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GEOTHERMAL IN EUROPE

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GEO-HEAT CENTER QUARTERLY BULLETIN

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS

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GEOTHERMAL USE IN EUROPE

John W. Lund
Geo-Heat Center

Geothermal energy has been used for thousands of years in Roman and Ottoman baths and district heating in France during the middle ages, and for extracting various borate compounds at Lardarello, Italy, starting in the 1700s. These uses and their impacts on the local population can be read in detail in "Stories from a Heat Earth" edited by Cataldi, Hodgson and Lund (1999) and available from the Geothermal Resources Council. More recently, extensive direct heat utilization projects have been undertaken in many central European countries, and electric power developed extensively in Italy and Iceland. Finally, geothermal heat pumps have come into their own in Austria, Switzerland, Germany and Sweden.

The present status of geothermal use in Europe is as follows (Lund and Freeston, 2001; Huttrer, 2001). Note: Turkey and the Siberia area of Russia are included in these numbers.

As documented in the table below, geothermal has been reported used in 28 countries in Europe. The main high temperature resources suitable for electric power generation are only found in Italy and Iceland. Most of Europe is dominated with intermediate- to low temperature geothermal resources, thus direct uses such as: space heating, district heating, greenhouses, bathing, and geothermal heat pumps dominate. The direct-use amounts to 41.5% of the world's installed capacity and 40.5% of the annual energy use, with a

	Direct Heat		Electric		
Country	MWt	GWht/yr	MWe	GWhe/yr	Remarks (main uses)
Austria	255	447			Space/heat pumps
Belgium	4	30			Greenhouse/heat pumps
Bulgaria	107	455			Space/greenhouse heating
Croatia	114	154			Space/bathing
Czech Republic	12	36			Bathing/heat pumps
Denmark	7	21			District/heat pumps
Finland	80	134			Heat pumps
France	326	1,360	4	25	District/heat pumps
Germany	397	436			District/heat pumps
Greece	57	107			Greenhouse/bathing
Hungary	473	1,135			Greenhouses/district/bathing
Iceland	1,469	5,603	170	1,138	District/greenhouse/industry
Italy	326	1,048	785	4,403	District/greenhouse/industry
Lithuania	21	166			Heat pumps
Macedonia	81	142			Greenhouses
Netherlands	11	16			Heat pumps
Norway	6	9			Heat pumps
Poland	68	76			District/heat pumps
Portugal	6	10	16	94	Greenhouse/bathing
Romania	152	797	<2	8?	District/greenhouse/bathing
Russia	308	1,707	23	85	Space/greenhouse/industry
Serbia	80	660			Space/greenhouse/bathing
Slovak Republic	132	588			Space/greenhouse/bathing
Slovenia	42	196			Space/greenhouse/bathing
Sweden	377	1,147			Heat pumps
Switzerland	547	663			Heat pumps/bathing
Turkey	820	4,377	20	120	District/aqua/bathing
United Kingdom	3	6			District/heat pumps
TOTAL	6,281	21,526	1,020	5,873	

load factor of 0.39. Only four countries, Turkey, Portugal (Azores), Italy and Iceland have produce substantial electric power from geothermal energy. Romania has an experimental binary unit at the University of Oradea (see article this issue), Austria has installed a 240 kW binary unit at Altheim (operational in 2000?), and Greece at one time had a small generator on Milos (2 MWe). France and Russia have plants outside of Europe (Guadeloupe and Kamchatka), but are included in the above table. The electric installed power is only 13% of the world total, and the energy produced is only 12%, reflecting the low availability of high-temperature resources in the region..

The papers in this issue are edited selections from the European Summer School on Geothermal Energy Applications held at the International Geothermal Training Center of the University of Oradea, Romania in April/May 2001. Approximately 25 students from Turkey, Bulgaria, Romania, Slovak Republic, Poland and Greece attended the course. Twenty-five lectures were given by professionals from France, Iceland, Germany, Italy, Romania, Macedonia, Turkey, Portugal, Switzerland and the U.S. John Lund and Toni Boyd of the Geo-Heat Center, along with Gordon Bloomquist of the Washington State University Energy Program were the U.S. lecturers. The program was organized by Dr. Marcel Rosca with the help from members of the Romanian Geothermal Association: Ioan Cohut, Cornel Antal, Codruta Bendea and Miklos Antics, and with support from the Rector of the University, Dr. Teodor Maghiar. Copies of the proceedings (printed or CD-ROM) can be obtained from Dr. Marcel Rosca at: <mrosca@energ.uoradea.ro> or by mail: University of Oradea, 5 Armata Romana, Oradea, 3700 Romania. The Geo-Heat Center thanks the University and the authors for permission to reprint their papers.

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Lund, J. W. and D. H. Freeston, 2001. "World-wide Direct Uses of Geothermal Energy 2000," Geothermics, 30/1, Elsevier Science, Ltd., Oxford, UK, pp. 29-68.

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Figure 1. ***Students and lecturers from the Summer School in Oradea, Romania***.

INSIGHT INTO GEOTHERMAL RESERVOIR MANAGEMENT DISTRICT HEATING IN THE PARIS BASIN, FRANCE

Pierre UNGEMACH
Geoproduction Consultants, Paris, France

SUMMARY

The first attempt to exploit the hot waters occurring in the Dogger carbonate formations of mid-Jurassic age dates back to year 1962, at Carrières-sur-Seine west of Paris. The well, despite its high productivity, was abandoned due to highly mineralized brine incompatible with the disposal of the wastewater in the natural medium (a surface stream). This led, in 1969, Sthal, a private joint venture (Cgc, now Vivendi, operator, and Laurent-Bouillet) to commission the first field application of the geothermal doublet concept of heat mining combining a production well and an injection well pumping the heat depleted brine into the source reservoir.

