

THE ENVIRONMENTAL IMPACT OF THE GEOTHERMAL INDUSTRY

by D. Mendrinou and Dr. C. Karytsas

*Centre for Renewable Energy Sources
19th km Marathonos ave, 19009 Pikermi Attikis, Greece.*

1. Introduction

Geothermal energy is the heat of the earth. Medium and/or high temperature geothermal systems are classified either as hydrothermal systems (low or high enthalpy), which are encountered in specific locations associated with the presence of fluids and permeability within the earth, or as enhanced geothermal systems, which can be engineered everywhere. The economics of the latter can be improved if they are located within or close to the boundaries of a hydrothermal system.

2. Geothermal Heat Pumps

Geothermal heat pumps utilize the heat content of the upper part of the earth, and do not have any adverse environmental impact related to the geothermal energy itself. However, as heat pumps, they need considerable quantities of electricity for their operation and they contain refrigerants of very high greenhouse potential, in case they leak to the environment. Therefore, their environmental impact is limited to contribution to the greenhouse effect due to electricity consumption and due to possible refrigerant leakages. Due to the higher efficiency of the geothermal heat pumps (COP = 4 to 6) compared with air source heat pumps (COP = 2,5 to 3,5) and fossil fuels (efficiency = 80-90%), overall impact to the greenhouse effect is significantly less than burning fossil fuels or using air source heat pumps.

3. Low Enthalpy Hydrothermal Fields

The positive environmental impact of all geothermal plants is attributed to foregone CO₂ and other emissions (e.g. carbon monoxide, carbon particles, nitrogen oxides, sulfur oxides), had the same quantity of energy been produced by fossil fuels.

However, in some low enthalpy geothermal fields the deep hot water may contain dissolved CO₂ in the form of bicarbonate ions. When these fluids are brought to the surface and their pressure is lowered, they tend to deposit calcite and release CO₂. Such fluids are usually located at the margins of larger hydrothermal systems. In Nigrita geothermal field of Serres prefecture, Greece, which produces CO₂ rich geothermal fluids of 60°C, the corresponding CO₂ emissions are 15-20 times less than the ones released by fossil fuels when producing the same amount of energy. The CO₂ emissions from a geothermal field can be minimized by engineering the exploitation scheme accordingly. For example, maximizing the energy extracted from a given flow rate by placing the users in cascade, results in minimum CO₂ emissions. In agricultural uses, the geothermal CO₂ can be directly released within the greenhouse, in order to increase the growth rate of the plants and save fossil fuels.

Adverse environmental impact may occur from low enthalpy geothermal utilization, associated with the chemistry of the geothermal fluid, which may include considerable quantities of chloride, small quantities of boron, and traces of arsenic, ammonia, mercury, or heavy metals, making it unsuitable for disposal to the surface. The problem is effectively solved by reinjecting all the produced geothermal fluid to the same deep reservoir it originated from. This practice also has benefits to the water replenishment of the deep system, improving sustainability and the economic life of the plant.

Other impact from long term low enthalpy geothermal utilization may be the dropping of water level of near surface aquifers and the flow reduction or dry-up of nearby springs and shallow water wells. The problem can be solved by reinjection, effective reservoir engineering and if the previous two measures do not solve the problem, by donating deep wells to affected water users.

4. High Enthalpy Hydrothermal Fields

In high enthalpy hydrothermal systems, the steam phase of the geothermal fluid frequently contains small quantities of non-condensable CO₂, the quantity of which varies from field to field but it is limited to a few percentage units, usually in the range 0,05-5%. CO₂ emissions from geothermal power plants compared with conventional power plants are presented in table 1.

Table 1: Comparison of CO₂ emissions between geothermal and conventional power plants

Plant	Net Power, MW(e)	CO ₂ , % w/w	Conversion efficiency	CO ₂ emissions, kg / kWh(e)
Milos, Greece	-	1,0 – 1,5 %	19,1 %(*)	0,10
Lago	8,30	1,7 %	13,3%	0,16
Monterotondo	8,19	1,6 %	13,2%	0,16
Molinetto	17,95	4 %	17,7%	0,29
Gabbro	16,52	12 %	14,6%	1,05
Radicondou	36,89	5 %	19,0%	0,34
Travale	40,75	5 %	21,0%	0,31
Natural Gas			50%	0,38
Diesel Oil			33%	0,75
Coal			33%	0,90

(*) steam phase only

The CO₂ emissions of the geothermal plant are expected to decline over time, after many years of exploitation, especially if reinjection is practiced. In high enthalpy hydrothermal systems, CO₂ emissions can be reduced considerably by increasing conversion efficiency and dramatically, e.g. by one order of magnitude (5-10 times or even more), by utilizing all the waste heat from the plant. One way to do this is to introduce geothermal heat and power cogeneration plants by coupling the power plant with a district heating system.

Exploitation of high enthalpy hydrothermal reservoirs, concerns much more energy quantity and generates waste both in terms of liquid brine and steam. The environmental impact of the liquid brine, is similar to the one of low enthalpy geothermal energy, as has been described above.

