CURRENT STATUS OF THE KOREAN EGS PILOT PLANT PROJECT

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ABSTRACT

Korean government launched a geothermal power generation project in Pohang, southeastern part of Korea, adopting Enhanced Geothermal System (EGS) technology at the end of 2010. The EGS pilot plant project is the first attempt to realize geothermal power generation in Korea. It is a five-year term, government funded and industry matching project. The project consists of two phases: I) site preparation, drilling down to a 3 km deep well and to confirm the temperature anomaly in two years, and II) extending the 3 km deep well down to 4.5 - 5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW class binary power plant in another three years.

During the first phase, geophysical data were reassessed and stress measurement along an exploratory hole was made to figure out stress distribution around the site. A micro-seismicity monitoring system with nine borehole three-component accelerometers has been installed and is currently under operation. The first well spudded in September, 2012 and reached 2,241 m GL in December, and drilling has been temporarily stopped. During the drilling, a seismic-while-drilling (SWD) survey was tried by deploying four radial surface geophone arrays to determine velocity structure which is critical in micro-seismic interpretation.

Drilling of the first well re-started in May 2013, reached 3,547 m of granite basement in July and again temporarily stopped until the end of August. Progress of the drilling has been delayed mostly due to lack of experience in deep drilling and engineering, and will be completed by the end of November 2013. First hydraulic stimulation for testing and creating geothermal reservoir is scheduled to be performed early 2014 which will be followed by detailed assessment of reservoir, next well design, and so on.

Keywords: Enhanced Geothermal System (EGS), Pohang, power generation, drilling, micro-seismicity

1. INTRODUCTION: BACKGROUND OF THE PROJECT

Geothermal utilization in Korea has been direct use, especially with ground-source heat pump (GSHP) installation, because there is no high temperature resources associated with active volcano or tectonic activity. GSHP installation in Korea has increased rapidly since middle of 2000's and total installed capacity exceeded 200 MWt in 2010 (and further, exceeded 400 MWt in 2012). This successful deployment made general public as well as people in energy sector become well aware of what the geothermal energy is, especially its nature of covering base load. Exploration and exploitation of low-temperature geothermal water through deep fractures have been tried by Korea Institute of Geoscience and Mineral Resources (KIGAM) over some potential regions from the beginning of 21st century. Information on recent stories of low-temperature power generation including enhanced geothermal system (EGS) in Europe, Australia and US have made decision makers and industries in Korea be interested in geothermal power generation, and these resulted in launching of the EGS pilot plant project at the end of 2010.

The EGS pilot plant project is the first attempt to realize geothermal power generation in Korea. It is a five-year term, government funded and industry matching project. Target area is the Pohang field of higher heat flow in southeastern part of Korean Peninsula. The project consists of two phases: I) site preparation, drilling down to a 3 km deep well and to confirm the temperature anomaly in two years, and II) extending the 3 km deep well down to 4.5 - 5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW class binary power plant in another three years.

Figure 1 shows a conceptual model of the Korean EGS pilot plant project. The Pohang site is composed of Tertiary marine sediments of some 200 m thick, Cretaceous sedimentary formations down to 2,220 – 2,400 m depth, and Permian granodiorite basement with granite intrusion. Target depth for reservoir creation or enhancement is 4.5 – 5 km at which subsurface temperature is expected to be 180 °C. Minimum target flow rate is 40 kg/sec for this doublet system assuming no natural permeability is met in that depth region. Doublet model is solely due to budget problem and it will be extended to a triplet system through commercialization once desired flow rate is accomplished.

