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Environment and geothermal energy - A case study in Western Anatolia, Turkey

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ABSTRACT

The geothermal energy together with solar, wind, biomass, and water power should be used as an energy resource to protect the environment. Utilisation of geothermal energy reduces the emission of greenhouse or aggressive gases going into the troposphere. On the contrary, the utilisation of geothermal energy can affect problems to the environment such as (i) destructive exploitation, (ii) emission of hazardous dissolved compounds into rivers and pollution of soils, and (iii) emission of aggressive gases - without complete reinjection. Inhibitors which are used to prevent corrosion and scaling can contaminate groundwater resources after reinjection. To improve the necessity for reinjection, a case study was carried out in the Eastern **Buyiik** Menderes Graben of Western Anatolia.

KEYWORDS

Geothermal energy, environment, greenhouse effect, emissions, pressure drop, inhibitors.

1. Introduction

Geothermal energy is a sustainable energy resource. The utilisation of the Conventionals such as coal, oil, and natural gas pollutes the environment drastically as they emit CO_2, CO, NO, SO_2, dust and soot. Geothermal energy is considered to be environmentally friendly. Utilisation of any energy resource affects the environment. However, the negative effects of the Renewables are less than those of the Conventionals.

2. Investigated area and methods

The studies were conducted in the Eastern Buyiik Menderes Graben and the Kizildere geothermal plant (10 MW_e) of Western Anatolia. **A** 180 MW_t district heating system for Denizli (with reinjection) was planned. The production of geothermal fluid by the geothermal plant causes environmental problems such as (i) drop of the reservoir pressure and (ii) contamination of the Büyük Menderes River (BMR) with boron.

The sinter terraces of Pamukkale (25 km east of Kizildere) consist mainly of calcite. It has been precipitated since prehistorical time by the geothermal outcrop water. Due to the regional tourism, several hotels and thermal wells were built. The drop of the reservoir pressure decreased the carbonate precipitation. The weathering attacks the terraces now.

Investigations on the thermal fluids, on the Buyiik Menderes river water, and on the sinters were carried out. Physical parameters and unstable constituents were determined onsite, the rest was determined in the laboratory. The sinters were analysed chemically by cold HCl digestion and mineralogically (semi-quantitatively) by XRD. P/T-logs were used to calculate the content of CO_2 within the reservoir fluid. Balances were performed.

3. Benefit: less greenhouse effect and less tropospheric pollution

The earth's atmosphere accumulates heat via aerosols and atmospheric greenhouse gases such as carbon dioxide, methane, water gas, and dinitrogenmonoxide. The CO_2 content in the atmosphere was increased drastically after the industrial revolution. The increase depends mainly on the consumption of coal, later oil, and gas. However, CH4 was emitted as well. A part of the emission of CH_4 is from the exploitation and utilisation of fossil gas. Its greenhouse effect is 30 times higher than that of CO_2.(for details see GIESE 1998: 3).

The forced accumulation of heat in the troposphere can cause climatic changes. The convective systems, the water budget, and the global ocean level may change. The "climatic catastrophe" is stimulated by the rise of the greenhouse and feedback effects.

Reduction of emissions - Processing efficiency

By the utilisation of sustainable energy resources – regardless of their emissions due to processes and equipment production – the emissions of CO_2 and CH_4 can be reduced preventing exploitation and utilisation of fossil resources. By substituting fossil fuels by geothermal energy, the emissions of SO_2, NO,, and dust can be decreased further (table 1).

In conventional power plants, the energy released from 1 kg of coal is equal to 29.3 MJ (123 g coal = 0.123 SKE ≡ 1 kWh_t; 1 SKE ≈ 0.9 kg graphite carbon). The application of sustainable energies reduces the CO_2 emission by 0.5 kg per kWh of total energy. But, the saving has to be reduced by the specific CO_2 emission (depends on the efficiency, table 2).

Table 1: Saved emission (negative) from a conventional coal power plant **for** *thermal and electrical application) and emissions (positive) from the Kizildere geothermal plant (in kg per kWh_t* **or** *kWh_e; FRIDLEIFSON & FREESTON 1994; GIESE 1997; Inf. Eng. G. Ruoff).*

Resource	Efficiency γ_{tot}	kWh specific Emission	CO_2	SO_2/H_2S as S	NO_x/NH_3 as N	Dust
Coal	0.4	kg/kWh_e	-1.25	$-1.1*10^{-2}$	$\leq -5.0*10^{-3}$	$-2.5*10^{-1}$
Coal	1.0	kg/kWh_t	-0.50	$-4.4*10^{-3}$	$\leq -2.0*10^{-3}$	$-1.0*10^{-1}$
Geothermal	0.1	kg/kWh_e	+2.10	$+4.7*10^{-5}$	$+1.2*10^{-3}$	----

Table 2: Estimation of the efficiency factor γ_{tot} for the generation of electricity from and the direct application of geothermal energy and coal (idealised; GIESE 1998: 1).

