Feasibility of Geothermal Energy Extraction from Non-Activated Petroleum Wells in Arun Field

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Abstract. The big obstacle to develop geothermal is frequently came from the economical viewpoint which mostly contributed by the drilling cost. However, it potentially be tackled by converting the existing decommissioned petroleum well to be converted for geothermal purposes. In Arun Field, Aceh, there are 188 wells and 62\% of them are inactive (2013). The major obstacle is that the outlet water temperature from this conversion setup will not as high as the temperature that come out from the conventional geothermal well, since it will only range from 60 to 180°C depending on several key parameters such as the values of ground temperature, geothermal gradient in current location, the flow inside of the tubes, and type of the tubes (the effect from these parameters are studied). It will just be considered as low to medium temperature, according to geothermal well classification. Several adjustments has to be made such as putting out pipes inside the well that have been used to lift the oil/gas and replacing them with a curly long coil tubing which act as a heat exchanger. It will convert the cold water from the surface to be indirectly heated by the hot rock at the bottom of the well in a closed loop system. In order to make power production, the binary cycle system is used so that the low to medium temperature fluid is able to generate electricity. Based on this study, producing geothermal energy for direct use and electricity generation in Arun Field is technically possible. In this study case, we conclude that 2900 kW of electricity could be generated. While for direct utility, a lot of local industries in Northern Sumatera could get the benefits from this innovation.

1. Introduction
The suitable well characteristics and abundance of ex-petroleum wells in several fields are why they are potentially a beneficial source of geothermal energy. Sumatera is a part of Pacific Ocean’s “Ring of Fire” and scattered with both active and dormant volcanoes. Estimates of the magnitude of the available Indonesian geothermal resource vary greatly. The 2007 West Japan Engineering Consultants study estimated the exploitable potential across 50 fields at 9,000 MW. In 2011, MEMR revised the country’s geothermal potential to 29,215 MW from 27,000 MW a decade earlier, indeed, the 27,000 MW figure is cited in many World Bank reports, and appears to be the basis for claims that Indonesia possesses 40\% of the world’s geothermal resources.

However, no matter what report that we use, Indonesia still has abundant geothermal resources that can help meet the country’s rising electricity demand and increase the electrification rates. Indonesia’s estimate of conventional geothermal resource base is generally considered to be among the largest in the world. This is why Indonesia has the potential to use geothermal resources not only to generate electricity but it can also be used to utilize the direct use and most of this potential is located in the Island of Sumatera.
Indonesia has a large number of geothermal fields and most ambitious plans for accelerated geothermal power development in the world: 4,000 MW by 2014-2015 and 9,500 MW by 2025. Figure 1 is a map of the country showing the most well-known geothermal sites.

However, there is a perception among some geothermal stakeholders and sponsors outside Indonesia that the resource related risk in geothermal development in Indonesia is substantial. Yet, we find no statistical basis for this perception, even though there are some 100 known geothermal fields and prospects in the country, and nearly 300 deep wells. This ambitious plan will require strong government support to materialize. Any shortfall in the expansion of geothermal power generation capacity will most likely be met by additional coal-fired power plants. Over the past decade, the government has intensified its efforts to scale-up and speed-up geothermal power development.

Despite government efforts, progress in the last few years was slow. The perception that the Indonesian geothermal program has stalled is widespread, and exists among many stakeholders. From 2010–2013, only 135 MW was added, and the best estimation suggests that by the end of 2016, no more than an additional 190 MW is likely. No power purchase agreements (PPAs) were signed under the 2012 FIT (feed-in tariff).

One of the main problem to develop geothermal is usually came from the economical viewpoint. The cost will mostly came from the drilling cost to make the well, which responsible for a big chunk of the project cost. Over the last decade, geothermal drilling costs have increased at unprecedented rates, which cannot be explained merely by any increase in depths or general inflation. The driving force has been the demand for drilling in the oil and gas sector, which has been reactivated by the increase in global oil prices and (in the US) by drilling for shale oil and gas (fracking).

Figure 2 is a histogram of the drilling cost per MW of successful wells in Indonesia, based on the correlation in GeothermEx (2004). It shows that the drilling cost per MW well capacity in Indonesia ranges from US$100,000 to nearly $2,000,000 the most probable range being $300,000 to $400,000 per MW.