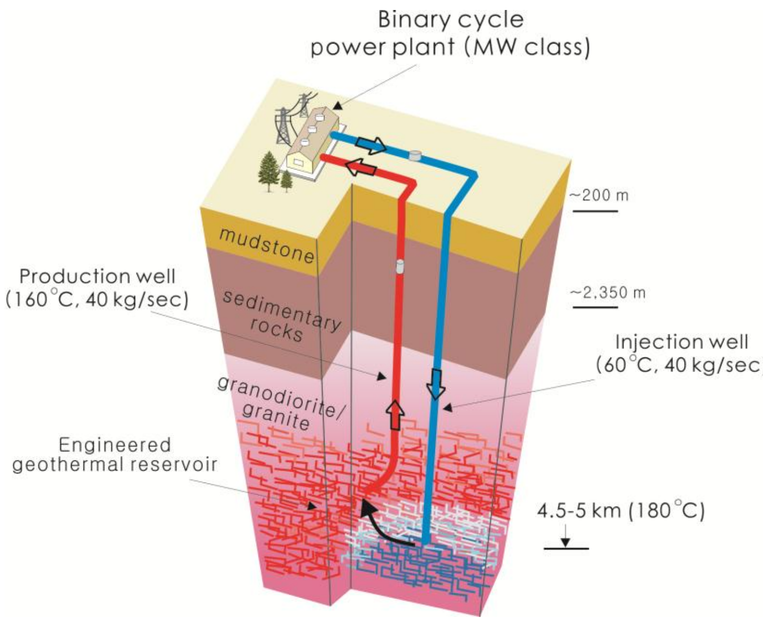

Fig. 1. Conceptual model of the Korean EGS pilot plant project.

2. EXPLORATION AND DEVELOPMENT HISTORY OF POHANG SITE

Pohang area is the only region in Korea covered with Tertiary sediments. The Pohang geothermal site belongs to the Tertiary Pohang Basin overlying Eocene volcanic rock (tuff), Cretaceous sedimentary (sandstone and mudstone) and volcanic (tuff and andesite) rocks, and Permian granodiorite basement. The Pohang Basin consists of Miocene marine sediments and bottommost clastic sediments layer. The marine sediments are of low thermal conductivity and hydraulic permeability preserving high geothermal gradient of 35-40 °C/km comparing to average value of 25.1 °C/km in Korea (Kim and Lee, 2007), which is quite uncommon in Korea. The basin also shows relatively high heat flow; up to 80 mW/m^2 or higher, and that is why geothermal exploration and exploitation activities have been concentrated on this area since 2003 by KIGAM.

The fact that the Pohang Basin is of Tertiary marine sediments had led Korean government to try to explore petroleum resources from middle of 60's until the early 80's. There were many exploratory boreholes and the deepest one went down to 3 km in 1976. Although there could not be found any evidence of economic resources, people came to know that subsurface temperature at this area is higher than other region in Korea. Furthermore, there found many permeable fracture zones during drilling, which was partly driving moment of hot spring development in this area.

In 2003, KIGAM started a low-temperature geothermal project to develop geothermal water for district heating and agricultural application in Pohang. The target area was selected first by the geothermal anomaly shown from heat flow and geothermal gradient maps. Then, lineament distribution analysis using Landsat image and structural geological mapping was applied to find possible deep fractures that would work as geothermal water conduits.

We have applied various geophysical exploration methods such as gravity and magnetic surveys to interpretation of the regional geologic setting, magnetotelluric (MT) and controlled-source audio-frequency MT (CSAMT) surveys to mapping the resistivity structure and possible fracture zones, and self-potential survey to examining hydrologic condition associated with geothermal flow. Drilling of two pilot wells 165 m apart each other, one is a rotary well (BH-2) and the other is a coring borehole (BH-1), started in August 2003 to confirm the existence of the geothermal reservoir. BH-2 went down to 1.5 km and BH-1 to 1.1 km. The drilling results showed a geothermal gradient of 40 °C/km in Tertiary sediments and existence of several permeable zones related with fracture systems in lower part.

After finishing the pilot wells, pumping tests along with monitoring of self-potential over the area and draw-down at the adjacent well, and chemical analyses of pumped water have been performed to confirm that there exist several permeable zones associated with deep fractures. The pumping test produced geothermal water of 51 °C in temperature and of 560 m^3/day in flow rate, which is fairly good condition in Korea. A three-dimensional imaging of subsurface structures using MT data has been made and it was identified that the fracture zone extended down to at least 2 km in depth.

Based on these results, another well (BH-4) has been drilled down to 2.383 km, to find basement at depth of 2.265 km at the end of 2006. Several geophysical loggings were performed only down to less than 2 km due to instruments durability against high pressure and temperature at its bottom. Drilling and geophysical logs, however, indicated that there are several permeable zones, where considerable amounts of leakage of the drilling mud and abrupt change in temperature profile was observed.

There have been met various problems in the well BH-4, such as incomplete well casing, partial collapse in uncased depth interval, remaining mud cakes in permeable zones, etc. All of these problems have resulted from lack of experience in deep drilling of even water well. Nevertheless, it is quite important experience in Korea in that this is the first systematic trial of deep geothermal development beyond hot spring exploration and made people learned valuable lessons (Lee and Song, 2008). Static temperature measurement along BH-4 was made in 2009 by deploying a distributed temperature sensing (DTS) technique to show 91 °C at the depth of 2 km which tells that we have average geothermal gradient of 38 °C/km considering mean annual surface temperature of 15 °C.

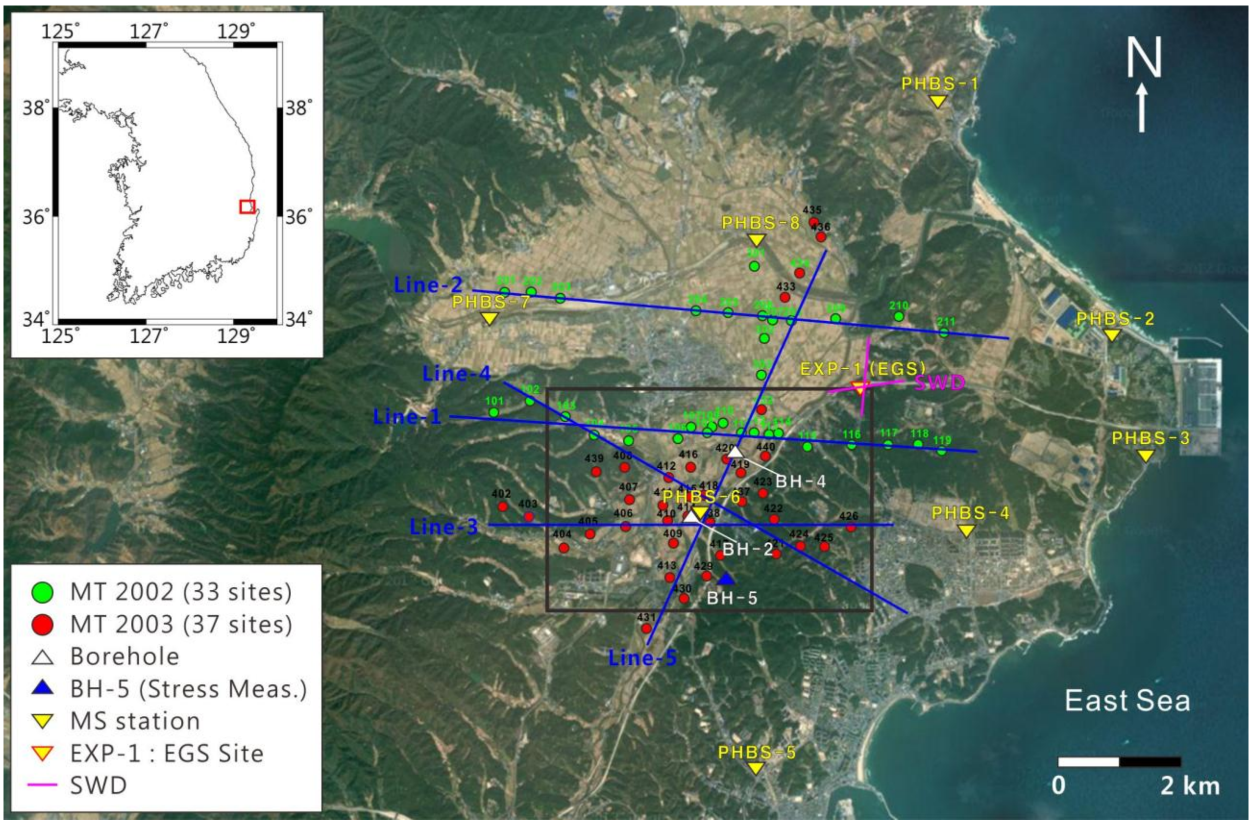

Fig. 2. Location map of the Pohang site showing MT measurements, major wells, geophone lines for seismic-while-drilling (SWD), and nine MS monitoring stations (PHBS-1~8 and EXP-1). Boreholes BH-1 and BH-3 are in close vicinity of BH-2 and BH-4, respectively, so are omitted for the sake of simplicity. Note that EXP-1 is located at EGS drilling site.

3. MAJOR ISSUES IN THE BEGINNING OF THE PROJECT

There were some scientific and technical issues in the beginning of the project. Electricity generating capacity linearly increases with temperature difference between producing and injection geothermal fluid, flow rate and thermal efficiency. For thermal efficiency of binary cycle power plant, due to thermodynamic limit there is little room to enhance the currently accepted empirical relationship as used in Beardsmore et al. (2010). For temperature of subsurface which governs the producing fluid temperature, we assume to have 180 °C at the depth of 4.5 km, which requires average 37 °C/km of geothermal gradient considering mean annual surface temperature of 15 °C. We could see geothermal gradient of as high as 38 °C/km with long-term monitoring down to 2 km along the offset well BH-4 so that there is little uncertainty of the subsurface temperature considering that the final depth of drilling would be between 4.5 and 5 km.

Then most important issue was to create the subsurface reservoir enough to make sure flow rate of 40 kg/sec. Because growth of reservoir as a consequence of a hydraulic stimulation in crystalline rock is governed by stress regime, accurate knowledge of stress distribution of the site is quite important. Although there can be found a recent compilation of stress measurements over the southeastern part of Korea (Chang et al., 2010), the measurements were limited to shallow depths only (mostly less than 300 m) and no data are found in the vicinity of the Pohang site. Information on stress is necessary not only in terms of spatial distribution, but also in vertical profile, so new measurement along deep borehole was required. Permeable fractures in target depth can reduce the risk of the insufficient flow rate, if any, but there is no detailed information on deep fracture system either.

Micro-seismic (MS) monitoring is practically the only way to observe growth of reservoir resulted from hydraulic stimulation, and installation and operation of MS monitoring system should start far before stimulation. Because locating method of micro-earthquake events is exactly the same as in earthquake monitoring, accurate information of 3-D velocity structure is critical in accurate location of events. Unfortunately, neither surface nor borehole seismic survey has been performed in the region mainly due to absence of petroleum exploration activity. 3-D seismic survey may be necessary to provide accurate velocity structure and information on possible deep fractures. However, 3-D seismic survey is not an option because complicated land usage along with adjacent small villages would not allow use of big sources (explosives or vibroseis) for deep penetration besides budget problem. Therefore we have to device other way to define velocity structure.

Besides limited budget, lack of experience in deep drilling and engineering was another serious concern. An EGS project should be well prepared arranging every technical and scientific procedure in one Gantt chart in order to not only save time and money but also reduce possible technical risk. Furthermore, there is no service company related with deep drilling in Korea and timely procurement was also an important issue. So almost everything was the first trial and the project team had to help themselves from the very beginning of learning curve. An effective way of making progress was to keep close contact with international expert groups in EGS to consult and to get valuable and critical comments at each step and, at the same time, was to device an efficient management scheme, which was partly successful so far.

4. PROGRESS OF THE PROJECT AND CURRENT STATUS

Selection of drilling site may be the first thing to do once project is approved. After reassessment of many existing geophysical results and logging data at offset wells, boundary of candidate region was defined. Major concerns were access to main road, power line and water supply. EXP-1 site in Figure 2 was finally selected and civil engineering work was performed. The site has direct connection to main motor way and power line while water for drilling is from groundwater well. Future demand of water for hydraulic stimulation is to be met by an agricultural reservoir nearby.