	Units	Geothermal Electricity	Coal Electricity	Both Direct Applic.
T_{upper} (turbine)	°C	150	534	------
γ_{tot} (process)	dimensionless	0.1 to 0.2	0.3 to 0.4	0.5 to 1.0

In the conventional electricity generation from geothermal energy, energy loss can occur due to technical and physical effects such as (i) the primary heat loss from the silencer and the waste water, (ii) the secondary heat loss during the cooling-down of the steam pipe and due to turbine effects (CO_2; mechanical efficiency), and (iii) the thennodynamic loss (entropy loss). This loss can be expressed as (P = power, y = efficiency; GIESE 1998: 1)

$$P_{el} = P_{tot}*\gamma_{prim}*\gamma_{sec}*\varepsilon_{carnot} = P_{tot}*\gamma_{tot} = P_{eff}*\gamma_{sec}*\varepsilon_{carnot}$$

The upper turbine temperature is nearly the temperature of the separator steam. The lower temperature can be estimated to be 8 K more than the T of the environment (for a low-pressure turbine: $T_{cool} = T_{cond} + 5$ K, $T_{cond} = T_{env} + 3$ K). Using the CARNOT efficiency

$$\varepsilon = 1 - (T_{lower} / T_{upper})$$

and the calculated effective power (effective energy in time, $dE_{eff}/dt = P_{eff}$), the primary system efficiency can be calculated. Without thermal applications, the inner enthalpy of the residue below T_{upper} is not useful. Compared to the thermal application (perfect efficiency of up to 100%), the production of electricity (ε = **20%**) emits 5 times more CO_2 per kWh. Due to the higher energy specific emission, the question is, whether conventional generation of electricity from geothermal steam without new concepts (binary fluid, boost-up fuels) is likely. The secondary heat loss can be avoided using (i) better steam-pipe isolation, (ii) advanced technology, and (iii) separation of non-condensable gases (CO_2). Direct applications may avoid the primary heat loss up to 100%.

4. Negative effects to the environment

Three types of negative effects of the utilisation of geothermal energy without reinjection can be distinguished, (i) groundwater lowering, (ii) hydrogeochemical and thermal impacts into receiving streams plus geochemical impacts into the atmosphere, and (iii) the application of artificial substances by the injection into natural resources (inhibitors).

Precipitation	Evaporation	Recharge	Surface Runoff	Deficit
$m^3/(a*100\ km^2)$	$m^3/(a*100\ km^2)$	$m^3/(a*100\ km^2)$	$m^3/(a*100\ km^2)$	$m^3/(a*100\ km^2)$
$6.52*10^7$	$3.00*10^7$	$9.20*10^6$	$2.60*10^7$	$-2.80*10^5$

Technical feedback effects are (i) drop of the wellhead-pressure and decrease of the discharge, (ii) dislocation of the scaling precipitation, (iii) ending of the spontaneous outflow, and (iv) drop of the temperature and change of the chemical characters by bypass. Natural effects are (i) drying-up of spring sites, (ii) conversion of springs into vapour outcrops, (iii) conversion of vapour outcrops into cold-gas outcrops, (iv) interruption of the precipitation of natural sinters, and (v) dislocation of groundwater current regimes.

The overdraft of the thermal groundwater resources of Pamukkale has affected the overgrowing of erosion on the famous terraces. In 1999 the situation is worst. The body of the terraces is threatened by (i) mechanical aggression of the weathering and utilisation and (ii) chemical interaction with atmospheric gases, magmatic gases (sulfatification), and water according to:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2;\ CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2\ HCO_3^-$$

The regeneration of those terraces is necessary, e.g. by (i) stopping the thermal water production, (ii) re-irrigation (natural or artificially), (iii) artificial recharge of the groundwater by reinjection, and (iv) substitution of the geothermal energy by solar or others. A detailed hydrogeological study should be carried out.