The doublet (two deviated, 7" cased, wells) produced in self-flowing mode was put on line in 1971 on the Melun l'Almont emblematic site, south of Paris, to supply heat and sanitary hot water to the local residential dwelling compound. It enabled the use of the new titanium alloyed plate heat exchangers able to cope with a corrosive geothermal fluid -- a slightly acid (pH = 6), saline (30 g/L eq. NaCl) and hot (74°C – 165°F) brine. The system has been operating satisfactorily since start up, the doublet moving in the meantime towards a triplet array including two injector and one new, innovative, production well combining steel casings and freely suspended, non cemented, fiberglass liners. Noteworthy is that this pioneer achievement was completed independently from any energy crisis or public subsidies whatsoever. Regarded at the time as a technological, fairly exotic curiosity, it has been extended since then to the whole Paris Basin geothermal district heating schemes.

The energy price crisis following the 1970s oil shocks led the French authorities to promote, among other alternative energy sources, low-grade geothermal heat as base load to district heating grids and other space heating systems. This was concluded by the development, in the Paris Basin, of fifty-five geothermal doublets of which thirty-four are still operating to date (Figure 1).

This is indeed an outstanding, almost unique accomplishment comparable to the heating of the city of Reykjavik in Iceland, which belongs; however, to a significantly different geological (volcanic rocks, high source temperatures), technical (no reinjection) and socio-economical (insularity) context.

It has undoubtedly benefitted from three main driving factors: (1) the evidence of a dependable geothermal reservoir (Dogger limestones) of regional extent, identified thanks to former hydrocarbon exploration drilling (Ungemach, 1988); (2) a strong voluntary commitment of the State in favor of alternative energy sources and ad-hoc accompanying measures (mining risk coverage, mutual insurance–sinking funds against exploitation hazards, financial support to district heating grids and miscellaneous incentives); and, (3) last but not least, the location above the geothermal resource of large residential dwelling buildings, eligible for district heating, which are numerous throughout the Paris suburbs.

This stated, the geothermal venture did not avoid contagion from infantile diseases inherent to the implementation of new technologies as evidenced by various symptoms, mainly:

- Structural: lack of expertise from operators (chiefly of the public sector) in managing industrial installations and energy processes with a strong mining impact,
- Technical: insufficient mastering in operating heating grids, under a retrofitted scheme combining several base load, back-up/relief energy sources and fuels, repeated failures of submersible pump sets and, above all, devastating corrosion of casings, well heads and equipment by the geothermal fluid,
- Administrative and managerial: imprecise definition of the duties and obligations of concerned intervening parties (operators, engineering bureaus, heating companies, consultants) and of relevant exploitation/service contracts, inefficient marketing and negotiation of heat sales and subscription contracts, and
- Economical and financial: severe competition from conventional fossil fuels (heavy fuel oil, natural gas) penalizing heat sales and revenues, persistent low energy prices in the aftermath of the second oil shock, adding to a debt nearing 85 % of total investment costs in a capital intensive (5 to 8 Meuros(ε) ~ 4.5 to 7.2 million US$), low equity, high interest rate (12 to 16 %) environment; this clearly placed most geothermal operators in a typically third world situation.

With time and experience, structural and technical problems were overcome in many respects by (1) systematic monitoring of the geothermal fluid and primary production/injection loop, (2) periodic logging inspection of well casings, and (3) innovating work-over and chemical inhibition processes aimed at restoring well performance and preventing corrosion/scaling damage; the latter supported by the State through relevant R & D programs and funding.

