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WELLHEAD POWER PLANTS

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ABSTRACT

Wellhead power plants have been around for many decades in the geothermal industry. With the rapid expansion of the industry in Eastern Africa for the last decade the demand for wellhead power plants has increased. The modularity and simplicity of wellhead power plant allow for accelerated construction time and shorter time period from drilling completion to power production. Cost of a wellhead power plant is also similar to a large scale unit connecting multiple wells. However, the simplicity of the wellhead power plant affects its efficiency and ultimately the utilization of the geothermal resource. Another approach has been to use wellhead power plants for early generation in a geothermal field and replace them with a large scale power plant when enough steam has been secured and then mobilize the wellhead power plants to a new location. These two approaches influence the selection between technologies used for the wellhead generator, i.e. condensing flash, back pressure flash or an ORC type binary cycle. The article analyses cost of the wellhead power plants and cost scaling for early estimates as well as installation and mobilization time for the different power plant technologies. The analysis aims to assist geothermal developers in creating a geothermal field development plant taking into account possible use of wellhead power plant, large scale plants or a combination of both. For best results the strategy for wellhead power plants should be made clear from the beginning of field development. The strategy involves deciding whether the units shall be portable and thus temporary or permanent as this effects the size and in some cases the technology selected.

1. INTRODUCTION

Geothermal power has been utilized for centuries to generate electricity and currently around 13 GWe are installed around the world. As can be seen in figure 1 the installed power, based on reference data from geothermal turbine manufacturers (1980-2013), has increased in the recent years and is predicted to increase even more rapidly by 2020.

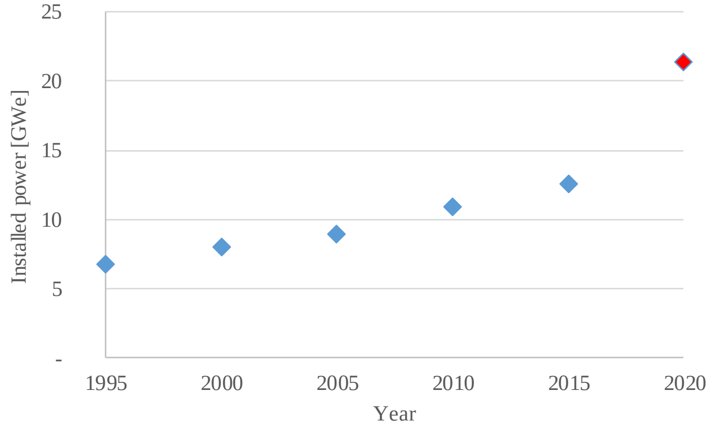

Figure 1: Installed and predicted future power generation with geothermal energy in the world (Bertani, 2015)

As can be seen in Figure 1 it is estimated that installed power will double in 2020. Utilizing geothermal power is often time consuming as the reservoir has to be proven before financing close can be achieved. In this aspect it can be of interest to install wellhead power plants and thus get early generation as well as continuously test wells for better understanding and modelling of the reservoir.

Small scale geothermal power plants are not a new concept but what can be considered innovative is installing them on wells normally intended for larger conventional power plants.

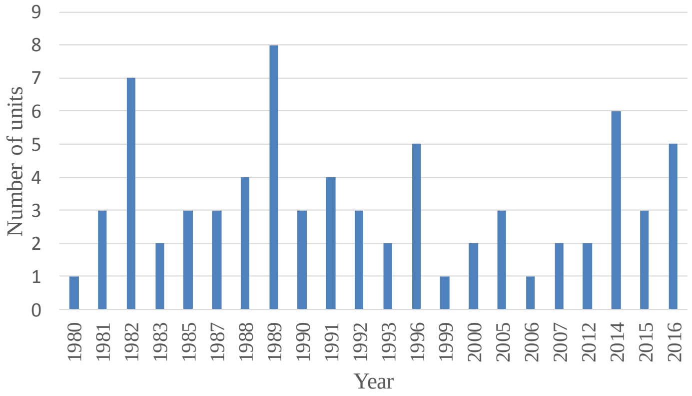

Figure 2: Number of installed power plants from various manufacturer (MHI, Fuji, Alstom, Ansaldo, Siemens, GEG, GE and Elliot, 1980-2012)

Wellhead power plants can either be a temporary installation which will be relocated to new well as conventional larger scale power plant is built or permanent wellhead power plant.

In this study comparison between wellhead power plants and the conventional large scale geothermal power plant is presented. Furthermore, the difference in using a wellhead power plant as a temporary or a permanent solution is discussed.

