Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Study of an EGS Power Plant Preliminary Feasibility Design by an Assumed Productivity Index

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Keywords: EGS, productivity index, injectivity index, power cycle, binary power plant, ORC, design, well diameter.

ABSTRACT

A study is presented on choosing a well program and electric power cycle for a preliminary feasibility of an EGS electric power plant, before the reservoir characteristics are known. As no well has been drilled into the target reservoir, a way is presented for calculating the feasibility by assuming a productivity index (PI) of the proposed wells to get a comprehensive design with unknown reservoir parameters. Thus, the number of wells and fluid flow can be determined, allowing an optimized electric power cycle to be chosen. The study of the well profiles and surface systems is decoupled from the reservoir by assuming the productivity and injectivity indexes. Linear productivity and injectivity indexes are assumed and both indexes set to the same value, allowing for simpler calculations. Scenarios are calculated for different values of the indexes allowing the required index for the project to become feasible. Results show that a wide well diameter is the preferable option, because narrow wells are only advantageous for low a productivity index and then the total project becomes unfeasible.

This preliminary study is for an EGS Power Plant to be constructed in South Hungary, close to the municipality of Battonya. The project is co–funded by the NER300 funding of the European Commission.

1. INTRODUCTION

Drilling is costly and is usually started in the exploration phase of geothermal power plants. To finance the drilling and the exploration phase a preliminary feasibility study is done in the preparation phase to assist in obtaining financing, licensing, an environmental impact assessment, a drilling contractor and an initial infrastructure for the project. The remaining project phases are appraisal and construction phase, followed by operation (Sverrisson et al., 2013).

Before the first exploration well is drilled into the reservoir target, most of the reservoir parameters have to be assumed from similar reservoirs based on geology or from other wells in the area (if available). Thus, reservoir parameters, such as temperature, pressure, enthalpy, permeability, dissolved solids, salinity and gas content, are unknown and have to be assumed. All those parameters can have a large uncertainty and thus affect the preliminary study quantitatively in a substantial way. This makes the preliminary feasibility study difficult to perform because of the number of unknowns. It was decided to perform the preliminary study by choosing three different simplified injectivity and productivity indexes (see Chapter 2) and thus performing the study from parameters that are easily measured after the exploration well has been drilled. The injectivity and productivity indexes are assumed to represent the final production and injection performance of the wells in operation, but these indexes should only be taken as indications if measurements are carried out right after drilling the well and the well has not been given time to warm up. It is also expected that the reservoir fluid is liquid and that there is no two phase flow, which is usually the case for enhanced geothermal power plants and is for this case.

EGS Hungary Consortium is participating in a project co–funded by the European Commission (NER300 programme) for the construction of an EGS power plant, located in Battonya, South Hungary. Enhanced (or Engineered) Geothermal Systems (EGS) are engineered reservoirs created in a hot rock, with low permeability or porosity, where a fracture network is created or stimulated to allow fluid flow between injection and production wells. The fluid extracts thermal energy from the hot reservoir rock before being pumped to the surface, where it is utilized in a power plant for electric generation or for direct use of the thermal energy before being reinjected (Tester et al. 2006).

EGS Hungary Consortium, which consists of EU– FIRE kft. and Mannvit kft. (a subsidiary of Mannvit hf. in Iceland), in close cooperation with the Ministry of National Development in Hungary, have done a preliminary feasibility study of an EGS power plant in South Hungary. The project is a 7 MW_e EGS power plant, with 5 MW_e delivered to the grid. It is financed partially by NER300 funding, which is a financing instrument managed by the European Commission, European Investment Bank and EU Member States, which subsidize innovative low carbon energy commercial demonstration projects. The NER300 funding was financed by selling 300 million carbon emission allowances set aside in the New Entrants Reserve (NER). The application was awarded on the 18th of December 2012 and the total budgeted cost for the project is currently estimated to be €116 million, of which the funding from NER300 amounts to approximately €40 million.

2. PRELIMINARY PARAMETERS

All wells drilled in the area were hydrocarbon wells that were stopped when the granite layer was encountered. The granite layer is the reservoir target for this EGS power plant and the initial assumptions of the reservoir parameters are assumed based on the known properties of the top of the granite layer and other similar reservoir properties. The design is to drill at least 500 m into the granite layer, depending on the reservoir temperature encountered. The reservoir fluid temperature needed is 170°C at the power plant intake and the wells needed should have a total depth up to 4000 m with about 500 m open interval. The reservoir rock is expected to be a granitoid and partly metamorphic schist. More parameters are listed in Table 1.

Table 1: Battonya reservoir parameters.

Parameter	*Unit*	*Value*
Reservoir rock type		Granitoid and partly metamorphic schist
Temperature gradient above basement rock	°C	60
Calculated heat flow	mW/m2	105
Expected well depth	m	3500 – 4000
Distance to electrical grid connection	km	3

2.1 Injectivity and Productivity Index

The injectivity and productivity indexes are simplified from a wellbore model for single phase liquid reservoirs. The injectivity or productivity is assumed to stay constant with flow rate, which is often the case for liquid reservoirs and small pressure changes. These assumptions are still within the range of unknowns for an unknown reservoir and thus are good enough approximations for this preliminary study.

The injectivity and productivity indexes are defined as:

$$II = PI = \frac{W}{(P_f - P_w)} \tag{1}$$

where *II, PI, W,* P_f, P_w are injectivity index [kg/(s·bar)], productivity index [kg/(s·bar)], mass flow [kg/s], fracture (reservoir) pressure [bar] and well pressure [bar], respectively.

In the prefeasibility study the productivity index was varied from 0.5 – 2 kg/(s·bar) for all the simulations. The injectivity index was set the same value as the productivity index to reduce the number of simulation factors in the feasibility study.

2.2 Wells

The wells chosen for this reservoir type were narrow and wide programmed. The narrow program uses a ⌀6″ bit in the open hole section but the wide uses a ⌀8½″ bit. The well profile is shown in Figure 1 for both the narrow and shallow casing programs and the wide casing program is listed in Table 2.

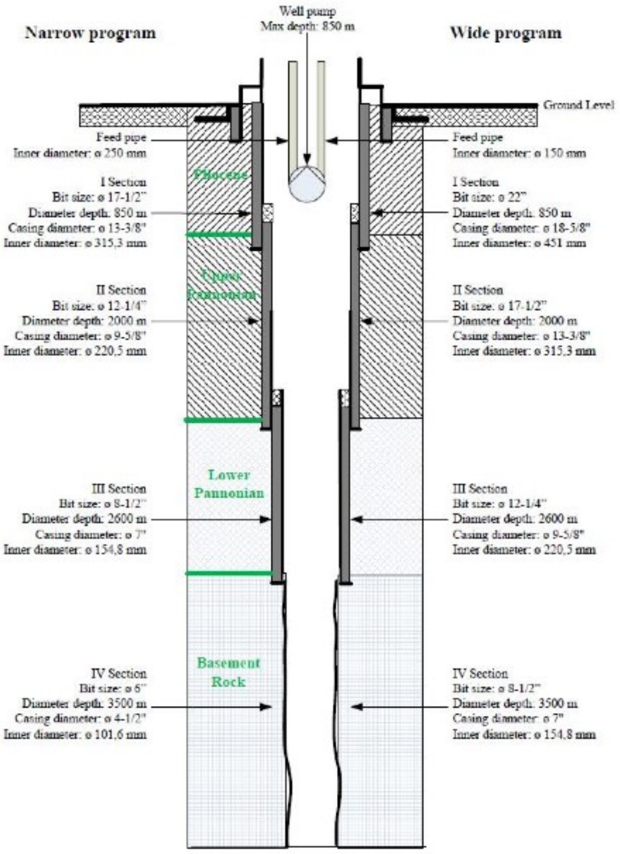

Figure 1: Narrow and wide well design parameters for the production wells.

The open hole sections may be cased off with a perforated liner if it is considered necessary after drilling the well. The reservoir liquid is pumped up with an ESP (electrical submersible pump) set to 800 m depth. This limits the reservoir fluid to 180°C to prevent excessive wear on the pumps due to the temperature, obtaining commercial pumps that are reasonably priced. Each pump is limited to 450 kW of pumping power.

Table 2: Wide casing program.

Section	*Casing*	*Casing depth [m]*	*Section length [m]*	*Bit size*	*Casing OD*
I	Surface casing	0 – 30	30	Hammered	30”
II	Intermediate casing	0 – 150	150	22" or 26"	18⅝"
III	Anchor casing	0 – 1300	1300	17½"	13⅜"
IV	Production casing	0 – 2600	2600	12¼"	9⅝"
V	Production liner	2500–3500	1000	8½"	7"
VI	Open hole	3500–4000	500	8½"*	-

** Opened up, 6" for the narrow program*

3. RESULTS

Simulation results showed that the cost was highly dependent on the productivity and injectivity indexes and a total of 160 kg/s of reservoir liquid was needed at 170°C average temperature. The main effects of the productivity and injectivity indexes were on the number of wells needed to supply the power plant for the generated capacity, as expected.

3.1 Power Cycle

Organic Rankine cycle (ORC) will be used to generate 7 MW_e of electricity of which 5 MW_e are to be delivered to the grid, which is about 70% of the total generated electricity. The ORC cycle uses isopentane as the binary fluid. About 30% is lost to parasitic loads, where pumping the reservoir liquid requires the highest load.

The ORC power cycle is shown in Figure 2 where the reservoir liquid is pumped up in production wells and returned back to the reservoir through injection wells. About 160 kg/s of reservoir liquid at 170°C is needed to generate 7 MW_e and it is returned at 90°C. The power cycle may be changed to utilize the fluid more effectively and as a result return it colder. The reservoir fluid is kept at pressure above its flashing point to prevent flashing, and thus scaling from dissolved chemicals. There is also a booster pump to add make-up water for the water losses in the reservoir which can occur a lot for EGS projects. The prefeasibility study assumed the water losses to be 15% of the total produced flow, which is in the higher range of known losses (Driscoll and Middlemis, 2011).

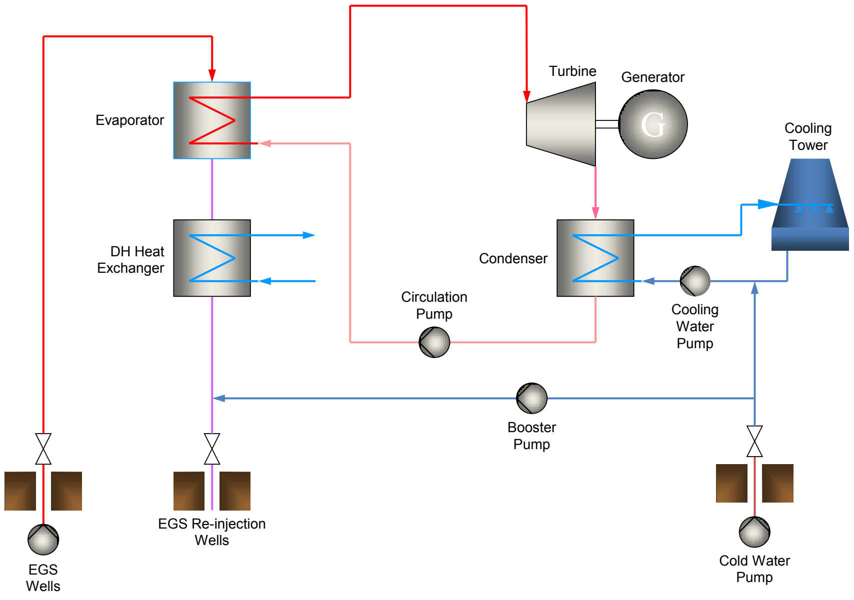

Figure 2: Process flow for the EGS power plant process with isopentane ORC. A heat exchanger for cogeneration is shown but it is not used in this study.

The cold end of the power cycle is planned as a water cooled condenser with an accompanying air cooled cooling tower. An air cooled condenser may be considered for a revised design. The average wet bulb temperature is 11°C and the tower cools the water from 41°C to 21°C before returning it to the condenser. The efficiency of the electric generation cycle is 11.4% and the total efficiency of the EGS cycle including well pumps is 9.1%.

3.2 Productivity Index

The simulation of the total flow and electric generation is sensitive to the productivity index. The results of the simulations are shown in Figure 3, where the wide casing program becomes more feasible when the productivity index increases above 1 kg/(s·bar) and before that the narrow wells were more feasible due to the total parasitic load from pumping the reservoir fluid to the surface. The jumps that appear in the figure show when an additional well is subtracted to sustain the total reservoir liquid flow required.

