well that may be expected for pumped wells with reasonable permeability reservoirs are comparable to the values obtained from self-flowing wells in low and medium temperature systems.

![Figure 9. Summary of the results of this modelling, overlaid on the [10]](image)

6. Financial Implications

The possible viability of pumped well geothermal projects in Indonesia using the well productivity estimated in this work has been tested with a financial model that calculates the tariff required by a developer in order to achieve their required IRR.

Using typical financial assumptions for a State Owned Enterprise (SOE) developer which has a lower required IRR and access to concessional finance, and assuming the following main input assumptions, our preliminary modelling resulted in a calculated tariff requirement of about 12 US¢/kWh:

| Table 4. Tariff Requirement |
|-----------------------------|
| Plant Capacity (MW)         | 40  |
| Well depth (m)              | 1,000 |
| Power plant ($/kW)          | 1,500 |
| Capacity per well (MWnet)   | 5    |
This is about 10% higher than a similar sized project high temperature project using typical costs and well productivity assumptions for that type of development.

Testing the sensitivity of the different key parameters showed that the well capacity (MW/well), project size (MW) and well depth (m) were the parameters that have most effect on required tariff (Figure 10).

![Tariff Sensitivity Against Base Case](image)

**Figure 10.** Sensitivity of the required tariff to variability of key parameters

### 7. Conclusion

This paper has outlined the current status of pumped well technology, typical areas in Indonesia where this technology is appropriate and estimates of expected well productivity.

Indonesia potentially has a large amount of low and medium temperature geothermal resources that traditionally have been overlooked in favor of exploiting high temperature magmatic resources. Low temperature systems have been developed internationally, and pumped systems have been the dominant type of geothermal technology utilized in projects in the USA over the last 5 years. In the USA such projects appear to be cost competitive, even while operating in a very competitive tariff market.

Modelling of pumped wells in Indonesian conditions shows that with reasonable productivity indices (i.e., moderate permeability of at least 20 tph/bar) it should be possible to achieve 4 to 9 MWe net per well over a resource temperature range of 160 to 200°C. Resources with temperatures less than 160°C may not currently be economic in Indonesia.

The reasonable indicated well power capacities (in terms of MW/well) and potential for drilling shallower wells at lower cost than is required at many typical high temperature projects indicates that pumped systems may be cost competitive with similar sized high temperature projects.

Preliminary financial modelling indicates that, with reasonably favorable conditions, it may be possible for a SOE developer to develop a project in a tariff regime of about 12 US¢/kWh. However, further economic analysis comparing the development with other traditional geothermal developments is warranted.
The findings of this study indicate that lower temperature resources may be attractive targets (from a technical standpoint) for pumped well developments in Indonesia if they meet the following technical criteria: (1) Resource temperatures over 160°C; (2) shallow/artesian piezometric levels, and / or the ability to site wellpads at low elevations relative to system hydrology.

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