Before securing the drilling site, stress measurement was performed along the borehole BH-5, 3.8 km apart from the EGS site (see Figure 2). Although the depth of the BH-5 is 1 km, we could measure the data only for depth interval from 670 m to 810 m due to extremely weak formation for applying hydraulic pressure. Hydraulic fracturing tests over the three separate depth intervals along with images of the drilling induced tensile fractures and the borehole breakouts showed that the direction of maximum horizontal stress (σ_H) is rather constant to be N48°W and of strike-slip regime in general. However, because the covered depth range was too short and the formation is extremely weak, there is still some uncertainty in stress regime.

Micro-seismicity is critical in monitoring creation and growth of a geothermal reservoir as a result of hydraulic stimulation. We have completed construction of MS monitoring system with nine borehole three-component accelerometers. Eight observatories are located on two circles with radius of 3 and 5 km, respectively, centered on EGS site as shown in Figure 2. Depths of accelerometers are 120-130 m except the one at the site which was installed at 180 m depth. All nine observatories are connected to high speed internet network so that we can process the data with sampling frequency of as high as 1,000 Hz in real time.

Drilling of the first well PX-1 was spudded on 19th of September 2012 with 17.5 inch bit through pre-installed surface conductor of 20 inches in diameter. Figure 3 shows the drill rig on site, and design specification and current status of the well as of July 2013. Because there has been no deep drilling for oil and gas in Korea, rig must be imported either by purchase or by lease basis. Considering relative short term of drilling, long time interval between the first and the second wells, and cost for mobilization/demobilization in case of lease, a rig with API static hook load of 3,150 kN has been purchased. Besides relative delay of the rig import, progress of drilling was much slower than plan mainly due to lack of experience including procurement problem of spare parts, necessary items and services. We reached 2,250 m (2,241 m GL) on 14th of December and decided to stop drilling temporarily due to unexpected delay of progress.

While drilling PX-1, a surface shallow reflection seismic survey was performed to define uppermost sediment layer in terms of depth variation and travel time. Because velocity structure is a fundamental input parameter for processing and interpretation of MS monitoring data, we adapted a seismic-while-drilling (SWD) survey scheme, a variation of reverse vertical seismic profiling (VSP) with drill bit vibration as seismic source, in order to get information on seismic velocities in deeper region. For SWD, four radial surface geophone arrays were deployed to 500 m length each and geophones were at every 10 m in array as shown in Figure 2. Covered bit depth ranges were from 330 m to 1,700 m in 2012.

After careful check of rig and other equipment and assessment of performance in 2012, we re-enter the PX-1 well on 23rd of May 2013. After several days of drilling we met top of the crystalline rock at the depth of 2,347 m GL (Figure 3). 9 5/8 inch drilling went down to 2,391 m GL and the well has been cased and cemented. Drilling continued with 8 1/2 inch bit until another temporary shut off at 3,547 m GL due to frequent drill string instability problem. Image of geologic sequence as a result of mud logging is superimposed on the well diagram in Figure 3, of which depth to the top of granodiorite was measured from gamma ray logging. Bit depth covered by SWD survey was from 2,782 m to 3,556 m in 2013.