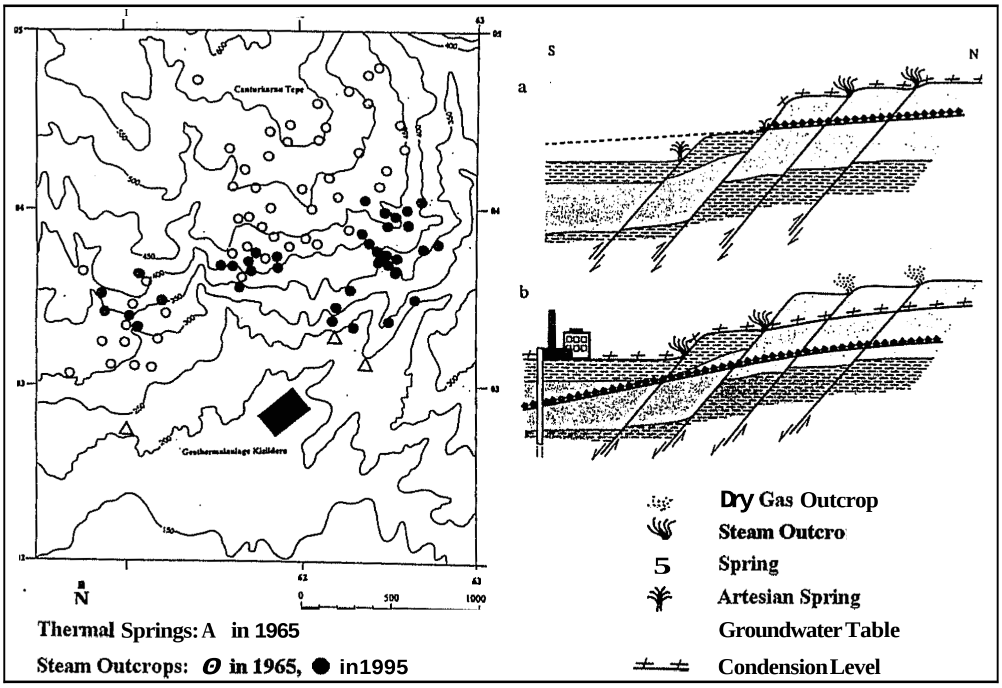

Figure 1: Hydraulic effects in the Kizildere geothermal field. Left: Dislocation of steam outcrops. Right: Scheme of the hydraulics before and after production started.

4.2 Hydrogeochemical and thermal effects

Emissions from the utilisation of geothermal fluids affect the environment. We have to distinguish (i) the emission of dissolved species plus heat going into rivers (receiving streams) and (ii) the emission of gaseous species going into the atmosphere.

4.2.1 RECEIVING STREAMS

After water-rock interaction, the TDS of (non saline) continental geothennal fluids does not exceed 10,000 mg/kg. If leaching of salts or incorporation of fossil brines is involved, the TDS easily can exceed 100,000 mg/kg. Emitted geothermal waste water can contain (i) high amounts of salts (e.g. NaCl), (ii) agriculturally hazardous species (e.g. boron), (iii) physiologically toxic substances (e.g. arsenic), and (iv) water polluting species (e.g. NH_4^+, NO_2^-, NO_3^-). Geothermal waste water after separator and silencer has a temperature of up to 100°C at pH 8-9.5. Under worst conditions, the utilisation of geothermal fluids without reinjection of the waste water can affect the environment drastically (figure 2).

The thennal aspects are (i) the suffering of the geothermal energy budget due to unnecessary losses and (ii) the disturbance of the ecology of surface-water biotopes by the thermal impacts. The influences depend on (i) the flow rate ratio between surface water and emission, (ii) the inner energy of the geothermal runoff, and (iii) the amount of environmental re-equilibrating effects (affecting the dimension of the influenced area). For instance, under worst conditions (dry-weather runoff of the Buyiik Menderes River during the summer) the maximum increase of the river water's temperature is **3** K (locally). In interference with nutrient inputs, ecological effects may occur. However, these effects **are** local, exceeded by the geochemical effects.