2. WELLHEAD GENERATORS

There are mainly three types of work cycles that are applied in electricity production in geothermal power plants. The work cycles are referred to as condensing, back pressure and binary (ORC). For wellhead power plant the same cycles are used.

2.1 Condensing (single flash) – description

Single flash turbines are the most common turbine type in geothermal power plants. A schematic diagram of single flash power plant with a condensing turbine is shown in Figure 2.

The two-phase flow of a geothermal fluid is piped from the production well to the separator (Stream 1), where the fluid is separated from the steam. The liquid is disposed into the reservoir through a re-injection well (Stream 4). The steam flows from the separator through a turbine (Stream 2) and electrical power is generated in the generator, coupled to the turbine. The steam then enters the condenser (Stream 3), where it is condensed at sub atmospheric pressure. This condenser provides cooling with cooling water circulating through a cooling tower.

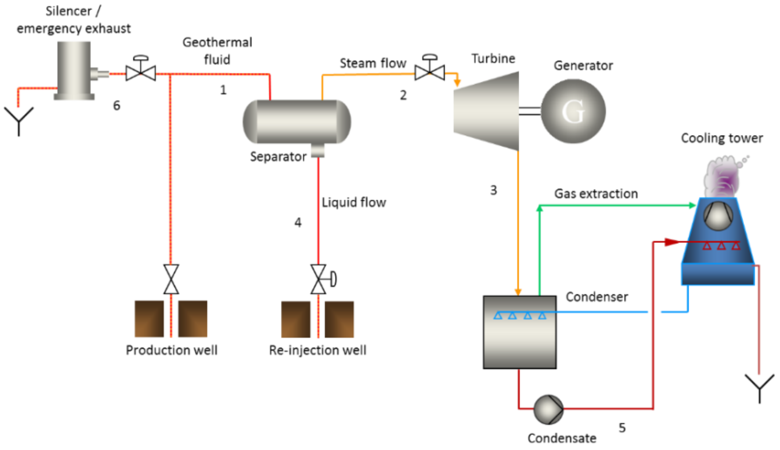

Figure 2: Single flash cycle diagram.

2.2 Back pressure

The back pressure power plant is in many ways similar to the condensing power plant, except there is no condenser and cooling system. A schematic diagram of a flash power plant with a back pressure turbine is shown on Figure 3.

A two-phased flow (mixture of geothermal steam and liquid) is piped from the production well to the separator (Stream 1), where the liquid is separated from the steam. The liquid is disposed into the reservoir through a re-injection well (Stream 5). The steam flows from the separator through a turbine (Stream 2) and electrical power is generated in the generator, coupled to the turbine. The steam then exhausts to ambient atmospheric pressure (Stream 3) in the steam exhaust. The condensate is then pumped to the re-injection well (Stream 4) and injected with liquid from the separator (Stream 5). The pressure of the stream exhaust from a back pressure power plant is above atmospheric pressure and the steam is not condensed. Since the steam is not condensed, the entire cold end not required and therefore, the cost of back pressure power plants is considerably lower than the conventional condensing power plant, but the available power form the well is not as efficient in condensing or ORC plant.

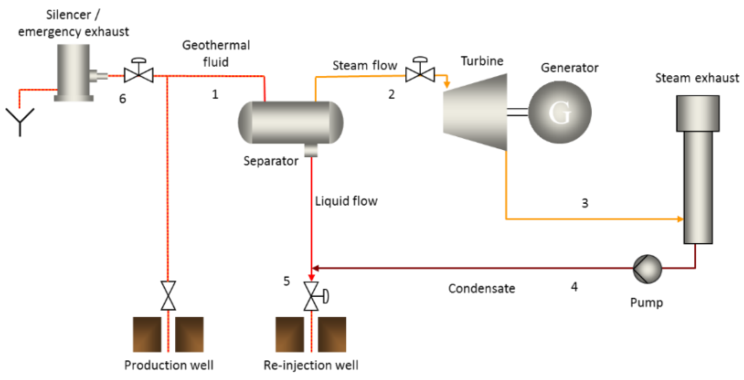

Figure 3: Back pressure cycle

2.3 Organic ranking cycle (Binary)

The binary power plants are significantly different from the back pressure and condensing power plants. A schematic diagram of Organic Rankine Cycle (ORC) binary power plant is shown in Figure 4 and Figure 5.

