Chapter 6

Compilation of Case Studies

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Chapter 6

Compilation of Case Studies

6.1. Power Generation and Direct Heat Use

The lessons learned in Chapter 5 for high-enthalpy geothermal utilisations (power plant and direct heat use) are summarised below.

China 1: Yangbajain (binary power plant)

- Lack of systematic survey: 'Seeking heat from heat' type of exploration.
- Failure in implementing reinjection: Importance of injection was recognised at start of production but problems related to poor skills of drilling/operating crew and scaling in initial injection cools, prevented the successful full implementation of reinjection.
- No prevention of subsidence: Caused abolished well and dry-out of natural manifestation.
- Delay of strategy change in reservoir management: Although the shallow reservoir encountered pressure and temperature drop, they did not change the production zone into deep reservoir, that caused drastic production decline.

China 2: Xiaotangshan (direct heat use from single liquid phase reservoir)

- Successful reinjection in production scale may recover water level.
- Monitoring of water chemistry including geothermometry, water level, and water quantity is important.
- Resources management was achieved by water level control.

Indonesia: Case study from six geothermal fields

- Most common problems in geothermal power plant are scaling (in production wells, piping, reinjection, and turbine), corrosion (in particular in production wells), and water mixing.
- Chemical inhibitor and mechanical cleaning (workover) are the most common methods to overcome the mineral scaling problems.
- Make-up well is common practice in order to maintain steam supply.
- Major surveillance activities are to monitor the quantity of steam produced, the

geochemistry of reservoir fluid, microgravity, induced seismicity, temperature, and chemical tracers.

- Silica sinter problem was reduced by new production design (by pressure and temperature control)

Japan: Matsukawa (Steam dominated reservoir with super-heated zones)

- An over-heated vapour dominant reservoir, such as Matsukawa, showed an increasing stem production with water injection.
- Tracer test is one important method for evaluation of the production recovery.
- We have to check other over-heated reservoirs and water dominant reservoirs to discuss the possibility of EGS and water injection to maintain geothermal power generation.

Philippines 1: Tiwi geothermal field

- The Tiwi geothermal field has been affected by a number of resource management challenges including meteoric-water influx (MR), injection breakthrough, acid fluids utilisation, scaling, and corrosion.
- The biggest challenge was the influx of MR in the Nag area, which necessitated the relocation of the entire production system. Repeat precision gravity survey is becoming useful for monitoring.
- To prevent detrimental effects of injection breakthrough, the relocation of 'infield' to 'edgefield' and 'outfield' injection was an effective strategy in the Nag area.
- Production wells 'at risk' are carefully monitored and allowable injection rates are limited for specific injection wells to avoid cooling.
- As for mitigating corrosion attack from acidic fluids, the new well design with a cemented blank liner run to below –1000 m mean sea level (msl) was proven effective to case-off potential acid zones.
- For controlling superheated steam zone, pressure balance of shallow steam zone and deep reservoir is essential and pressure monitoring in these zones are important.
- The key to overcoming these challenges is to have a strong multi-disciplinary resource team in place that can understand the problems and provide feasible solutions.

Philippines 2: Tongonan geothermal field (TGF)

- The experiences in TGF have shown that proper resource management and well intervention are effective in sustaining field generation.

- Though the effects of pressure drawdown due to extraction are inevitable, the negative impacts on steam flow production can be controlled.
- Some of the strategies used in TGF and described in this work are:
  - optimisation of injection loading so that the benefits of mass recharge and pressure support are balanced against the drawbacks of cooling and mineral deposition;
  - use of sacrificial wells to redirect cold natural recharge away from the depressurised production area; and
  - well-intervention techniques to address decline in production due to mineral deposition within wellbores.
- Careful monitoring of reservoir conditions through geochemical and reservoir engineering data were found to be useful in developing sound resource management strategies.
- As production continues, integration of the different data available will lead to continuous refinement of these strategies or even replacement with better methods.
- With sound resource management, TGF may be able to sustain production for another 25 years.

Thailand: Fang binary plant (economical sustainability)

- Mineral scaling problem is solved by chemical or mechanical cleaning to sustain system's operations.
- The operating cost of the geothermal project was three times cheaper than production from fossil fuel, with several times cheaper maintenance cost and longer durability, which may be an important factor for sustainable use in commercial sense.

Example of other country: New Zealand fields (liquid dominated reservoirs)

- Region of subsidence is strongly related to geology: clay in shallow subsurface.
- The initial subsidence was caused by mass production, but the major (ten times larger) subsidence was due to pressure drop by injection into steam zone.
- Subsidence rate was stabilised by deep injection (stop shallow injection), but slow subsidence is continuing due to creep phenomenon triggered by early injection.