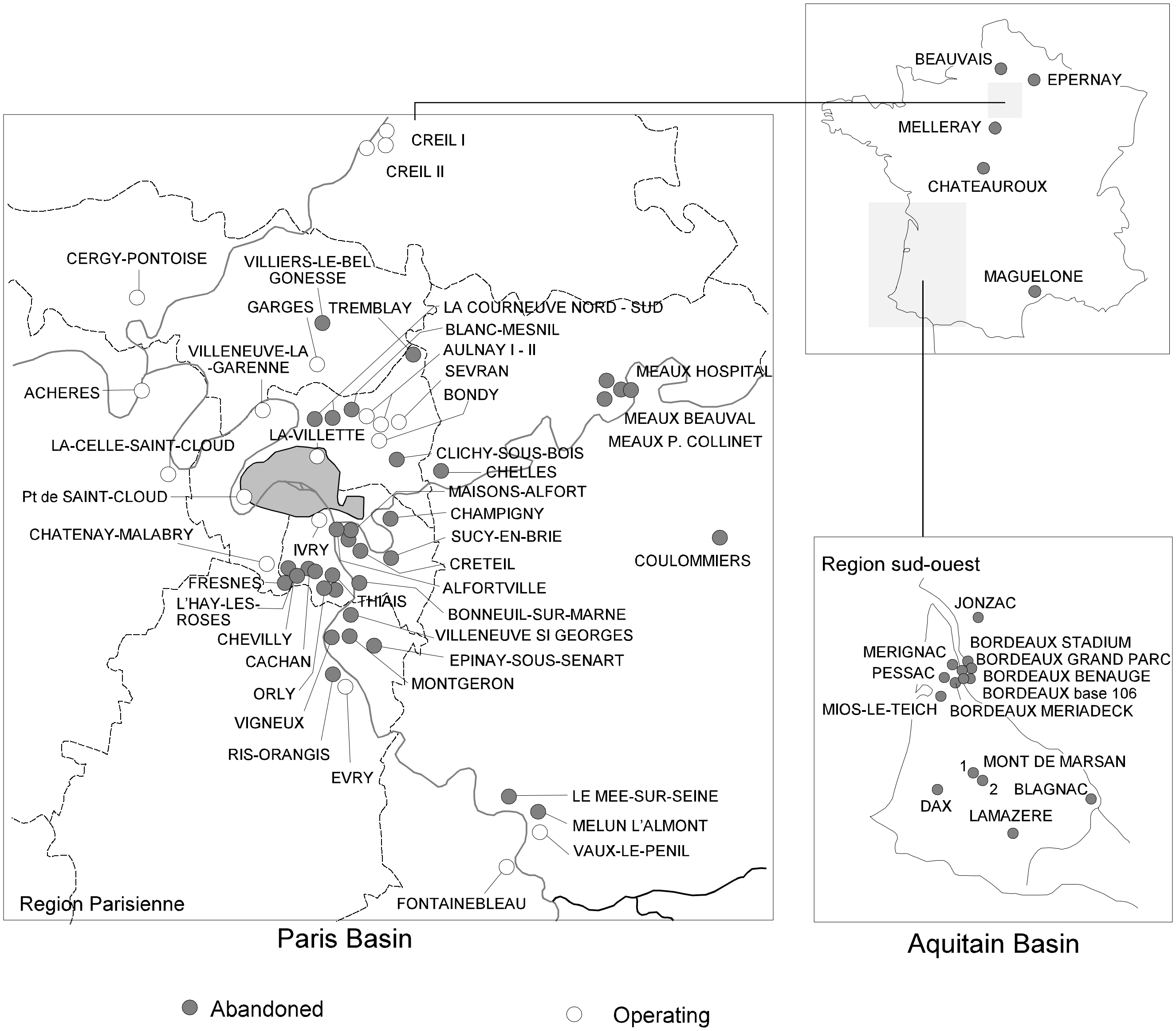


Figure 1. Location of French geothermal sites.

In the early 1990's, the so-called "Brosse Mission" made it possible to mitigate the debt charge, which was renegotiated via a spreading out of annuity repayments and interest rate reductions. Tax deductions were applied to geothermal operators, regarded therefore, as energy producers, the most significant one addressing the VAT (value added tax) (set a 5.5 % instead of the former 18.6 % rate). Simultaneously, improved administrative and financial management of geothermal district heating grids could be noticed among most operators.

The revival of a technology, at a time endangered to such a point that its abandonment has been seriously envisaged. This could be achieved at the expense of the shut in/cementing of 22 doublets, i.e. ca 40 % of the initial load and of a subsequent loss in heat supplies summarized in the following figures:

	1986 (target)	2000 (actual)
• number of operating doublets	54	34
• installed capacities (MWt)	360	227
• yearly heat supplies (heating + SHW) (GWht/yr)	2,000	1,240
• yearly fossil fuel savings (toe's)	135,000	225,000

The situation, although stabilized, remains precarious on purely economic grounds. As a matter of fact, falling energy price trends ultimately condemn geothermal district heating with the exception of 10 to 12, presently profitable, doublets.

The challenge is clear. To remain competitive, the geothermal MWht selling price must stand at ca 200 FRF (30 ε ~ 27 US$)(i.e., no more than 10 % above the natural gas) (LCI - lower calorific index) price according to the B2S (distribution) tariff offered to industrial users. Consequently, gas co-generation appeared to many geothermal operators, while negotiating renewal of past heat subscription contracts, as the only viable issue securing the survival of their grids and installations. Hence, as of late-2000, 12 combined gas co-generation plants and geothermal district heating grids were operating, a figure likely to match the twenty marks at the November 2001 deadline.

Gas co-generation provides stable earnings from sales to the utility (Electricité de France, Edf) of the whole generated power at a high contractual purchasing price, guaranteed over 12 years, elsewhere indexed on natural gas prices (i.e., at minimum financial risk). Co-generation supplies cheap heat as an electricity by-product recovered via the cooling of the generating units (gas engines or turbines). Maximization of power revenues causes co-generation to be operated as base (constant) load over the 151-calendar day contractual period (from 1st November to 31st March). This is at the detriment of geothermal heat whose contribution during winter drops by 40 %, if not more, when no extension of the existing grid is commissioned in the meantime (only three sites, out of 12, to date).

Environmental, clean air, concerns and limitation of greenhouse gas (mainly CO_2) emissions could turn geothermal district heating into an asset favoring its sustainability, if not its (re)development. Such a statement, however, ought to be mitigated in consideration of recent government measures and those likely to be decided with respect to energy and environmental fiscal matters which presently lack consistency.

First, the VAT applicable to heating grids subscription contracts has been reset at the 20.6 % rate against the former 5.5 % rate, the latter still in force for gas and power subscriptions as well as for maintenance/repair works in collective buildings and individual residences. This indeed penalizes geothermal heating grids vis-à-vis building fossil fuel fired boilers or gas/electricity individual heating as exemplified by the following costs (heating service charges/maintenance costs amounting to 3,500 FRF (530ε ~ 480 US$)(all taxes included) applicable in 1999 (Finance Law 2000, in force as of September 1999):

	FRF (VAT free)	FRF (VAT included)
• building heating, geothermal grid	2,920	3,462
• building heating, gas fired boilers	2,920	3,399
• individual gas heating	2,945	3,320
• individual electric heating	2,920	3,414

Second, the modification of the professional tax penalizes heating grids operated under lease/concession contracts (non-deductible infrastructure rental costs).

Thus, the fiscal prejudice amounts, for a heating grid serving 5,000 dwellings, to ca 450,000 FRF (68,600ε ~ 61,700 US$) (VAT free). It represents a serious handicap, especially while negotiating heat subscription contracts with, often shortsighted ownership representatives and other building managers. It clearly defeats the district heating route previously promoted by the State.

The State issued White Book introduces in its ecotax project (the so-called TGAP, general tax on polluting activities) a damaging discrimination aimed at exempting individual users (families) in the name of the principle that ecological taxation cannot apply to them! In fact, available energy consumption statistics, summarized hereafter:

	Fuels (Mtoe's/yr)	Electricity (TWh/yr)
• domestic uses (families): residential	34	119
• transports	24	58
• corporations, transports	25	8
• tertiary sector	10	91
• industry	26	131
• agriculture	18	30

This highlights the dominant share from individual consumers and speak for a uniform ecology taxation unless deliberately contradicting its meaning.

