Chapter 7

Guidelines for Sustainable Use

This chapter should be cited as

Sakaguchi K. and V. Anbumozhi (2015), 'Guidelines for Sustainable Use', in *Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia*. ERIA Research Project Report 2014-41, Jakarta: ERIA, pp.167-174. Available at: http://www.eria.org/RPR_FY2014_No.41_Chapter_7.pdf

Chapter 7

Guidelines for Sustainable Use

7.1. Power Generation and Direct Heat Use

With steam field production, many of the reservoir processes and their attendant problems had developed as the geothermal reservoir responds to field-wide exploitation. Since these problems are derived from physical and chemical processes of the subsurface region, sometimes different solutions are needed for the same and/or similar phenomena occurring at the surface, depending on the field characteristics. For reservoir management, special attention is necessary to the type of the reservoir (single liquid phase, liquid dominated, steam dominated, and super-heated) and fluid chemistry to attain effective reservoir management and therefore sustainability of geothermal energy utilisation. Some of the production-related reservoir processes, their effects and resulting problems as well as the solutions that have been implemented as a direct response to steam and brine withdrawal from the deep reservoir, include:

(1) Reservoir Drawdown

Mass withdrawal from deep and shallow reservoirs leads to pressure and temperature declines and drop in reservoir water level if the steam-water extraction is continuous without pressure and mass support.

➢ Reservoir drawdown and reduction of steam zone pressure (in case of two-phase or steam reservoir) may result in:

- Reduction of the size of steam zone and even damage the steam zone
- Invasion of shallow cooler waters and mixing with production
- Additional drilling needed to maintain steam supply
- Control through optimisation of injection loading and balancing of mass recharge with pressure support
- Control of steam zone through pressure balance of shallow steam zone and deep reservoir is essential

(2) Brine and Condensate Injection

Injection is essential to maintain the reservoir pressure for long-term production. However, several problems may be caused by the injection of cooler fluid. Monitoring injection fluid, including tracer test is essential. Among these injection induced problems, serious ones for reservoir management and their mitigation methods are listed below.

- Injection breakthrough into production zones:
  - May reduce the enthalpy of the produced fluid and steam ratio.
  - Scaling may occur due to cooling of the reservoir by injection fluids and dilution of brine.
  - To prevent injection breakthrough from cooling reservoir, relocation of injection to 'outfield' and/or deeper part may be effective.
  - Production wells 'at risk' should be carefully monitored and allowable injection rates are limited for specific injection wells.
  - Cooler fluid inflow may be avoided by sacrificial peripheral wells continuously being discharged to portable silencers.
  - Use of repeat precision gravity survey is becoming useful to delineate mass changes either through withdrawal or injection.

Injection returns are sometimes beneficial by bringing mass recharge into boiling reservoir, sustaining reservoir pressure, and preventing fine solids discharge from dry-steam to steam-dominated reservoirs. To balance the benefits of mass recharge to the highly two-phase reservoir and the cooling effects of injection breakthrough to the producing wells, the injection wells' load distribution are modified and optimised.

There are also environmental problems induced by injection.

- Subsidence (in case of two phase or steam reservoir)
  - Reduction of shallow steam zone pressure may cause even more serious subsidence than subsidence by fluid production. It may last longer as creep phenomenon even after the cause is removed.
  - It may be avoided to change the injection depth to deeper zones.
  - Shallow geology should be investigated since subsidence occurs at soft near-surface formation.
  - Well locations should be carefully chosen based on shallow geology to avoid subsidence.

(3) Acid Corrosion and Mineral Scaling

Corrosion and scaling are still common problem in many fields, which sometimes prevent us from producing fluid from such zone.

- Acid corrosion
  - Acid brine seriously corrodes wells, pipelines, and power plant components. Dilution of acid fluid may cause calcite scaling.
  - New well design with a cemented blank liner run below acid zones is effective to case off potential acid zones.
  - Effects of acid corrosion in other operating fields are contained through: 1) use of corrosion-resistant alloys for casings and liners, 2) well-head cladding with exotic metals, 3) buffering acidic fluids with caustic soda down hole, and 4) use of corrosion inhibitors.
- Mineral scaling
  - Occurs mostly in production wells with acidic fluid discharge, pipelines, reinjection wells, and turbines.
  - Mechanical cleaning through workovers of wellbores and vertical discharging of wells may be effective at least for a short period.
  - As a more long-term fundamental solution, deeper injection is effective if the injection return accelerates the mineral deposition.
  - Some production fields implement various ways of minimising the risks from mineral scaling, such as: 1) acidizing, 2) scale inhibition, 3) having higher separation pressures (with equivalent high saturation temperatures), and 4) modification of discharge fluid chemistry through acid injection.

(4) Superheated zones

Fluid production may turn steam zones into super-heated zones. Although some dry-steam production fields show increased production with water injection, special attention is needed for such zones to sustain steam supply. Solids discharge may occur in superheated steam zones.

- Controlling superheated steam zone
  - Pressure balance of shallow steam zone and deep reservoir is essential.
  - Well balanced injection may be useful.
  - Pressure monitoring in these zones is important.
  - Other operating fields' methods to address effects of super-heated steam and erosion include: 1) use of wellhead washing either with river water, brine, or condensates, and 2) drilling of deeper replacement wells into the liquid reservoir of existing production horizons.

(5) Meteoric Recharge

Since it is a natural phenomenon, it is difficult to control and difficult to trace. Its flow pattern is controlled by natural barriers such as impermeable fault.

- Cooling by meteoric recharge
  - It necessitated the relocation of the entire production system in a part of Tiwi (Philippines).
  - For its monitoring, repeat precision gravity survey is useful for long term and tritium tracer was useful for shorter term.
  - Cooler fluid inflow may be avoided by sacrificial peripheral wells continuously being discharged to portable silencers.

Beside these specific technical issues, several important matters should be pointed out.

- Low permeability wells are enhanced by: 1) stimulation using massive water injection, 2) thermal cracking, or 3) with acid injection.
- Careful exploration and monitoring
  - For better understanding of the reservoir, continuous observation, analysis, and interpretation of the reservoir data are essential.

- Major surveillance activities include: 1) monitoring of quantity of steam produced, 2) geochemistry and reservoir engineering data of wells, production reservoirs, and reinjection sinks, and 3) microgravity and induced seismicity from mass withdrawal and injection.
- Integration of monitoring data leads to improved reservoir management strategies and sound resource management can sustain production over time.

➢ Disciplined human resources

- The key to overcoming operational problems is having a strong multi-disciplinary resource team in place that can understand and react to the issues and provide workable solutions.

7.2. Ground Source Heat Pump Systems

(1) Making suitability map

➢ For sustainable use of GSHP systems, a system design suitable for the hydrogeological settings of the location and GSHP application purpose is needed.

➢ Heat exchange rate and preferred drilling depth of a GSHP system varies with local hydrogeological settings.

➢ For sedimentary regions, groundwater and geological surveys to perform numerical simulation on groundwater flow and local heat exchange are needed to compile suitability maps of GSHP systems. For hard rock regions, mapping of heat conductivity of rock is recommended to make suitability map.

➢ Design of GSHP systems can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.

➢ Suitability maps for sedimentary regions can be made in the following order of procedures:

1. Groundwater and geological survey
    - Groundwater survey should be widely conducted in a basin or plain, by collecting data from existing wells.
    - Water table, chemical component (electric conductivity) of groundwater, and temperature profile of the well should be measured.
    - Temperature profile should be measured in observation wells or unused wells where the temperature reached the equilibrium to the ground temperature.

- On the other hand, water chemistry should be measured at regularly used wells with fresh groundwater.
- Geological surveys should be conducted to understand the basic structure of the region. Sand-gravel ratio of shallow layers needs special attention to estimate hydraulic conductivity of the layer.

2. Atmospheric temperature survey (for tropical climate only)

- For tropical areas where only space cooling is needed but subsurface temperature is high, a comparison of atmospheric temperature and subsurface temperature at the target place should be done first (after temperature survey of the wells) to see the applicability of GSHP systems.
- Monthly mean maximum and minimum air temperatures may be used in the comparison.
- Similar methods can be applied for moderate climate areas to estimate cost performance of GSHP for space heating.

3. Regional groundwater flow simulation

- Regional groundwater flow simulation in a scale of whole plain or basin should be conducted to get input data for local heat exchange simulation for the places without well data.
- Water table, chemical component (electric conductivity) of groundwater, and temperature profile of the well may be used as a constraint for regional groundwater flow simulation.

4. Heat exchange simulation of the site

- Using results of groundwater flow simulation as boundary conditions, a local heat exchange simulation will be conducted. Its result will be used for making a suitability map.
- For a closed-loop GSHP system, the thermal response test result is an important input data for heat exchange simulation, as well as groundwater flow rate (or effective heat conductivity), and hydraulic head of the place.
- For an open-loop GSHP system, hydraulic conductivity, porosity, heat capacity, and heat conductivity are needed.

5. Making suitability map

- Weighted overlay method may be used for making a suitability map.

- For a closed-loop system, overlaid parameters are groundwater velocity, sand-gravel ratio, and water table.
- For an open-loop system, overlaid parameters are horizontal and vertical groundwater flow rate and permeability of geological layers.
- Making a suitability map for both space heating and cooling in moderate climate areas needs only parameters listed above, while that for space heating needs subsurface temperature data additionally.

(2) Thermal response test (TRT)

A thermal response test on site is recommended especially for large facilities to confirm the system design is appropriate.

(3) Monitoring the installed GSHP system

- For long-term sustainability, monitoring of the system is important.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored to measure the real effective thermal conductivity and to monitor the subsurface thermal influence.
- Also, ideally the air temperature of the air-conditioned room will be monitored to assure that the system is working effectively.
- The flow rate and temperature of the primary and secondary fluid and electric consumption of the heat pump and circulation pump should be monitored to calculate actual COP and long-term performance including extracted heat from underground, saving energy and running cost.

For GSHP systems, simulation on the system performance using subsurface characteristics data may be done for system design. Unlike geothermal power plants, system performance is mainly controlled by system design suitable for the subsurface characteristics of the site, not by the nature of the resource. Monitoring is conducted to check the real system performance.