Additional and more intense effects to local environment are associated with the chemistry of the steam, which may contain non condensable gases, such as CO₂, traces of H₂S and entrained silica or other dissolved solids in the liquid phase. In Milos field, during the short time operation of the 2 MW(e) pilot plant, sulfur smell and silica scale on car windows were two of the three annoying factors to local population. These problems can be effectively alleviated by minimizing the steam losses from the geothermal plant (in fact steam losses should be allowed only at the safety valves), and by conveying the non-condensable gases to the cooling tower draft, where they are diluted by large quantities of air. If these measures fail to limit the H₂S concentration in the air below the smelling threshold, then an H₂S treatment plant should be installed.

Other problems associated with high enthalpy hydrothermal plants are:

- Micro-seismic activity: it is of small magnitude, only registered by the seismographers and does not pose any threat to buildings or structures. It associated with fracture development in both reinjection and production zones. In Berlin geothermal field, El Salvador, after 7 years of monitoring magnitudes reported fell in the range 0-3. Monitoring micro-seismic activity during exploitation for further research is enough.
- Soil subsidence: it is of one or more meters magnitude and should occur in the centre of the production zone after many years of exploitation and withdrawal of large quantities of geothermal fluids. Horizontal soil movements are also possible. In Wairakei, New Zealand, after 20 years of exploitation, a subsistence zone more than 2 meters deep covering an area of 1 km² has been observed at the borders of the production zone. Maximum reported subsistence was >9 meters. The problem is alleviated by reinjecting both the separated liquid phase and the steam condensate back to the geothermal reservoir. During the plant design phase, care should be taken not to locate in the subsistence zone any buildings, pipelines or other structures. Furthermore, monitoring micro-gravity transients and regular topographic surveys are necessary during exploitation, in order to study the evolution of the subsistence zone.
- Noise: can be severe and a nuisance to local residences who live close to the geothermal plant. In Milos field, during the short time operation of the pilot plant, noise was the third annoying factor to local population. It is encountered by proper plant engineering (e.g. avoiding noisy equipment) and by placing noise barriers if necessary.
- Damage to local flora: it occurs every time steam or hot geothermal fluids are released on local plants. It happens due to the high temperature and salinity of the geothermal fluids. During the recent exploration of the Vounalia area in Milos geothermal field, several cedar trees were withered due to careless practice of the drillers during well testing. Care should be taken during the exploration and field development phases for proper disposal of fluids delivered to the surface. Removal of damaged trees, plants, etc., may be necessary for improving local aesthetics, while compensations for damaged property should be foreseen.
- Aesthetics: with proper design, the geothermal plant can be transformed to a tourist attraction, rather than an ugly mass of metal.
- Heat pollution: when waste heat is released to local environment. It can be encountered by minimizing the waste heat disposed to the surface from the plant. Effective solutions are reinjection, and geothermal heat and power cogeneration.

5. Enhanced Geothermal Systems

In the case of enhanced geothermal systems, where water is initially injected and then circulates through the system, not only zero CO₂ emissions are foreseen, but also none of the above problems are anticipated. However, as mentioned above, it pays to engineer enhanced geothermal systems within or just outside the boundaries of a hydrothermal system, in order to benefit from bonuses in temperature, depth and limited natural permeability or fluid presence. In that case, some of the environmental consequences mentioned above may occur, but probably in a much lesser extent and magnitude. But we cannot tell for sure what will be the case, as no plants are in operation in such systems at present.

One problem that has been reported during engineering of enhanced geothermal reservoirs, is the occurrence of micro-seismic activity, probably associated with the hydraulic fracturing works. These micro-earthquakes have a magnitude up to around 2 in the Richter scale and pose no danger to existing buildings or structures. Whether they will also be present during exploitation, and how they will evolve overtime, remains to be identified in the field, but we anticipate that this micro-seismic activity should not be greater than the one encountered in hydrothermal systems. The reaction of local people to a possible presence of micro-earthquakes remains to be identified and managed.

In any case, in order to a-priori guarantee the success of a geothermal exploitation scheme, close collaboration, cooperation and relations with the local community should be established. That way the local community will maximize their benefit from the geothermal plant, any misunderstanding and possible conflicts will be resolved and the consent of the local community towards geothermal development in their region will be achieved. Related good practices have been adopted in the geothermal fields of Philippines by PNOC EDC, where approximately 2000 MW(e) of geothermal power plants are in operation.

References

1. Santini P., 2005: Modular Geothermal Plants in Italy: Technical Characteristics and Operation Results, Proc. World Geothermal Conference 2005, Antalya, Turkey, 24-29 April.
2. Rivas J.A., Castellon J.A., Maravilla J.N. 2005: Seven Years of Reservoir Monitoring at Berlin Geothermal Field, Usulután, El. Salvador, Proc. World Geothermal Conference 2005, Antalya, Turkey, 24-29 April.
3. De Jesus A.C. 2005: Social Issues Raised and Measures Adopted in Philippine Geothermal Projects. Proc. World Geothermal Conference 2005, Antalya, Turkey, 24-29 April.
4. Mendrinós D., 2000: Geothermal Energy and the Environment, 3rd Conference on Natural Wealth, Technical Chamber of Greece, Athens 22-24 November, Proc. Vol. B', pp. 577-581.
5. Allis R.G. and Hunt T.M. 1986: Analysis of exploitation-induced gravity changes at Wairakei Geothermal Field. *Geophysics*, Vol. 51, No 8 (August), pp 1647-1660.