When a petroleum reservoir is depleted beyond an economically feasible point, the wells will be abandoned, decommissioned, and reclaimed. These wells are sometimes referred to as abandoned or inactive wells. Abandoned petroleum wells are an enduring liability to oil/gas companies, as these companies are responsible for the possible environmental contaminations and litigations. Indonesia also has many these abandoned wells (around 13,097).

Compared to a conventional geothermal system, repurposing an abandoned petroleum well for a geothermal project can reduce the capital costs of the project by up to 50% (Bu and Ma 2012). It can also make a constructive use for an enduring liability. The capital costs for a geothermal project can be further diminished by employing a closed loop configuration (i.e. closed circuit of pipes), as it can be retrofitted to a single borehole. Alternatively, an open loop configuration requires at least two boreholes.
to operate, namely an injection well and an extraction well. Additionally, a closed geothermal loop does not require a water management system, compared to a compulsory water management system for open loop configurations. Closed loop configurations will also need less pumping power compared to an open loop configuration which requires overcoming gravitational head. Moreover, closed loop configurations can use a non-aqueous fluid to increase the rate of heat exchange with the earth.

The present study aims to do an early feasibility and engineering design study in optimizing the utilization of decommissioned wells to generate electricity and direct use in Arun Gas Field. The heat extraction on the outlet fluid temperature are determined. Total electricity generation potential are estimated using comparison method. Potential for direct use utilizations around this field are also investigated.

2. Conversion Issues

Unique measures have to be done in solving several technical constraints in converting a petroleum well into geothermal well.

Firstly, the reservoir area in a petroleum well will contain toxic and dangerous substances such as brine, oil, gas or even hydrogen sulfide. It will be a disaster if those fluids rise into the surface or contaminate the fresh water zone. Before conversion can be run, all connection between the well and formation has to be terminated. One way to do it is using cement plug. We must ensure that these plug is properly installed and will not leak or fail in the future.

Secondly, another issue in this conversion is the temperature. Most petroleum wells do not located in a high earth temperature gradient area. Thus their formation temperature is not as high as what available in the conventional geothermal wells, even in the bottom of those wells. Technologies such as binary cycle will be needed in order to utilize these wells for electricity generation.

3. Result

3.1. Indirect use

The best geothermal configuration for this conversion case is closed loop binary cycle which can be seen in Figure 3.

The fluid temperature that are expected from those converted wells will not be what we call as high temperature for electricity generation use. For this reason, the most prominent way of utilizing them is by using the binary cycle technology. Binary cycle is able to produce electricity using low temperature outlet fluid because it uses organic fluid (e.g. isobutene, isopentane or ammonia) in its system which has a very low boiling point compared to fresh water, thus making it possible to spin the turbine even with low temperature fluid.

Closed loop well configuration is used in term of increasing the efficiency. This means that it will neither produce nor inject any fluid into or from the formation. It helps to reduce impacts for the environment. Also, if compared to the conventional geothermal open loop, this closed loop will not let the fluid inside its pipe to interact with the environment so it minimize the possibility of contamination into the freshwater zone. Second reason is that it will prevent production related problems to happen such as scaling, pressure depletion or subsidence.

Another move is to improve the heat harvested from the formation by using spiral type heat exchanger in the bottom of the well. This type has proven to be the best configuration when compared with W-type, 2U-type or U-type heat exchanger, in case of efficiency. Average heat exchange rates for 100 hours of U, W 2U, and spiral type GHEs were 35.71 W/m, 40.76 W/m, 39.03 W/m, 76.80 W/m respectively (Lee, Seung-Rae et.al., 2013).

For its conductive grout around the spiral, silica sand is selected because it has a good conductivity and common setup for ground heat exchanger.

An analytical solution can be used, however some assumptions are needed. The first assumption is that because the spiral is located in the bottom of the well (ex-reservoir zone), we used constant average reservoir temperature instead of depleting depth-dependent temperature. The second assumption is that
there is no heat loss in this system because insulators are used to keep the precious heat and improve efficiency. The third assumption is the heat flow from the reservoir is equal to the heat given to pipe wall as well as fluid.