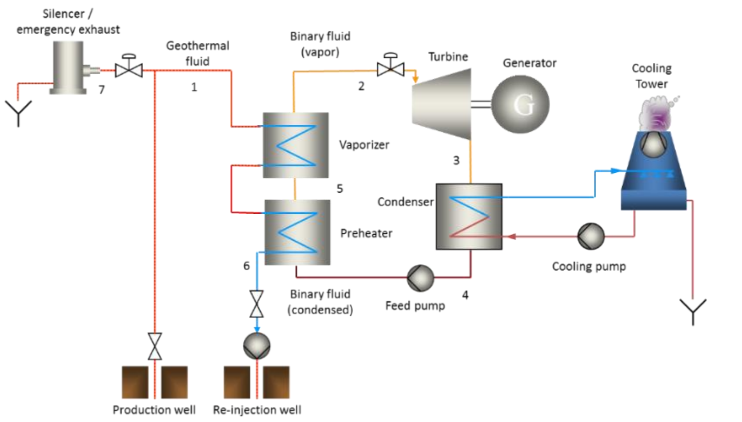

Figure 4: Organic Rankine Cycle (ORC) diagram with wet cooling condenser.

Stream 1 shows the path of the reservoir fluid through the production well. The binary working fluid is heated and evaporated in the vaporizer and preheater and piped to the turbine (Stream 2). The binary fluid impels the turbine and electricity is generated in the generator, coupled to the turbine. The slightly superheated binary fluid exits the turbine at lower pressure as Stream 3 and enters the condenser where it condenses back into liquid form (Stream 4). A feed pump circulates the condensed binary fluid to the preheater and then again to the vaporizer (Stream 5), repeating the process. The geothermal fluid is injected back into the reservoir (Stream 6) through a re-injection well.

The condenser requires cooling which may be provided by either water (wet cooling) or air (dry cooling) (see Figure 4 and Figure 5 respectively).

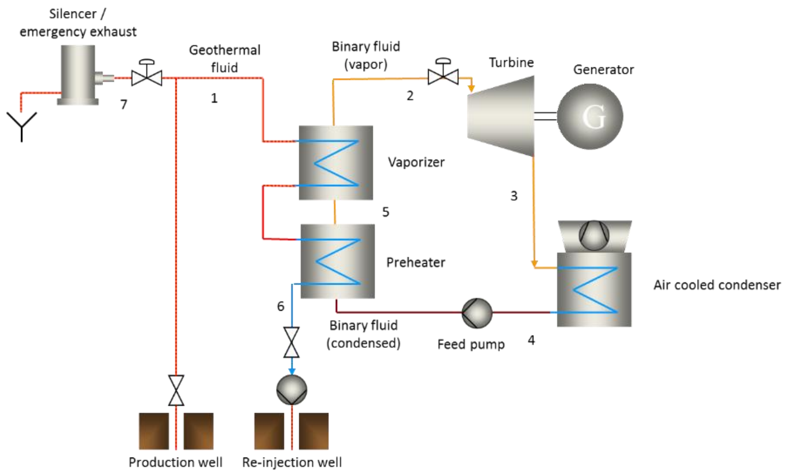

Figure 5: Organic Rankine Cycle (ORC) diagram with air cooled condenser.

Due to the heat transfer both in the preheater and the vaporizer the power regulation characteristics in the ORC plant is different from backpressure and the condensing steam plants.

3. COMPARISON TO CONVENTIONAL PLANTS

In the power industry, the rule of thumb is that larger equipment is less expensive (per MW) and more efficient. However, the geothermal wellhead power that have been available in the past years have had similar capital cost per MW, as large scale permanent power plants. This seems to be the result of simpler balance of plant systems and more modularized units. The smaller sized units do still have lower efficiency and can be expected to require more steam than conventional power plant. Example of steam rate comparison between a large scale plant and a small scale plant is presented in the Figure 7.

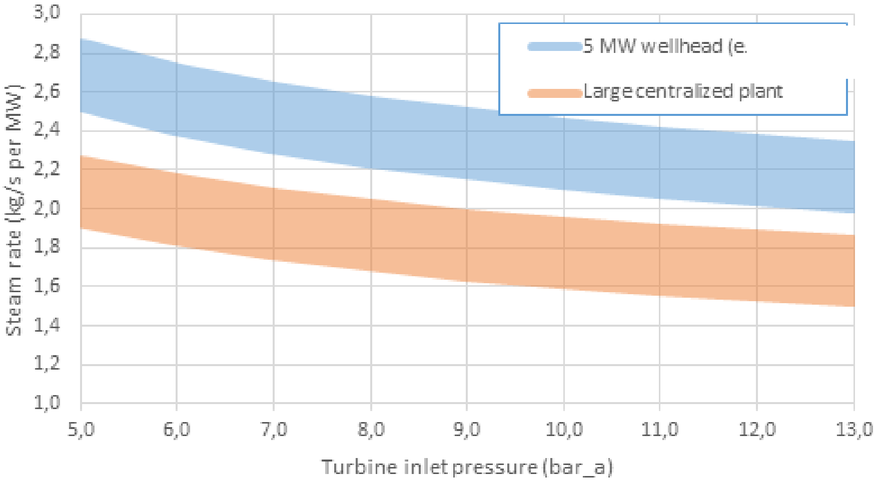

Figure 7: Example of efficiency difference

Higher steam rate per produced energy unit means that more wells need to be drilled in a field and the total field will have less total production.

For large scale power plants selection of separation pressure has significant impact on the efficiency of the equipment. In conventional power plants the characteristic curves of individual wells is analysed in order to select the optimal separation pressure. Figure 8 shows a collection of well output curves as a function of pressure. When a power plant, supplied by multiple wells is designed, a single separation pressure that gives the highest total output is chosen. The nature of geothermal wells is that they are rarely identical in characteristics, even though they are in the same field. As can be seen from the curves in Figure 8, a single pressure system means that not all of the wells are running at the optimal pressure. In some cases, there are wells that are not usable at the separation pressure because it is above their closing pressure. The lost output from a field can be 5-20%.

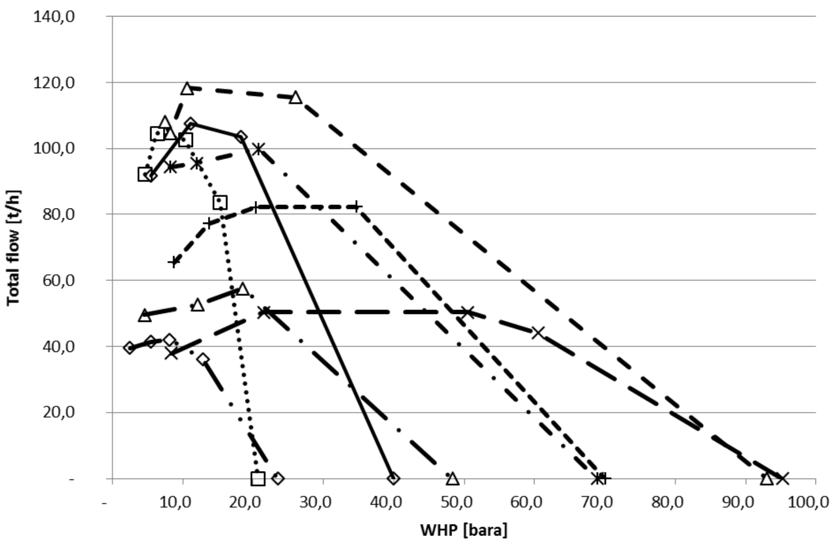

Figure 8: Example of well flow curves as a function of pressure

By using wellhead power plants for each individual well they can all be running at their own optimal pressure and none will be unusable due to low closing pressure. If this is done, it will help to increase the total output the field and will counter act to the lower efficiency that result from using smaller equipment.

Based on this, developing a field with wellhead instead of a large scale plant is an option. However, each field is different and has to be analysed separately. The more a field varies in well characteristics the more likely a wellhead plant solution to be more feasible than a conventional large scale plant. Furthermore, a mixed field development with both large scale and wellhead plant can be a viable option for many fields.

4. OTHER INFLUENCIAL FACTORS

When a geothermal project is developed, efficiency does play a large role to determine the amount of energy sold from the field. There are however many other factors that influence the projects. By using a wellhead power plant, many systems in the geothermal power plants are different from the conventional plant, such as geothermal fluid collection systems, control system and grid connections.

4.1 Geothermal fluid collection systems

Wellhead power plants are installed at the wellhead and therefore steam gathering system is minimal relative to the cross country piping required to gather steam and brine in large plants. This can decrease cost of piping system and pressure losses.

In geothermal plants the spent geothermal liquid needs to be disposed into the reservoir through re-injection wells. Re-injection is considered an important part of comprehensive geothermal resource management as well as an essential part of sustainable and environmentally friendly utilization. In wellhead power plants the reinjection fluid needs to be collected from each well pad and piped to the reinjection sites. This is a drawback of having distributed smaller plants.

4.3 Control system

If wellhead power plants are used instead of a large scale power plant, control and monitoring becomes more difficult as operations are distributed across the developed field. Each wellhead plant has a control system similar to the large scale plants and group of wellhead plants will most need a centralized monitoring system.

4.4 Grid connection

The connection to the grid can be a ruling factor in deciding if wellhead power plants are feasible or not. If several plants are installed a common substation should be envisioned in order to save cost and transmit the power at higher voltage. In many countries evacuating electricity to low voltage grid results in many trips of the plants and will have significant impact on the capacity factor of the plant. It is therefore essential to select the location of the wells with respect to potential connections to common substation.

For wellhead power plants the transmission lines from the plants to the substation will have visual impact and cause environmental impact, similar to the cross country steam gathering system of large scale power plants. It is however optional to put the power lines underground resulting in some additional cost. Such an option is currently not considered feasible for steam gathering piping.

4.5 NCG emissions

The CO_2 and H_2S emission is the same from each well regardless weather it is connected to a large power plant or a wellhead power plant. The main difference is that by installing wellhead power plants the emission is distributed over a larger area which can be beneficial for the disbursement of the gases.

5. PERMANENT OR MOBILE WELLHEAD POWER PLANTS

One of the problems that geothermal projects face is the high cost of drilling as well as the long time from when the first well is drilled until a power plant is commissioned. By using wellhead power plants, this time can be reduced, since the construction of the wellhead plant can start as soon as a single well has been completed (Carlos Atli Cordova Geirdal, Maria S. Gudjonsdottir, Pall Jensson, 2013). Furthermore, the construction time of a wellhead plant is typically less than for a large scale plant. Shortening the time from when capital is spent on drilling until revenue is generated does improve the overall economics of the power plant and can help the a geothermal developed to become feasible.

Some geothermal developers have used wellhead power plant for early generation, where the long term intention is to relocate once there is enough steam available for a large scale, more efficient, power plant. In that case the down time of the wellhead unit becomes very important, which depends on how much time is required to mobilize the unit from one site to another and re-commission. The time required to relocate a wellhead power plant is dependent on the technology and the complexity of the equipment to be relocated. In order to minimize the downtime of the plants civil works at the new location need to be ready when dismantling of the plant takes place. This leads to foundations being considered to be a permanent structure which has to be removed after relocation of the power plant. Wiring between equipment in the field has to be rewired but all internal wiring in cubicles and between cubicles in electrical container and on the turbine/generator can be considered to be portable.

Pipes are taken apart either at flanges connection or the pipes are cut apart. Where insulation has to be removed in the steam supply system new insulation will be fitted. The equipment in the steam supply has to be looked into when relocation is considered especially as it is not given that the pipes and equipment can be utilized at the new location e.g. control valves at the brine site depend heavily on the enthalpy of the well.

For this study the time required to relocate a wellhead power plant of 5 MW in capacity has been estimated for the three different technologies discussed in this study. Estimated time is presented in Table 1.

Table 1: Estimated downtime for different technologies

Technology	**Estimated relocation time**	**Estimated down time**
Condensing power plants	6 months	3 months
Back pressure power plants	4 months	2 months
Binary power plants	7 months	4 months

The time estimated assumes that the layout is kept approximately the same between power plant locations. It will take between 4-7 months to prepare, move and reconnect a wellhead power plant from one well to another, depending on the technology. That includes taking it down, moving it, putting it up and testing it at the new location.

The cost of moving a wellhead power plant is estimated to be 5% (mostly civil works, preparation and management) of the initial capital expenditure of the power plant prior to the shutdown of generation and 10% of the capital expenditure after the power plant has been shut down, i.e. in total 15% of the initial capital expenditure. The relocation cost was found after discussions with supplier of wellhead power plants and accounting for some unexpected expenditure e.g. new brine valve, measurements, minor road construction.

Based on this a back pressure unit is the quickest to relocate and a binary plant takes the most. Main influential factor in relocation is the complexity of the technology.

6. CONCLUSION

For best results the strategy for wellhead power plants should be made clear from the beginning of field development.

If standardized plants, envisioned as portable units, are purchased they are not intended to optimize the utilization of the resource but are considered a temporary solution until more efficient conventional power plant is commissioned. Their main goal is early generation, reservoir monitoring and data gathering. Relocation of wellhead units can take between 4-7 months depending on technology.

Permanent wellhead power plants should be considered in the overall feasibility of a larger conventional power plant and not as standalone projects. A combination of conventional power plant, permanent and temporary wellhead power plants are likely to be the most feasible option for geothermal field development.

REFERENCES

Bertani, R. (2015). Geothermal Power Generation in the World 2010-2014 Update Report.

Carlos Atli Cordova Geirdal, Maria S. Gudjonsdottir, Pall Jensson. (2013). Economic comparison between a well-head geothermal power plant and a traditional geothermal power plant. *Thirty eight workshop on Geothermal Reservoir Engineering, Standord University, SGP-TR 198*.

MHI, Fuji, Alstom, Ansaldo, Siemens, GEG, GE and Elliot. (1980-2012). Refernece list from manufacturer.