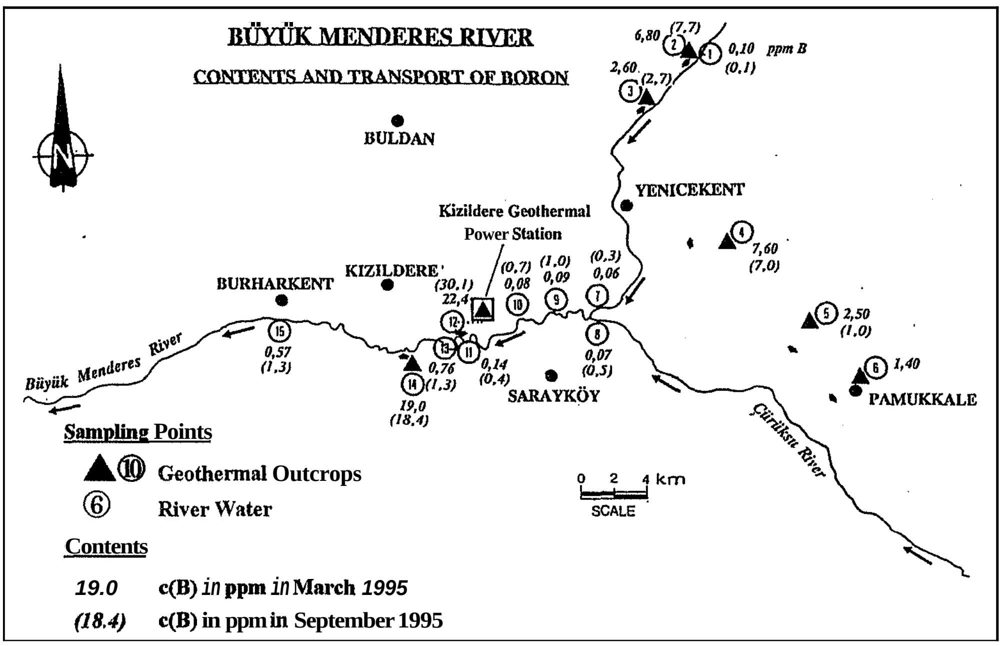

Figure 2: Geogenic background in and input into the Büyük Menderes River (of boron).

Geothermal waste water can contain chemical compounds which are aggressive agents to surface waters such as (i) salts, (ii) heavy metals (if they are present, often **As** and Sb), (iii) boron, and (iv) alkalines. In the Kizildere area during low-water flow rate (dry weather conditions) of the BMR, there is an high impact by (i) boron (GALLO 1998), (ii) nitrogen species, (iii) alkalinity, and (iv) salts. The emission by the Kizildere waste water amounts **7** g/s B, 1500 g/s dissolved solids, and 0.4 g/s **As.** However, the emission of **As** cannot change the content in the river water drastically. On the contrary, the boron emission results in a drastic pollution. During dry-weather run-off, the boron content in the river water can exceed the tolerance limit for the irrigation of citrus plants (2 mg B/l). Long-term irrigation using contaminated water pollutes the soil with boron. In the Kizildere region, contaminated agricultural areas without further utilisation exist.

4.2.2 EMISSIONS TO THE ATMOSPHERE

Geothermal fluids emit aggressive gases such as CO_2, H_2S, SO_2 (and H_2SO_4 aerosols), and NH3 (maybe HF and HCl; compare 3.1) to the atmosphere. The emission rate of carbon dioxide consists of (i) the geogenic background and (ii) the anthropogenic boost-up part. The overprint depends on chemical content of the reservoir fluid. In the Kizildere geothermal field, the emission of the greenhouse gas CO_2 amounts to nearly 500 t per day. The CO_2/energy ratio amounts to 2.1 kg CO_2 /kWh$_e$. After addition of direct applications, this ratio could be decreased to below 0.2. Coal power plants have a ratio of 0.5, oil power plants 0.3, and natural gas heating down to 0.24. The ecological cost of the CO_2-emission is estimated to be 200-400 DM/t emitted CO_2 (SCHIEFENDECKER et al. 1991).

Geothermal production without reinjection emits NH3 and H_2S to the environment. Atmospheric oxidation forces the metabolism of H_2S into sulphuric acid aerosol:

$SO_2 + 0.5\ O_2 \rightarrow SO_3$ $\quad\quad$ $SO3 + (x+1)\ H_2O \rightarrow H_2SO_4 * x\ H_2O$

There are wet (as rain) and *dry* deposition mechanisms (as fog, directly from air, or bound to dust particles). In humid regions the effect of volcanic acid rain can be observed ("dying forest" on São Miguel, Acores). In semi-arid climates the dry deposition succeeds (e.g. sulphatification of the Pamukkale sinter; see 4.1). S-species compounds threaten the health and can affect the ecology locally or regionally. In Lardarello/Italy the emission-energy ratio amounts to 3.5 g S /kWh$_e$, in Krafla/Iceland *6* (natural gas utilisation: 0.005, oil and coal applications: up to 11; FRIDLEIFSON & FREESTON 1994).