Tables 6.1 shows the summary of lessons learned for power plant and direct heat use in a matrix of problems and solution in each case study.

Table 6.1. Summary of Lessons Learned for Power Plant and Direct Heat Use

	Well and Reservoir Processes Monitoring	**Reservoir Drawdown**	**Brine and Condensate Reinjection**	**Super-Heated Steam and Erosion**	**Mineral Scaling (Sio2, Caco3, Caso4, etc.)**	**Corrosion**	**Others** -Subsidence -Turbine rundown -Poor permeability
China Yangbajain	Minimal monitoring for wells and reservoir.	Shallow reservoir has encountered pressure drawdown and temperature decline.	Carried out reinjection test several times, but reinjection was not successful.	No occurrence	CaCO3 and SiO2 scaling occurred with mechanical cleaning conducted daily.	No serious corrosion occurred in old wells.	Deep reservoir has been explored and assessed, but information was not used for reservoir management.
China Xiaotangshan **Direct Heat Use**	Monitoring has been carried out over time for 58 years.	Reservoir drawdown has been controlled basically by reinjection where water level had risen continuously over 3 years.	Reinjection has reached 40%–60% of production flow rate.	No occurrence	No scaling problem so far for the low-temperature geothermal fields.	Very little corrosion for low temperature fields.	No other problem
Indonesia Six fields	Major surveillance activities are to monitor quantity of steam produced, geochemistry of reservoir fluid, microgravity, induced seismicity, temperature, and chemical tracers.	Reservoir drawdown results to pressure drop which occurs mostly due to cooler water mixing other than over production. Additional wells are needed to	Problems related to reinjection are scaling and cooling due to brine water mixing with reservoir fluids. Reinjection strategy was reformulated to	Not a problem	Scaling mostly occur in production wells, pipelines, reinjection wells, and turbine leading to generation decline. Mechanical and chemical cleaning from scaling are	Corrosion occurs in production wells and also together with erosion in the turbine blades.	Low permeability wells are enhanced by stimulation using massive water injection, thermal cracking and

		maintain geothermal steam supply.	reduce effects of mixing problem.		practiced to maintain well production.		with acidizing.
Japan Matsukawa	Production recovery is monitored through tracer tests.	Effects of pressure drawdown is monitored by determining the relationship between production rate and injection rate.	Effects of reinjection is monitored by determining the relationship between production rate and injection rate.	A dominant super-heated steam reservoir such as Matsukawa, showed an increasing steam production with water injection.	(Not discussed in case studies)	(Not discussed in case studies)	(Not discussed in case studies)
Philippines Tiwi and Tongonan	Monitoring of geochemistry and reservoir engineering data is done to develop sound resource management strategies: 1) high-risk producers are monitored and injection rates are limited for specific injectors to avoid cooling, 2) wells with	Effects of pressure drawdown have negative impacts on steam flow production. This can be controlled through: 1) optimisation of injection loading, and 2) balancing mass recharge and pressure support against the drawbacks of	Influx of reinjection returns necessitates the: 1) dispersion farther outfield of the reinjection system or even relocation of the entire production system, 2) repeat precision gravity survey is becoming useful	In controlling superheated steam zone: 1) pressure balance of shallow steam zone and deep reservoir is essential, 2) pressure monitoring in these zones is important, and 3) erosional effects are	Intervention techniques to address decline in well performance production due to mineral deposition includes: 1) mechanical clearing by well workovers, 2) acidizing, 3) scale inhibitors, 4) higher separation pressures, and	Mitigation of corrosion attack from acidic fluids can be done through: 1) new well design with a cemented blank liner run to case-off potential acid zones, 2) use of corrosion-	The key to overcoming these challenges to sustaining production is to have a strong multi-disciplinary resource team in-place that can understand the problems and provide

	performance decline were stimulated to sustain field generation, 3) data integration leads to improved reservoir management strategies, and 4) sound resource management can sustain production beyond 25-year economic life.	cooling and mineral deposition.	for monitoring, and 3) use of sacrificial wells to redirect cold natural recharge away from the depressurised production area.	addressed with either wellhead washing or drilling of deeper M&R wells into liquid reservoir.	5) modification of discharge fluid chemistry through acid injection.	resistant alloys for casings/liners and wellhead cladding, 3) buffering with caustic soda downhole, and 3) corrosion inhibitors.	feasible solutions.
Thailand Fang	No continuous applications	No occurrence	No occurrence	No occurrence	Mineral scaling problem is solved by chemical or mechanical cleaning to sustain system's operations.	No occurrence	The project's operational cost is 3 times cheaper than from fossil fuel, also with cheaper maintenance with longer durability.