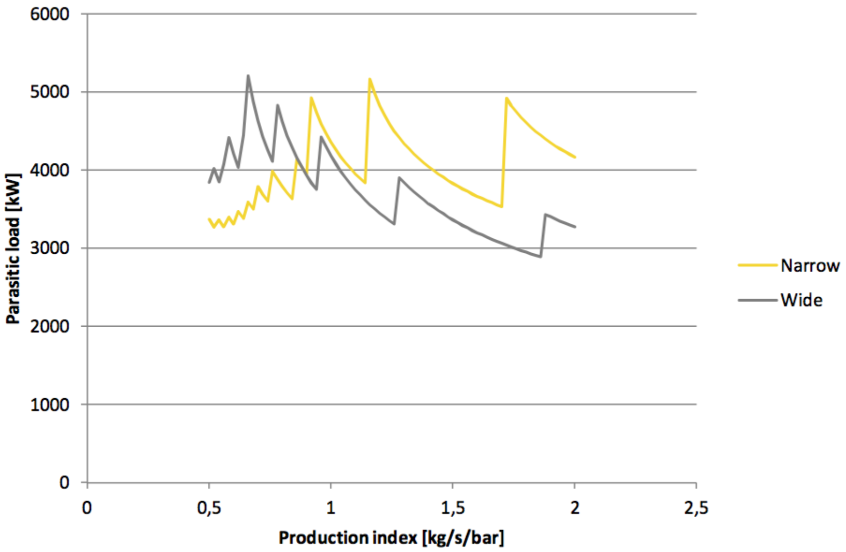

Figure 3: The effect of the parasitic load increasing with lower productivity index and well profile.

But the drilling cost has also to be taken into account and that is shown in Figure 4. The drilling cost for wide wells is assumed to be 17% higher than for narrow wells. The figure shows that the wide wells are more effective if the reservoir has a productivity index higher than 1.2 kg/(s·bar) because fewer wells are needed to sustain the total flow needed for the power cycle. If the total drilling cost exceeds 25 million EUR then the total project becomes unfeasible. Thus, it may be concluded from these simulations that the narrow program is not feasible at all and wide wells should only be considered in subsequent planning. Also, a productivity index below 1.2 kg/(s·bar) would result in an unfeasible project. Further work and feasibility design do not need to consider the narrow wells which results in simplification of planning the drilling operations. It is also beneficial to have such a simple metric to be able to have an idea if the project is not sustainable if the first reservoir creation and fracturing would not result in more than the 1.2 kg/(s·bar) productivity index.

The results of the simulations are listed in Table 3. The results are shown for two different productivity indexes, 2 and 1 kg/(s·bar).

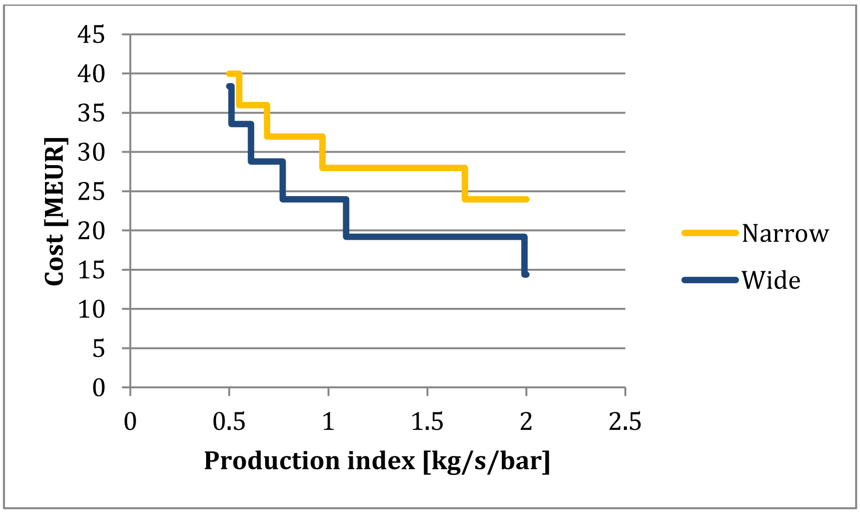

Figure 4: Cost of drilling in relation to the productivity index and well program.

Table 3: Simulation results for different productivity indexes.

Productivity index [kg/(s·bar)]	**2**	**1**
Power$_{net}$ [MW$_e$]	5	
Well Program	Wide	
No. of production wells	3	5
Well pump depth [m]	850	850
Turbine (Power$_{gross}$) [kW]	7 070	6 970
Evaporator [m^2]	2 500	2 500
Condenser [m^2]	3 200	3 100
Circulation pumps [kW]	290	290
Cooling tower [kW]	160	160
Cooling cycle pumps [kW]	130	130
Make-up water pump [kW]	70	60
Booster pump [kW]	40	40
EGS well pumps total [kW]	1 380	1 290
EGS well pump each [kW]	460	258

5. CONCLUSIONS

The simulation results show that the narrow well program is unfeasible. The reason is that the narrow program is only advantageous if the productivity index is below 1 kg/(s·bar), but then the project as a whole becomes unfeasible due to the number of wells needed to sustain the total liquid flow needed for the electric generation (the parasitic load increases with the number of wells and the pumping power needed to overcome the productivity index).

By using the productivity indexes, the main results from the simulations allow us to only consider one width of a casing program which reduces the number of unknown parameters. The results also show the productivity index needed for an economical project to be obtainable. This method of evaluation helped to split up the work packages in the project and to decouple the work.

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