**Figure 3.** Process flow schematic for closed loop binary cycle.

Heat flow from the pipe wall in a length (dx) is expressed by (1):

\[ \dot{q} \pi D \, dx = h \pi D (T_0 - T) \, dx \]  

(1)

The heat given to the fluid is given by (2):

\[ \rho u_m c_p \frac{\pi D^2}{4} \, dT = \dot{m} c_p \, dT \]  

(2)

By setting both of the equation equal and integrating them from the start of the heat exchanger, we get (3):

\[ \int_{T_1}^{T_2} \frac{dT}{T_0 - T} = \int_0^x \frac{4h}{\rho u_m c_p D} \, dx \]  

(3)
The result of integration for distribution along the heat exchanger pipe is (4):

\[
\ln \left( \frac{T_0 - T_2}{T_0 - T_1} \right) = -\frac{4hx}{\rho u_m c_pD} \tag{4}
\]

\[
\frac{T_0 - T_2}{T_0 - T_1} = e^{\frac{-nhDL}{mc_p}} \tag{5}
\]

Where \( c_p \) is water specific heat (kJ/kg.K), \( D \) is heat exchanger pipe inside diameter (inch), \( T_0 \) is heat exchanger pipe temperature (°C), \( T_1 \) is water temperature at heat exchanger inlet (°C), \( T_2 \) is water temperature at heat exchanger outlet (°C), \( h \) is heat transfer coefficient (W/m².K), \( L \) = heat exchanger pipe length (m), \( \dot{m} \) is mass flow inside the heat exchanger (kg/s), \( u_m \) is overall heat transfer coefficient (W/m².K), and \( \rho \) is fluid density (kg/m³).

A good simulation for this is by doing it for the case in Arun Field, Aceh. Arun is a very mature gas field in Northern Sumatera that is currently on its closing phase. Their field profile can be seen in Table 1. The properties of spiral coil tube heat exchanger are shown on Table 2.

**Table 1.** Profile of Arun Field. (Soeparjadi R A 1982)

| Profile                  | Specification |
|-------------------------|---------------|
| Producing formation     | Limestone     |
| Mean Depth, m           | 3,048         |
| Productive area, acre   | 21,450        |
| Average net pay, m      | 153.3         |
| Average pressure, psi   | 7100          |
| Average temperature, °C | 178           |
| 2013 producing well     | 72            |
| 2013 non-producing well | 116           |

**Table 2.** Example specification of coil tube heat exchanger used in this case.

| Design                  | Specification |
|-------------------------|---------------|
| Heat exchanger diameter, m | 0.152         |
| Helical height, m        | 0.5           |
| Helical length, m        | 0.692         |
| Total helical            | 306.6         |
| Total heat exchanger pipe length, m | 212.248 |
| OD, inch                 | 1.25          |
| ID, inch                 | 1.1           |
| Average water \( c_p \), kJ/kg.K | 4.2       |
| Silica sand h, W/m².K    | 1.4           |

There is also a rule of thumb of maximum flow rate constraint inside a 1¼-inch coil tubing which is approximately 1 barrel/min (Ackert, D. et al., 1989).

\( T_1 \) or the heat exchanger inlet temperature is the independent variable, while \( T_2 \) is the dependent variable. Figure 4 shows the result of equation (5) adjusted with the condition and setup in Arun Field. We get the relationship between the inlet and outlet temperature of the spiral heat exchanger as:
Figure 4. Outlet temperature vs inlet temperature of spiral heat exchanger in Arun Field.

Table 3. Binary cycle plants around the world (Franco A and Villani M, 2009)

| Plant                 | T2 (°C) | Working Fluid | Brine Consumption | Gross Capacity (kWe) |
|-----------------------|---------|---------------|-------------------|----------------------|
| Nigorikawa, Japan     | 140     | R114          | 50 kg/s           | 1000                 |
| Otake, Japan          | 130     | Isobutane     | 14.7 kg/s         | 1000                 |
| Husavik, Iceland      | 124     | NH$_3$-H$_2$O | 90.1 kg/s         | 1700                 |
| Nagqu, China          | 110     | Isopentane    | 69 kg/s           | 1000                 |
| Altheim, Austria      | 106     | C$_2$F$_2$    | 86 kg/s           | 1000                 |
| Wabuska, USA          | 104     | Isopentane    | 60.025 kg/s       | 1750                 |
| Chena, USA            | 74      | R134s         | 23.16 kg/s        | 400                  |
| Kuthya-Simav, Turkey  | 145     | R124          | 121.8 kg/s        | 2900                 |

Which means that the average outlet fluid from a single conversed well in Arun is 2.65 kg/s with temperature of 170°C. If all the non-produced wells in Arun field are utilized, this conversion might produce about 296.96 kg/s of 170°C fluid. For comparison of the other binary cycle plants in the world that can be seen in Table 3.