Source: Edited by authors.

6.2. Ground Source Heat Pump

The lessons learned in Chapter 5 for low-enthalpy geothermal utilisations (GSHP) are summarised below.

China

- Mapping shallow geothermal energy conditions, such as water type and soil type, is important to perform proper design of the GSHP systems.
- Monitoring of ground temperature is important to monitor thermal recovery of the ground and to assure the balance of heating and cooling.

Japan

- For sustainable use of GSHP systems, system design suitable for the subsurface condition of the place as well as GSHP application purpose is needed.
- Heat exchange rate and preferred drilling depth of a GSHP system varies with local subsurface conditions.
- In this context, a hydrogeological survey is very important for places in sedimentary basins and plains, while only rock properties are important for places with near surface hard rocks.
- To compile suitability maps of GSHP systems for sedimentary regions groundwater and geological surveys are needed to perform numerical simulation on groundwater flow and local heat exchange rate.
- Design of GSHP system can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.
- Suitability map can be made in the following order of procedures:
  1. Groundwater and geological survey
  2. Regional groundwater flow simulation
  3. Heat exchange simulation of the site
  4. Making suitability map
     - Weighted overlay method may be used for making suitability map.
     - For closed-loop system, groundwater velocity, sand-gravel ratio and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used.
     - Space heating suitability map needs subsurface temperature data additionally.

South Korea

- For long-term sustainability, monitoring of the system is important. The monitoring is mandated by a law in the case of South Korea but the problem is that the monitoring data has not been properly analysed in many cases.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored.

- Flow rate and temperature of the primary and secondary fluids and electric consumption of the heat pump and circulation pump should be monitored to calculated COP and long-term performance including extracted heat, amongst others.

Thailand

- For GSHP application in tropical regions where only space cooling is needed, the underground temperature should be measured first to ensure the applicability of the GSHP system.
- If the underground is cooler than atmosphere at least in daytime, GSHP may be effective.
- Thus as results of comparison of underground and atmospheric temperatures, applicability of GSHP system is shown for many cities in Thailand.

Viet Nam

- The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated.
- For GSHP application in tropical regions, the ground temperature should be measured first to ensure the applicability of the GSHP system in terms of temperature advantage.
- If the underground temperature is lower than the atmosphere at least in daytime, GSHP may be effective. Thus temperature survey results shows applicability of GSHP system in Ha Noi and many areas in Southern Plain of Viet Nam.

Table 6.2 shows the summary of lessons learned for GSHP in a matrix of problems and solution in each case study.

Table 6.2. Summary of Lessons Learned for Ground Source Heat Pump

China	Cost effective GSHP system design	Mapping shallow geothermal energy conditions, such as water type and soil type
	Monitor thermal recovery of the ground and to assure the balance of heating and cooling	Monitoring of ground temperature
Japan Tsugaru Plain and Yamagata Basin	Heat exchange rate and preferred drilling depth of a GSHP system varies from place to place both for open and closed loop systems.	Geological survey should be done to perform numerical simulation on local heat exchange rate are needed to compile suitability maps of GSHP systems. For sedimentary basins and plains, hydrological surveys should be done as well to conduct groundwater flow simulation to know water level and/or effective heat conductivity of the place.

	Low system performance and high initial and/or running cost because of inappropriate system design.	It may be improved by utilising such suitability maps.
	Procedures for making suitability map	1. Groundwater and geological survey 2. Regional groundwater flow simulation 3. Heat exchange simulation of the site 4. Making suitability map 3 and 4 differ for closed and open loops.
	Other matters learned from the case study	▯ Weighted overlay method may be used for making suitability map. ▯ For closed-loop system, groundwater velocity, sand-gravel ratio and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used. ▯ Space heating suitability map needs subsurface temperature data additionally.
South Korea Sejong Metropolitan City	Long-term sustainability	Monitoring of the system is important
	Subsurface temperature monitoring	Idealistically, down to the depth of heat exchange borehole is desired.
	Surface monitoring	Flow rate and temperature of the primary and secondary fluids and electric consumption of the heat pump and circulation pump should be monitored to calculate COP and long them performance including extracted heat.
Thailand Chao Phraya Basin **Viet Nam** Red river plain and Southern Plain	Tropical regions needs only space cooling but subsurface temperature might be high.	Underground temperature should be measured first to ensure the applicability of the GSHP system. If the underground is cooler than the atmosphere at least in daytime, GSHP may be effective.
	Subsurface temperature information	The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated.