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ECONOMIC AND TECHNICAL CASE FOR COMMERCIAL EXPLOITATION OF EGS

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ABSTRACT

The development of Engineered Geothermal Systems (EGS) has taken over 30 years to evolve from a basic concept to the exploitable technology based on modelling, experimentation, and observations. Given unlimited funds, EGS research could be far-ranging. However, funding is, in fact, limited, and so it must be focused toward addressing certain engineering parameters that make the overall economics of EGS cost competitive. In other words, economic parameters dictate the technical goals that must be met to make EGS commercially viable. It has been noted recently that the economic case made for raising capital in the market, in most cases, does not address the engineering parameters needed to make EGS economically viable. Additionally, the key issue in economic evaluations is the net power generation (including management and maintenance), and not the gross power generation, which is generally quoted.

Some of the engineering parameters to be addressed for economic evaluation are:

- Access to the high temperature heat reservoir at shallow depth as possible
- Life of the system
- Separation between wells (injector and producers)
- Maximum fluid production
- Water losses
- Productivity
- Thermal drawdown
- Heat transfer area
- Reservoir rock volume
- Water resource
- Power line
- Interest rate
- Preferential tariff

The paper will discus whether these parameters have been achieved, where we stand in terms of addressing them, and whether they should be included in the economic assessment.

INTRODUCTION

As the demand for energy increases, all available resources are being evaluated to see they can help mitigate the impending crisis. It is recognized that geothermal has the potential to play a major part in the future demand for energy. Los Alamos, in the 1970’s, came up with the concept that the stored heat from great depth can be recovered by creating an artificial reservoir that would mimic something like a natural hydrothermal system. The term **H**ot **D**ry **R**ock was coined to indicate that there was not enough natural fluid in the rock mass at depth to provide long-term sustainability. Subsequently, others have come up with terms such as **H**ot **F**ractured **R**ock, **H**ot **W**et **R**ock or **E**nhanced **G**eothermal **S**ystem, but all these descriptions fall under the generic definition of **E**ngineered **G**eothermal **S**ystem (**EGS**). In all these cases, a heat exchanger must be designed and engineered to a specification in order to extract the stored heat in the rock mass by circulating fluid through it, compared to a hydrothermal system where an access to the stored reservoir is obtained by drilling in to the existing reservoir of hot fluid.

While a geothermal resource can be viewed as a single resource that has geographically variable properties and is designated by a reservoir or system, the supply representation presented here incorporates, for convenience, two specific resource types of Engineered Geothermal Systems (EGS) resource – convective EGS that is associated with hydrothermal resources at depths less than 3 kilometers, and conductive EGS at depths between 3 and 10 kilometers. Both of these still need underground engineering to create an exchanger to extract the heat from hot rocks.

In order for an EGS project to be successful and economically viable, the heat exchanger must be designed and created with specific characteristics (Shock, 1986; Garnish, 1985).

Some of the studies carried out to look at the economic potential of a site do not always take into consideration the property of the heat exchanger or whether certain assumptions made have been technically achieved or are even plausible. This paper highlights some of these uncertainties and what has been achieved that can be regarded as technically possible.

EGS CHRACTERISTICS FOR ECONOMIC EVALUATION

The overall assessment of the economic viability of an EGS plant can be grossly divided into five groupings: a) Resource identification, licensing arrangement, funding and management structure; b) Site preparation, installation of infrastructure, planning, and drilling of wells; c) Model, design and creation of an appropriate heat exchanger to meet economic targets; d) Circulation and characterization of the heat exchanger, and e) Power production, reservoir maintenance, and management.

These are large topics to cover in one paper, but a short summary of what they may entail will be given here, although there are also published materials to fill the gaps.

a) Resource identification, licensing arrangement, funding and management structure

For an EGS system to be economically viable, many of the criteria used for a normal hydrothermal system can be incorporated here, such as high temperature with depth, access to the site, easier licensing arrangements, access to power transmission line, and higher or preferential tariffs. Additionally, tensional stresses are preferable for EGS. Also, a good understanding of stress regime with depth is essential, as are a water resource for stimulation. Similarly, one tries to avoid high compressive stress regimes to reduce problems with drilling, stimulation, and circulation. A significant body of literature exists on these topics, which therefore will not be covered any further. Economic assessment for this section should be relatively straightforward.

b) Site preparation, installation of infrastructure, planning, and drilling of wells

As in the previous section, a reasonable proportion of the knowledge from hydrothermal operations can be incorporated here, such as site preparation, installation of infrastructure etc., but drilling in a hard environment does need special attention in terms of drilling bits, roller-reamers etc. One of the difficulties is the successful use of down motors to control the direction of deviated wells. One normally associates the difficulty with high temperature electronics, but on one occasion the electronic assemblies fell apart because of the vibrations generated while going through highly fractured zones during the drilling of the 5-km deviated well GPK4 at the Soultz European Project.

Recent experience shows that a 5,000 m well (GPK3) was drilled for around 5 million euros in 2003, although the cost will vary depending on the geographical locations and the state of the hydrocarbon and steel industry.

In principle, this should a straightforward assessment, but care should be taken to allow good contingency funds. A first well in any zone is likely to be difficult and expensive, but the cost of subsequent wells should, in principle, come down.

c) Model, design and creation of an appropriate heat exchanger to meet economic targets

The extraction of energy from deep hot rocks for conversion into electricity requires that the results be competitively priced with electricity generated from other sources. This means that the heat exchanger creation process, the operating conditions for extracting the heat, and the life of the accessible heat volume are such that the EGS can compete with electricity from other sources. It is worth mentioning that the highest capital cost is the drilling of deep wells. Extensive work is continuing to reduce this cost as well.

Taking all this into consideration, various organizations have assessed the cost of electricity from an EGS system. Shock (1986), looked at the reservoir parameters needed to make this technology commercially attractive, came up the following engineering characteristics:

- Total circulation flow of around 75 kg/s
- Mean reservoir temperature of around 190°C
- Parasitic losses to drive the fluid through the system of around 0.1MPa/liter/sec.
- Overall fluid loss to be less then 10%
- The life of the reservoir to be ~ 20 years
- Temperature drawdown of ~ 10% at the end of the project life
- An effective heat transfer area of 4×10^6 m^2
- The fractured rock volume of the reservoir to be more then 200×10^6 m^3

The last 30 years of research in this field have not produced to date a single long-term operational plant on which all these parameters can be quantified. However, a significant understanding of the parameters that govern the above targets has been gained. Two sites in the last five years have come very close to achieving these targets: the European EGS site at Soultz, France, and the Geo X project in Landau, Germany.

Total circulation flow of around 75 kg/s

To date, a maximum flow through an EGS system has been around 25 kg/s (at Soultz), and it was anticipated that this could have been increased to 30 kg/s but the lack of appropriate infrastructure did not allow this to be established. With a three-well EGS module, it was expected that the flow would double bring it to ~ 60 kg/s and with time this could have been increased to 70 kg/s.

The commercially funded Geo X EGS project at Landau has been fortunate in accessing a large permeable fault, and thus it is able to deliver fluid at ~ 150°C degree with flow rate in excess of 50 kg/s.

Experience has shown that unless the heat exchanger characteristics are correctly engineered, increasing the injection flow may lead to higher fluid losses, expansion of the parasitic part of the heat exchanger and a potential for generation of larger seismic event, without taking in to consideration the financial cost of fluid and pumping power.

Mean reservoir temperature

The higher the temperature at shallow depth the more attractive it becomes economically but experience has also shown that the stress regime has to be such that it allows relatively easier to enhance permeability, give predictable direction of the growth of heat exchanger and doesn’t require high stimulation and pumping pressures.

Los Alamos (USA), Ogachi and Hijiori (Japan) are few examples where higher temperature at shallow depth did not help in the creation of a good underground heat exchanger.

Parasitic losses to drive the fluid through the system to be around 0.1MPa /kg/sec

The creation of a heat exchanger with effective economic properties is the heart of an EGS system. There is a contradictive requirement when designing and creating a heat exchanger. The pressure drop due to flow is required to be as small as possible at high rate of flow but the separation between the injection and production well has to be as large as possible to engulf large volume of hot rocks so that the life of the system is around 20 years.

This measurement involves all points of energy losses from injecting the fluid from the surface into the formation and back to the surface.

The understanding of the significance of the appropriate stress regime and the ability to manipulate it to create enhanced permeability was a significant jump in achieving this goal. At Soultz, the permeability was enhanced by a factor of 20-30. The separation of the wells was increased to 600 m and yet it was possible to obtain the pressure drop for flow of 0.29 MPa per kg/s at a flow rate of 25 kg/s. With a three-well system, it was expected to drop to 0.15 MPa per kg/s for total circulation flow of 50 kg/s. Experience has shown that the pressure drop with flow normally improves with time as the rock cools and shrinks near the well bore and in the formation. There is the possibility of it increasing if care is not taken to control the dissolution and precipitation processes during circulation.