It is clear from our result that Arun’s fluid production is greater and hotter than the biggest producer on Table 3, which is in Kuthya-Simav, Turkey. So it is realistic if we expect that the wells conversion in Arun is able to generate electricity more than 2900 kW.

3.2. Direct use
Geothermal also can be used as direct use usually for ground temperature normally below 180°C or in a case where the temperature is not hot enough to produce sufficient electricity. There are many examples of direct use and each of them has its own optimum temperature. One of the references about direct use activities that can be done at a certain temperature range is known as Lindal Diagram (Gudmundsson, et all, 1985). Based on this diagram, the direct use activities for the region around Arun gas field can be projected.

Basically, Geothermal is used to replace conventional energy like fossil fuel (oil or gas), wood, etc. Benefits we can get using geothermal are:

1. Less cost than most of other energies. According to Green Mountain Geothermal in 2014, Geothermal price is around 10$/MMBtu, while wood is 14.65$/MMBtu, Natural Gas 18.28$/MMBtu, and Fuel Oil $34.88/MMBtu.
2. High efficiency.
3. Less pollution. The emission of geothermal mainly only Carbon Dioxide and it is usually treated to reduce the concentration so it can be released to the air safely. While the other fuel also release dangerous gas like Carbon Monoxide, Sulfide Gas, etc.

Through a quick research, various activities around Arun Field will be able to gain benefits from the well conversion. Uses of geothermal in this area can be categorized into drying, heating, and cooling process.

3.2.1. Drying. In drying process, geothermal may able to replaces fossil fuel like oil and gas or other fuel, including wood. Temperature for this purpose usually around 95°C – 121°C. Benefits we can get using geothermal are:
   1. Less cost compared to oil and gas
   2. More efficiency compared to wood
   3. Less pollution

Examples of industries in North Sumatera that have been existed and need drying process in their business are:
   1. Lumber industry: To dry lumbers, after been cut, so it can continue its next processing steps.
   2. Pulp & paper industry: Pulp drying process.
   3. Desalination: To dry the seawater in producing salt.

3.2.2. Heating. This utilization is similar to drying, but in heating the temperature needed is not as high as in drying, only about 38°C – 66°C. Just as in drying, several benefits can be acquired from using geothermal in heating, such as lesser cost and pollution.

Industries in Sumatera that have heating process include:
   1. Biogas: To maintain optimum temperature in biogas processing.
   2. Aqua cultural: To be flowed into fish ponds in order to help stimulating growth of the fish.
   3. Recreational: To be used for recreational aqua activities.

3.2.3. Cooling. Beside for heating or drying, geothermal also can be used for cooling.
   1. Building Cooling and Water Heating
   2. Refrigeration

![Cost Per 1 Million BTU](image)

**Figure 5.** Energy cost per 1 Million BTU (Green Mountain Geothermal, 2014)
3. Soft Drink Carbonization: Lower temperature give better result because more gas CO$_2$ can be dissolved. Optimum temperature is around: 2 – 5°C.

Building cooling and water heating also refrigeration can be used not only for industry. These functions are common needs for everyone. But, if industry use these functions, the other benefit is it can reduce the operating cost. For example, a pulp and paper industry may not require cooling process in pulp and paper processing. But the function of geothermal in cooling can be used to cool the building or replace the air conditioner. With this, the operating cost for these things also can be cut so in overall, lower operating cost. As long as heating or cooling are needed in industries, there are wide possibilities that geothermal from this petroleum well to be useful.

4. Conclusion

This study used several assumptions such as neglecting heat loss, steady state heat source, uniform reservoir condition, sustain production, and single phase fluid flow. Thus, a more comprehensive and complex studies have to be done in assessing the next project feasibility. Economic assessment must also be made to know the worthiness of the project.

1. Petroleum well conversion in Arun Field is technically feasible due to its abundance of decommissioned wells and relatively high reservoir temperature.
2. To tackle some constraints in indirect utilization, special configuration is needed which involves heat exchanger, closed loop cycle and binary cycle generation.
3. Conversion in Arun Field is able to produce 2.65 kg/s, 170°C fluid, thus able to generate more than 2900 kW of electricity.
4. Using outlet temperature fluid around 170°C, several direct applications that can be used for industries around Arun Field are drying, heating, and refrigeration.

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