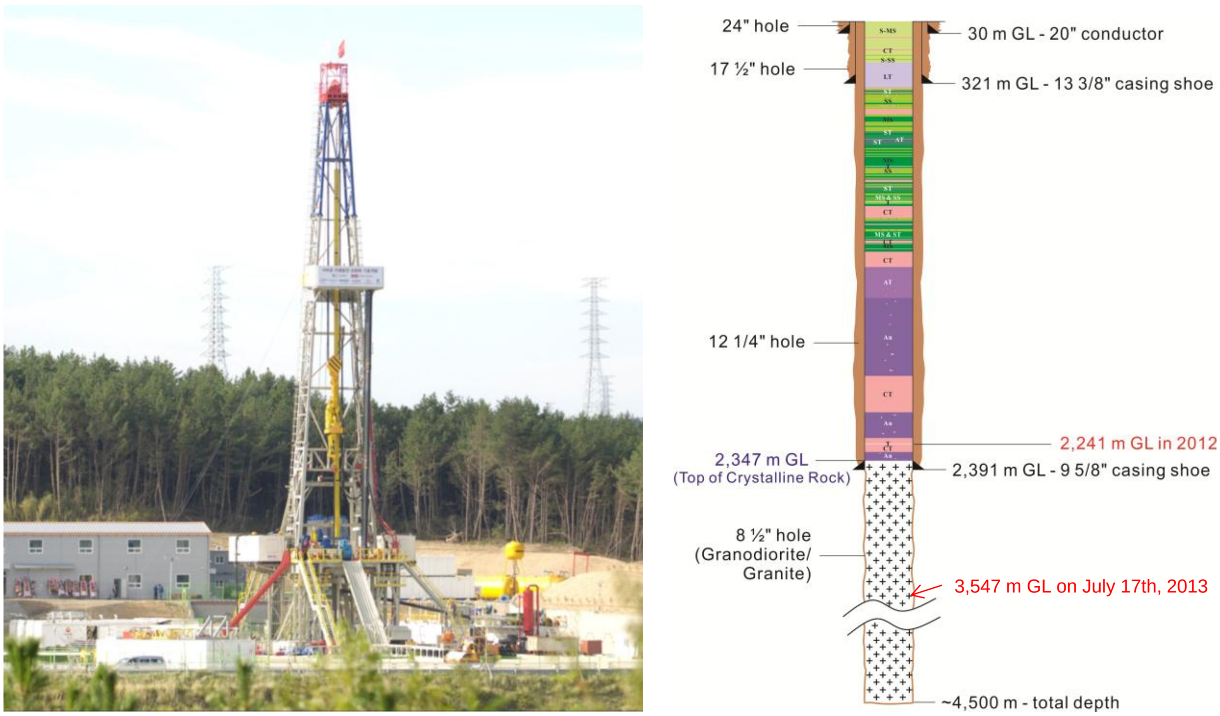

Fig. 3. Drill rig with API static hook load of 3,150 kN (left), and PX-1 well design and progress (right).

5. DISCUSSION AND FUTURE PROSPECT

Overall progress of the project is rather slow than original time plan due to extra budget demand for unexpectedly high cost of procurements and mostly due to lack of experience. First hydraulic stimulation for testing and creating geothermal reservoir is scheduled to be performed early 2014 which will be followed by detailed assessment of reservoir, next well design, and so on. Although we expect to enhance overall performance in that we have started from the beginning of the learning curve, there may be another unexpected factors causing further delay, for example higher cost of stimulation than planned, ambiguity in MS processing and thus improper feed-back to hydraulic stimulation parameters, and finally insufficient injectivity (in kg/sec/bar) as a result from the first hydraulic stimulation. Another important factor controlling the success of the project will be a proper design and drilling of the second well which is to deviate to meet reservoir geometry. Again due to complete lack of such an experience, collaboration with international expert group will be utmost important.

Recent research on the EGS potential in Korea following the protocol by Beardsmore et al. (2010) shows that theoretical and technical potentials are estimated to be 6,975 GW and 19.6 GW, respectively (Song et al., 2011). A technical roadmap of greenhouse gas reduction technology in Korea states that there can be 200 MW of installed capacity with geothermal by 2030 in Korea (KETEP, 2011), which is one percent of the technical potential. The outcome of this project, if successful, will surely be a milestone initializing the roadmap and we expect this pilot plant project to be scaled up to level of 10 MW class by 2020. Active participation from industries is critical in scaling up and further commercialization, which is currently affected by lack of legal frame for supporting geothermal power generation. There are some activities going on for including geothermal in Renewable Portfolio Standard (RPS) system with higher Renewable Energy Certificates (REC) and also for implementing legal frame for geothermal, so that we can expect a better future for geothermal power generation in Korea.

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