Newer stimulation technique, such as injecting in both wells simultaneously or creation of multiple stimulated zones, may be a way of reducing the flow impedance and increasing flow rate through an EGS system.

Overall fluid loss to be less then 10%

Water can become an expensive commodity if it is not available naturally in reasonable quantity. The overall water loss of 10% includes the water required for a cooling tower when generating power.

The concept of the three-well module was designed to help recover the fluid from the outer bounds of the pressurized heat exchanger. The injection well is in the center of the heat exchanger and the two production wells are on the two diametrically extreme side of the heat exchanger. If the system is relatively open, then it may be worth deploying submersible pumps in the two production wells to help suck additional water through the system. Hydraulic tests will need to be carried out to estimate the power used for running the pumps and how much additional power is generated from the increased hot fluid.

d) Circulation and characterization of the heat exchanger

It is very important that modeling is done prior to a stimulation to control the volume of stimulated rock, and that microseismic monitoring is done to assess the growth of the heat exchanger. In principle, a heat exchanger with large volume will have larger surface area and therefore larger leak-off, and thus increased water losses.

The life of the reservoir to be ~ 20 years

For economic evaluation, it is necessary to quantify how long an EGS system will last, and thus how much revenue and expenditure are associated with it. However, in reality there are no data available to see if this is possible with the current state of the knowledge. This is an economic requirement and numerical models do show that this can be attained, but the controlling factors are: how large is the heat exchange volume, how big is the heat transfer area, what is the flow rate, and are there preferential flow paths. Tracer tests generally indicate that longer breakthrough time and larger model volumes are associated with longer lifetime of a system. Additionally, the initial rise and the subsequent decline in the production temperature are used in conjunction with a numerical model to predict the life of an EGS system.

The life of around 20 years is also selected because of the degradation of mechanical components such as the casing etc. in the aggressive environment of EGS. The refurbishment or repair costs may outstrip the revenue.

Temperature drawdown of ~ 10% at the end of its life

Although electricity can be generated from around 130°C onwards, power plants are selected to maximize the power conversion at a narrow range of temperatures. The type of power conversion cycle may also change from flash plant to binary cycle, depending on the output temperature, flow rate, closed or open system etc. The power generation is one of the main capital costs, and this has to be recovered over the life of the system.

An effective heat transfer area (of 4 x 10^6 m^2), and the rock volume of the reservoir (to be more then 200 x 10^6 m^3)

Effective heat transfer area and fractured rock volume are to some degree interlinked, and are associated with the size of the stimulated volume and the joint distribution characteristics of the rock formation. Increase in both of these parameters generally means the life of a reservoir will be long.

Both of these parameters are difficult to measure and quantify. Tracers and other techniques are under investigation to help quantify these parameters. In a specify environment, it is possible to get smaller heat transfer area but much larger stimulated volume. This is normally associated with preferential fluid paths generated by exciting a large swarm of joints or a large fractured fault. These are easy to identify as the break-though times are relatively short followed by the accelerated temperature drawdown. Methods to treat these types of difficulties do not exist at present, and it is one of the uncertainties that must be included in the economic assessment of an EGS system.

e) Power production, reservoir maintenance, and management.

As stated earlier, the selection of a power plant will depend on the fluid temperature, flow etc.

Again, an EGS project has not been in operation for a reasonable time to quantify the cost of reservoir maintenance and management, but it should not be too dissimilar from a hydrothermal system. It may be possible to overlay the cost of maintenance and management from a hydrothermal system with minor amendments.

It is also important to bear in mind that net power production is more important that the gross production in estimating the economic viability of an EGS project.

Power lines, interest rates and preferential tariffs can play important parts in making EGS economically viable, and great care needs to be taken to take advantages of such opportunities.

CONCLUSIONS

There is not a single EGS project that has operated over a long enough period to allow us to quantify all the parameters required to assess economical viability, but there is enough knowledge from 30 years of research to show that these economic quantification cannot be made without considering aspects such as the size of the heat exchanger, the pressure drop, etc. Success in achieving target values of these parameters needs to be part of the economic assessment and risk in proposing a commercially funded EGS.

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