4.3 Application of chemicals

Depending on the precipitation of scaling in the production and reinjection systems, problems appear very often. Salty geothermal brines corrode casings or installed equipment. The addition of special artificial chemicals (inhibitors) can depress or stop the precipitation of scaling or the corrosion. Although the content of the inhibitor is very low (ppm), there exist two negative consequences, (i) high costs and (ii) pollution of the aqueous system. If the inhibitor is injected into the production well without further reinjection, the receiving stream will be polluted. If the inhibitor is reinjected into the reservoir, the groundwater will be polluted. The threat to the environment cannot be predicted as long as nothing is known about (i) the character of the substance at reservoir conditions and (ii) the identity and character of the metabolites which may fonn probably.

Inhibitors are very helpful substances. But, the groundwater resources have to be protected. Some producers try to hide the identity and the character of the inbibitors. Besides inorganic oligophosphates, several organic substances are used as inhibitors such as organic phosphates, **aminophosphonosulfoorganics,** or similar species. Substituted groups can be aromates like phenyl or benzyl. Organics like aromates, polycyclic aromates, and their derivates are harmful substances for groundwater.

5. Conclusions - Economy, ecology and society

Conventional resources such as coal, oil, natural gas, and atomic energy are still being consumed nowadays. These resources are not sustainable, and they are threatening to the environment. There are several reasons to force the utilisation of sustainable resources like solar energy, wind, biomass, water power, and ***geothermal energy*** immediately such as (i) the high cost of and the threat by the atomic industry, (ii) the emission of fossil CO_2, (iii) the contamination of the environment in general, and (iv) the working-out of deposits. But, the old structures of fossil energies resist. The ancient societies knew: by using the money as a means of measure, a loosening from the measure in human terms and a destruction of the environment occur. The Club of Rome (compare PEARMAN 1990) predicted the collapse of socio-economical-ecological structures and the (conventional) resources due to the expanding society. On the contrary, the principle of sustainability means any development of the world has to respect the interests of the future's generations and is not allowed to export regional problems. How to adapt these sustainable but in the beginning less effective energy resources to the recent circumstances? The answer must be: we have to. The reason is that there is no alternative way for the future. The society must accept that the benefit for community mainly depends on the health of the environment, on the health of the people, and less on the maximisation of financial profit. Everybody should agree to spend money for this new quality. The energy concepts for the future should prefer (i) electric and hydrogen technology, (ii) energy saving, and (iii) decentralised energy production, and they should not prefer (iv) any single „renewable" energy resource. Note: (1) no activity of the man to resist against the paths of the universe's entropy is neutral to the environmental and is finally successful. With respect to the universal history: **(2)** no endogenic or exogenic energy resource is renewable. The main point is: **(3)** we should not forget about our engagement for the environment. This includes (4) the discovering of sins and a decrease in or a prevention of negative effects.

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References

DOBBERSTEIN L. 1997. Zur Geologie im Norden des Geothermalfeldes Kizildere (W-Anatolien/Türkei). MSc Thesis FU Berlin Fac. of Geosciences: 40 p..

FRIDLEIFSON I.B. & FREESTON D.H. 1994. Geothermal energy research on development. Geothermics, **23** (2): 175-214.

GALLO, A. 1998. Erhohte Borgehalte in den Thermalwassern von Kizildere und des Umfeldes in der Riftzone des Buyiik Menderes, W-Anatolien/Türkei. MSc Thesis FU Berlin Fac. of Geosciences: 59 p.

GIESE L.B. 1997. Geotechnische und umweltgeologische Aspekte bei der Förderung und Reinjektion von Thermalfluiden zur Nutzung geotherm. Energie am Beisp. d. Geothermalfeldes Kizildere u. des Umfeldes, W-Anatolien/ Turkei. PhD Thesis FU Berlin: 201 p.

GIESE, L.B. 1998. DAAD Lect. Script **1:** Handbook on Applied Sciences in Geothermics. Block IV: Special aspects on the utilisation of geothermal resources: 41-43. **3:** Basics on Global Environmental Geology. Block 111: Global and regional atmospheric effects: 9-12.

PEARMAN G.I. [ed.] 1990. Limiting greenhouse effects controlling carbon dioxide emission. Dahlem Workshop Rep.: [number of pages unknown]; Wiley.

SCHIEFENDECKER B., BECKMANN H.-J. & BACHMANN I. 1991: Zur Wirtschaftlichkeit der Nutzung niedrigthermaler Tiefenwässer. In: BUSSMANN W., KABUS F. & SEIBT P. [eds.]. Geothermie - Wärme aus der Erde, 1. ed.: 138-154.