Summing up, the outlook for geothermal district heating seems presently limited to the operation of the thirty or so doublets online and to the implementation of gas co-generation units on two thirds of the existing grids, restricting geothermal heat supplies to ca 1,000 GWht/yr (Ungemach, 2000).

Privatization of geothermal doublets/heating grids, widely initiated in the past years under the form of acquisitions, concessions, leases and public service delegations should address in the short run over 15 installations equally shared between the three leading heating/energy groups: Dalkia/Edf/Vivendi, Elyo/Suez Lyonnaise des eaux and Cofatec/Coriance/Gaz de France. Only the Public and an established State policy, as was the case in the mid-1970s/ early-1980s, reverse these adverse trends and reactivate geothermal heating which, everything considered, has proven its technological and entrepreneurial maturity (Ungemach, 1998).

Last but not least, the impact among the Public of recent climatic disasters attributed to global warming and of high oil prices could initiate the necessary stimulus. In this perspective, the taxation of CO_2 atmospheric emissions, once scheduled by the Government, at a rate ranging from 200 FRF (30 ε ~ 27 US$) (2001) to 500 FRF (76 ε ~ 68 US$) (2010) per tonne of carbon, is obviously critical.

MILESTONES

The Paris Basin geothermal development milestones are highlighted in historical sequence, in which six main steps are distinguished and briefly commented on:

Pre-oil shock, 1960s. This addresses the first abandoned attempt to tap the Dogger geothermal aquifer, followed in 1969, by the successful completion of the first geothermal district heating doublet at the emblematic Melun l'Amont site.

Post-first oil shock, 1973-78. Completion of four geothermal district heating doublets, three (Creil and Le Mée-sur-Seine) combining vertical production/injection wells and one (Villeneuve-la-Garenne) deviated production/ injection wells fiberglass (7") cased. Three doublets (Creil and Villeneuve-la-Garenne) were equipped with electric submersible pump (ESP) sets, the fourth (Le Mée-sur-Seine) being produced in self-flowing mode. Simultaneously, the legal framework was enforced by the State via a relevant geothermal act classifying geothermal fluids as a mineral resource subject to the mining code and to exploration/ exploitation leases and concessions.

Post-second oil shock, 1979-1986. This period produces the Paris Basin geothermal development effort with the completion of 51well doublets of which one (La Villette) will never be exploited and a second (Melleray) exploiting the Triassic sandstones underlying the Dogger carbonate reservoir. The legal/regulatory/lobbying framework was finalized by the creation of the Comité géothermie, SAF Environnement, Afme/Ademe, Géochaleur and Agémo. The Triassic target, once contemplated west of Paris, was abandoned due to negative testing (resulting mainly from poorly completed wells) resulting in exploitation concentrated exclusively on the dependable Dogger reservoir. The success ratio was high as only two doublets (Fontainebleau and Fresnes) met the (semi) failure criteria set forth by the Comité géothermie, responsible for supporting geothermal ventures deemed feasible and thus eligible for the geological risk allocation and related subsidies. The first well damages and production pump (ESPs and line shaft pumps - LSPs) failure were experienced in the mid-1980s.

Early exploitation phase, Late-1980s. Most doublets had undergone severe exploitation problems as a consequence of (initially overlooked) hostile thermo-chemistry and subsequent corrosion/scaling damage, pump failures (lower than one year average lifetimes), hesitant management, poor heating practice (mainly regulation and monitoring) and, above all, critical financial losses aggravated by oil depleted prices. This implemented conventional well work-overs and of the first chemical inhibition trials.

Technological/managerial maturation and debt renegotiation, 1990-97 . In 1990, the State committed Brosse Mission led most geothermal operators to renegotiate their debt (loans mostly contracted with State owned banks) via a moratorium including a three-year grace period, extended annuity redemptions and lower interest rates. Expert advice was also provided regarding heating exploitation concession and contracts. Simultaneously, concerned governmental departments and agencies (Energy and Raw Materials Directorate, Industry and Research Directorate, Afme/Ademe) refueled the SAF mutual exploitation insurance (long-term) fund and promoted specific R&D actions aimed at designing and implementing novel well work-over/ restoration/ stimulation and thermo-chemical preventing techniques. The latter proved rewarding in upgrading restoration of casing status and related well productive/injection capacities and limiting corrosion/scaling damage at attractive cost to performance ratios. Doublets facing irreparable physical and/or financial damage, or in several instances managerial laxness, ceased commercial exploitation and these wells were cemented in compliance with petroleum/geothermal well abandonment regulations.

Still the economics remained fragile as a result of reduced oil prices and a highly competitive energy market dominated by heavy fuel and, at a greater extent, natural gas contenders.

New challenges, Starting 1998. Geothermal district heating in the Paris Basin demonstrates a mature–below ground and surface technology, clearly assessed exploitation and mining risks, controlled operation/maintenance/work-over costs, experienced management, socially accepted environmental benefits, seconded by instrumental expertise and services. Of the 54 completed doublets, 34 (i.e. 60 %, a reasonable score indeed) of the initial load, remain online as of mid-2000, with a reliably targeted 10-year life expectation, the duration of the recently extended SAF Environment mutual insurance contracts. However, the fierce competition prevailing while negotiating heating contract renewals prompted many geothermal operators to award co-generation (combined cycle) contracts or leases to the dominant heating groups (Vivendi, Suez-Lyonnaise des eaux, Gaz de France). This was in the wake of (partial) power deregulation and incentives in favor of gas co-generation initiated in France in the mid 1990s. This policy conformed to a survival rationale keeping most geothermal district heating grids alive, at the expense, in most instances (no grid extension), of decreasing supplies of geothermal heat no longer utilized as base load during the contractual one hundred and fifty one day (1st November to 31st March) winter heating period allocated to cogenerated heat. The spectacular rise in oil prices noticed since late 1999, peaking at ca 32 US $/bbl, likely to be followed by natural gas tariffs, alongside greater sensitivity of the public to global warming damage, and taxation envisioned by the State of greenhouse gas emissions (estimated at 40ε . 36 US$/tonne of carbon starting rate) could radically change the former bleak outlook. Instead of surviving, geothermal district heating could be given a second chance and momentum.

STATUS

Well Record

Fifty-six geothermal doublets have been completed during 15 years (from 1971 to 1986) at vertical depths ranging from 1,165 (Beauvais) to 1,980 m (Coulommiers) at locations mapped in Figure 1. The Melleray doublet, devoted to greenhouse heating, located 140 km south of Paris, addressed the Triassic sandstones and the La Villette doublet has never been exploited so far. The Ivry doublet aimed at preheating the steam fed into the Paris steam heating grid.

As of mid-2000, 34 doublets remain on line. The completion/abandonment record is displayed in the following historical sequence (Figure 2).

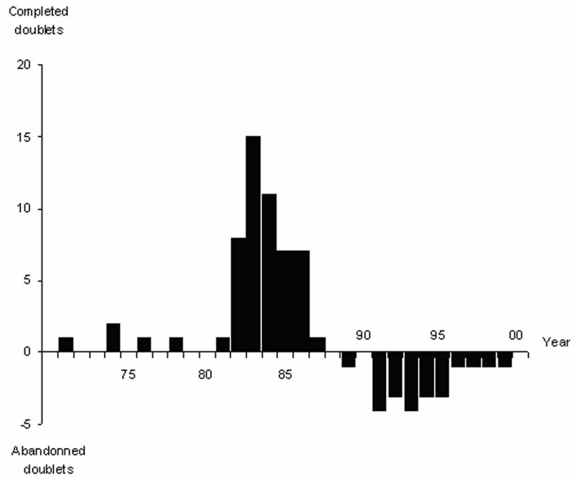


Figure 2. Completion/abandonment of doublet well over time.

Geothermal district heating doublets have undergone over 90 heavy duty work-overs, this figure not including the 22 abandonment cementing jobs. The State elsewhere funded, between years 1990 and 1995 (out of the over 90 figures), 41 specific well cleaning/corrosion preventing operations for implementing novel casing jetting techniques and downhole chemical injection lines.

Out of the 68 operating to date, 30 damaged (leaky, pierced casings) wells (23 production, 7 injection) were reconditioned either via casing lining (18 producer, 7 injector, total 25) or casing patches (5 producer wells). Reconditioning of production wells dealt, in all cases, with the repair (by lining or patching) of a damaged 13 3/8" pumping chamber and for one well only (Villiers-le-Bel/Gonesse) was added the 7" lining of the underlying 9 5/8" production casing.

Exploitation Update

Relevant figures, from early expectations to reality, are summarized below:

	Target (1985)	Achieved 1990	2000
Operating doublets	55	43	34
Total installed capacity (MWt)	360	260	227
Produced heat (GWht/yr)	2,000	1,455	1,240
Unit capacity (MWt)	6.5	6.0	6.7
Unit yield (MWht/yr)	36,000	33,800	36,200
Artificial lift wells	49	36	27
Self-flowing wells	6	7	7

At the beginning of heating year 1987-88, 54 doublets were assumed operational, thus close to the anticipated figure. Actually no more than 48 were in service, of which one-third were undergoing severe exploitation problems resulting in temporary shut in periods attaining in many instances several months.

In 1990, 43 doublets were serviced and about 1,450 MWht delivered to the heating grids (i.e., 25 % below initially projected yields). In year 2000, the annual delivery dropped to 1,230 GWht as a result of lesser operating doublets (34) and start up of 10 combined geothermal/gas co-generation systems. Despite this downward trend, optimiza-tion of the most productive doublets, which happen to coincide with the most recently completed (third generation) ones, resulted in unit capacities (6.7 MWt and 36,200 MWht/yr) close to initially anticipated targets. However, future implementation of commissioned and projected cogeneration systems is likely to reduce these unit capacities.

TECHNOLOGY

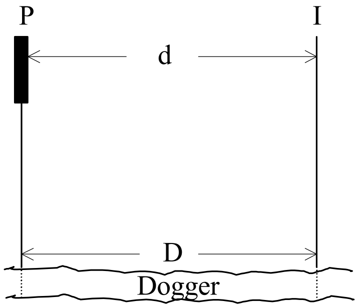
Well Completions and Doublet Designs

As a matter of fact, the geothermal doublet typology followed the patterns sketched in Figure 3. This strategy was largely inspired by the views of the National Geological Survey (BRGM) appointed by the State to launch the geothermal development programme. This strategy prevailed in spite of the early achievements pioneered by designers from the oil industry, on private investment bases, on the Melun l'Almont (1971) and Villeneuve-la-Garenne (1976) sites, the latter adding an innovative fiberglass casing ingredient. Those remained the exception until wide acceptance and generalization (third generation doublet) of this pertinent design in the mid 1980s.

First generation doublets. Two vertical production/injection wells. This configuration has been implemented at Creil (1974), Le Mée-sur-Seine (1978), Cergy (1982) and Achères (1983). The production well includes a 13 3/8" casing, to accommodate a 11" submersible pump, followed by a dual 9 5/8" x 7" casing protection (400 to about 1,000/1,200 km) of the intermediate Albian/Neocomian fresh water aquifers and a 7" production casing, the target Dogger geothermal reservoir being produced in open hole (6" diameter). The injection well replicates the dual 9 5/8" x 7" casing design with a single 7" injection column, and a 6" open hole reservoir section. A 1,000 to 1,400 m well spacing secures a useful system thermal life of 20 to 25 years (i.e., until damaging, 3 to 5°C (5 to 9°F), cooling of the production well occurs).

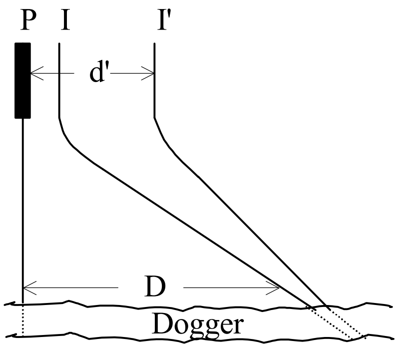
Second generation doublets. Vertical production well. Deviated injection well. Casing/open hole diameters and dual casing protection of the intermediate Albian/Neocomian fresh water aquifers identical to those adopted for the first generation doublets. Wells are drilled from a single plateform (eight doublets drilled between 1981 and 1985) with the exception of Meaux Collinet (1982) and Evry (1983); where, the well head spacings (200 to 300 m) enabled to reduce the injection deviation (slant) angle.

Third generation doublets. Two deviated production/injection wells drilled from a single platform. Two designs depending on production/injection casing diameters, either 13 3/8" (exceptionally 10 ¾") x 7" (production) and 7" (injection) including a dual 9 5/8" x 7" cased protection of the Albian/Neocomian fresh water aquifers (22 doublets) or a 13 3/8" x 9 5/8" (production) and 9 5/8" (injection) casing string with no dual casing protection of the Albian/Neocomian fresh water aquifers (nine doublets). In this latter design, the 9 5/8" production/injection casing is occasionally thicker than in



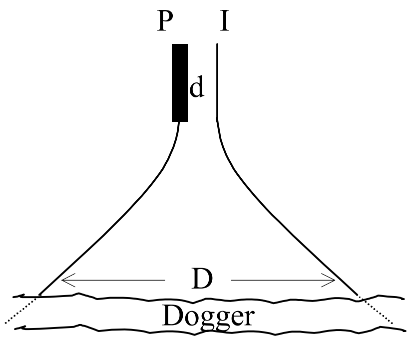
1st generation doublets

2 vertical wells
Diameters
P : 13 3/8” x 7" or 10 ¾” x 7"
I : 7"
Double 9 5/8” x 7" casing protection
of Albian/Neocomian aquifers



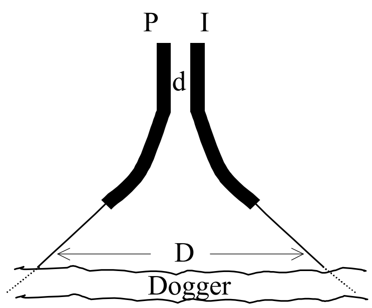
2d generation doublets

1 vertical (P) well, 1 deviated (I, I') drilled from one (I) or two (I') platforms
Diameters
P : 13 3/8” x 7" or 10 ¾” x 7"
I, I' : 7"
Double 9 7/8” x 7" casing protection
of Albian/Neocomian aquifers



3rd generation doublets

2 deviated wells drilled from a single platform
Diameters
(a) P : 13 3/8” x 7" or 10 ¾” x 7"
I : 7"
Double 9 5/8” x 7" casing protection of Albian/Néocomian aquifer
(b) P : 13 3/8” x 9 5/8”
I : 9 5/8”
No double casing protection of Albian/Néocomian aquifers



4th generation doublets

2 identical wells.
Increased pumping chaber length
Diameters
P : 13 3/8” x 9 5/8”
I : 13 3/8” x 9 5/8”
No double casing protection of
Albian/Néocomian aquifers

P : production well
I : injection well   z : pumping chamber
D : doublet spacing at top reservoir
d, d' : well head spacing

Figure 3. Geothermal doublet typology.

previous completions. Bottom hole (top reservoir impact) spacings are designed in compliance with doublet cooling specifications.

Fourth generation doublets. Two identical production/injection well 13 3/8" x 9 5/8" casing programs allowing for production/injection replication. The 13 3/8" casing is set at a (deviated) depth of 900 to 1,100 m (i.e., vis-à-vis the Albian/Neocomian freshwater aquifers whose protection is ensured via an increased steel thickness over the concerned interval).

Casing specifications conform to K55 soft carbon steel grades, compatible with service in the CO_2-H_2O aqueous system, either VAM or Buttress (BTC) threads, 9 to 11.4 mm wall thickness and range 3 lengths. Deviation (slant angles) vary between 30 to 55° with a build-up gradient of 1°/10 m initiated at depths (KOPs) ranging from 200 to 500 m.

New Well Concept

The novel geothermal well design was conceived to reduce corrosion and scaling that had severely affected the integrity and lifetime of Paris Basin geothermal district heating wells. This new generation geothermal well, which represents a material alternative to corrosion, was successfully completed at Melun-l'Almont on March 1995.

Under this new concept, the wells are completed by combining cemented steel casings and fiberglass liners while the annulus is kept free. The casings provide mechanical strength (propping function), while the liners furnish chemical resistance (corrosion and scaling protection). The free annular space allows: (1) circulating corrosion/scaling inhibitors and/or biocides, which otherwise would need to be circulated using a downhole chemical injection line; and, (2) removing and, if necessary, replacing the fiberglass liner whenever damaged. It is noteworthy that this design can accommodate a submersible pump set, in which case the upper fiberglass lining is placed under compression, and the lower one is freely suspended under its own weight. Vertical displacement of the fiberglass lining is elsewhere eased by an expansion spool and fiberglass centralizers (not by couplings as often contemplated in other centralizing designs). At Melun, due to exceptional reservoir performance, artificial lift was no longer required and, instead, self-flowing at high production rates prevails, a fact that led to the simplified design.

The well, put on line on late March 1995, demonstrated high productivity, producing about 70°C (158°F) fluid at a rate of 200 m^3/hr at 2.5 bars wellhead over-pressure. It has been connected to two existing wells (one producer and one injector); the whole system operates according to the triplet array (two producers, one injector). The wellhead design achieves the required sealing and fixing (seat/receptacle) functions.

The concept of using wells with steel casings and removable fiberglass liners is seriously considered as an alternative in order to extend the lifetime and improve the reliability of existing installations. The following strategy would be used: a new production well would be drilled and completed, the two existing wells would be reconditioned/lined into injectors, exploitation would resume under a triplet configuration (one producer, two injectors). Total project costs, including work-over, are estimated at about 3.5 million ε (3.2 million US$)(Geoproduction Consultants, 2000). Another, less innovative but cheaper, alternative would consist of drilling/completing a large diameter vertical steel cased well securing high self-flowing rates according to the design and cost estimates analyzed in Geoproduction Consultants report (2000).

Heating Engineering Insight

Operation of Paris Basin geothermal district heating grids conform to a standard engineering rationale, parameter system analysis and in the generic doublet/heating grid modules, namely:

- A geothermal supply module (the so-called geothermal loop): geothermal reservoir, production and injection wells and related equipment (production/injection pumps, electric and hydraulic control devices),
- A demand module: heat load consisting of end users' consumption, i.e. heaters connected, via substations, to a distribution grid,
- A back up/relief module: fossil fuel fired boilers, an interface: geothermal heat exchanger.

The following items deserve a special comment.

Heat loads: retrofitting is the rule. Geothermal heating had to comply with existing buildings and heaters seldom designed for low temperature service. Residential dwellings compose the majority of the load, followed by public office buildings, schools, swimming pools and gymnasiums. Supply of domestic sanitary (tap) hot water (SHW) adds in many instances to proper heating. Centralized SHW represents a bonus, with a supply amounting to about 10 % of heating loads.

Heating devices: forced-air convectors are absent. Therefore, heat is diffused by conventional cast iron radiators requiring high (90/70°C – 194/158ºF) inlet/outlet temperatures and floor slabs (50/30°C temperature range 122/86ºF)--the latter more favorable to geothermal heat. As a result, many heating grids are conceived to adjust to those two contrasted heaters by means of high-temperature and low-temperature networks. High-inlet temperature heaters restrict temperature depletion and achievement of low rejection (at injection well head) temperatures which remain close to 40°C (104 ºF) and seldom attain 35°C (95ºF).

Regulation: it is indeed the vital segment of any combined geothermal/boiler heating management as it aims at minimizing the back-up boiler supply, thus upgrading the geothermal coverage ratio. District heating as opposed to industrial or agro-industrial process heat loads is subject to climatic charges and subsequent variable demand. Two temperature thresholds (besides the minimum reference outdoor temperature, set at - 7°C (19ºF) in the Paris Basin, to which is matched the installed heat capacity) are thus defined: the so-called transition (Θ*) and non-heating (Θnh) temperatures respectively. Below Θ*, the doublet is circulated at its maximum (nominal) flowrate and the complementary (peak) demand supplied by fossil fuel fired boilers. In the (Θ* - Θnh) temperature range, the whole demand of the (centralized) grid is supplied by geothermal heat. Above Θnh, whenever SHW supply is required, the doublet is operated at its minimum flowrate. Hence, the geothermal and grid flowrates are ascribed to variable-speed drive achieved by frequency converters. Depending upon local grid/heater characteristics, the transition temperature varies between 5 and 8°C (9 and 14°F); the non-heating temperature is set by law at 17°C (63 °F). In the (Θ* -Θnh) range, the geothermal flowrate decreases linearly. Practically, these simple regulation criteria are managed by an automaton which handles the grid/ geothermal loop interface by driving, via pressure/temperature sensors, the frequency converters and the safety (low/high pressure) instructions by closing the motor-actuated well head valves. The regulation suite usually conforms to the following sequence: the grid demand is transmitted, in terms of geothermal flowrate, to the injection pump frequency converter which adjusts the pump speed to the requested flowrate; the injection pump inlet pressure transducer signals to the production pump frequency converter the adequate flowrate instruction. Whenever the production pump outlet pressure exceeds the high pressure (heat exchanger/piping protection) instruction, the geothermal loop is shut down and relief boilers actuated accordingly; the same criterion applies to the low pressure (injection pumps inlet) instruction (pressure below bubble point).

Environmental Impact

Geothermal exploitation in the Paris Basin can be regarded, from an environmental point of view, as a risk as well as an asset. Hazards relate to the production of over-pressured (up to 11 bars well head pressures and over 200 m^3/h artesian free flow), hot and saline brines including toxic and flammable solution gases occurring in freshwater aquifer and densely populated urban environments. They are materialized by casing leaks and wellhead failures leading to (exposed) aquifer contamination and surface blowout damage. Work-overs represent another risk source with respect to waste disposal, gas escape and noise. In many instances, these risks remain under control and their consequences minimized. Fluid chemistry, well head pressures/temperatures and well deliverabilities are periodically monitored and casings inspected by wire-line logs easing detection of casing leakage/piercing and prompting relevant repair procedures.

Work-over technology and practice are adapted to services in a sensitive urban context by means of sound proof (diesel) engines, waste processing units and flexible working schedules (no night shifts), indeed a contrast with the earlier days common, oil and gas inherited, practice. Nevertheless, the industry is still awaiting the advent of silent, electrically driven, service rigs and pumps.

Since blowouts are unpredictable, the operators professional association -Agémo- initiated an emergency service in order to limit their magnitude. The contract awarded (after due bidding) to GPC specified to design, acquire, maintain and operate a wild well control facility, which should be mobilized in less than 6 hrs. Twenty geothermal operators subscribed to a five-year (renewable) contract whose effectiveness was checked on four blowouts recorded to date.

The progresses registered since the pioneer days of geothermal district heating contributed to upgrade its image among the public. Better social acceptance and growing clean air concerns should, therefore, turn geothermal district heating into an asset in consideration of saved greenhouse gas emissions. Such savings, with reference to natural gas- fueled heating, amount to ca 120,000 tonnes of carbon/yr. If an ad hoc ecotax were passed, the geothermal industry could benefit from an additional income of ca 23 FRF (3.5ε ~ 3.2 US$/) /MWht on a taxation basis of 250 FRF (38 ε ~ 34 US$/)/tonne of carbon (i.e., almost 10 % of the present heat selling price).

ECONOMY

Total geothermal investment costs amounted in the Paris Basin to ca 3.2 billion FRF (i.e., 500 million ε ~ 450 million US$) representing a unit investment cost of about 9,200 FRF(1,400 ε ~ 1,260 US$)/installed kWt. Investment costs split as follows (million FRF):

	Min.	Max.	Mean
• mining (well) costs	12	18	15
• heat plant/primary surface loop	4	7	5
• grid construction/ substation modifications	30	90	45

It is a generally accepted fact that, under normal feasibility conditions, total investment costs stand close to 65 million FRF (9.9 million ε ~ 8.9 million US$) to which the whole geothermal loop (wells, heat plant, surface piping and equipment) contribute 30 % and the grid proper 70 % respectively. From 80% to 90% of the investment was provided by (public) bank loans and the remaining 10 to 20% by public subsidies and grants.

Operation and maintenance costs include three main headings: (1) energy (electricity and back-up fossil fuels); (2) light maintenance/monitoring and heavy maintenance/ equipment warranty; and, (3) miscellaneous (provision for heavy duty works, overhead) costs.

The grid (primary and secondary networks) is operated permanently by a heating company with an assigned staff of three to five employees. The geothermal segment is monitored periodically and serviced occasionally by a geothermal engineering bureau. A thermal engineering bureau is usually appointed by the geothermal operator to assist the management in controlling grid operation and heat supplies.

Description of the various capital investments and OM cost items relevant to Paris Basin district heating systems may be found in a comprehensive economic review developed in Ungemach and Ventre (1997).

Revenues address heat sales to end users connected to the grid. These sales include both geothermal and boiler (back-up/relief) generated heat.

Global cash flow streams, selected on sites deemed representative of Paris Basin conditions, are displayed in Table 1. It emphasizes the dominant financial share of the debt repayment annuity which often nears 60% of total expenditure. This, added to back-up/relief boiler costs sensitive to natural gas prices and to the geothermal coverage ratio, exemplifies the structurally fragile economic and financial balance of Paris Basin geothermal operations. Actually, out of 34 doublets, 12 achieve profitability, 12 breakeven and 10 show a deficit. Prices close to 250 FRF (38 ε ~ 34 US$) could hardly compete in the past years with natural gas whose tariffs could afford a near 200 FRF (30 ε ~ 27 US$)/MWht figure. It is worth mentioning, however, that on several doublets (A, C and D in Table 1, among others), debt repayments will cease in year 2002.

To overcome these financial problems, two issues can be contemplated, in the short term, combined natural gas co-generation/geothermal grids and, in the medium term, enforcement of an ecotax applicable to greenhouse gas emissions. The latter would definitely secure a more attractive profit margin for the mutual benefit of geothermal producers and end users. Along this line, a typical example of a Paris Basin prospective balance sheet is given in Ungemach and Ventre (1997) and several revival scenarios of presently abandoned doublets are analyzed in Appendix 4 of that publication.

THE CO-GENERATION ISSUE

Co-generation appeared recently as a realistic survival alternative to geothermal operators facing severe competition from cheaper fossil fuels, firing conventional boilers, while negotiating renewal of end users heating contracts.

Gas co-generation on geothermal district heating grids raises growing interest, a financially and fiscally attractive issue. The simple reason is that the power required to produce the heat, which remains largely unused (hardly 10 % of the grid capacity), is sold to the utility at a price guaranteed over 12 years and indexed on gas market prices, with tax incentives added as a bonus. The interest is mutual. The gas company (Gdf) increases its market share and sells significant gas quantities to meet the demand of the grid (currently producing between 30,000 and 50,000 MWht/yr). The grid operator purchases cheap heat produced at marginal cost as a by-product of power generation.

Table 1. Balance Sheet for Various Doublet and Boiler/Geothermal Scenarios

Item/Doublet	A1 (1)	A2 (1) (2)	B	C	D1 (1)	D2 (1) (2)
Total heat supply (MWht/yr)	58,000	43,500	48,888	51,000	40,000	31,000
- geothermal	39,500	32,500	42,000	41,000	26,000	15,000
- back-up boilers	18,500	11,000	6,000	10,000	14,000	16,000
- geothermal coverage %	68	75	87.5	80	65	48
Heat selling price (FRF/MWht)	251	241	247	258	272	272
Revenues (10^3 FRF/yr)	13,980	10,480	11,860	13,160	10,800	8,430
Expenditure (10^3 FRF/yr)	13,520	10,540	11,570	12,370	9,790	8,850
- debt charge	7,100	6,800	6,900	7,600	4,300	3,200
- power	875	710	1,030	590	560	520
- back-up fuels	3,330	1;980	1,080	1,800	2,520	2,880
- maintenance	1,620	1,470	1,840	1,760	1,810	1,650
- heavy duty work-over provision	360	240	400	330	250	250
- overhead	240	240	320	290	350	350
Balance (10^3 FRF/yr)	+ 460	- 60	+ 290	+ 790	+ 1,010	- 420

(1) dual doublet management (2) co-generation on line in 2000 7.30 FRF = 1 US$

Table 2. Typical Co-Generation Grid Economics

	grid 1	grid 2
Generating unit	gas engine	gas turbine
Power rating (MWe)	4	5.5
Power production (MWhe)	13100	16,400
Gas consumption (MWht ; HCI)	39700	57,700
Heat production (MWht)	16400	21,600
Revenues (10^3 FRF)	10980	13,470
- power sales	6600	8,260
- heat sales	4380	5,210
Expenditures (10^3 FRF)	8580	11,510
- debt charge	2040	2,100
- gas costs	5160	7,160
- maintenance	1180	1,940
- miscellaneous	200	300
Balance	+ 2,400	+ 1,960

Practical candidate (combined cycle) systems consist of natural gas fired engines or turbines driving alternators. Heat is recovered (1) on engines on the cooling circuit and, at a lesser extent, on exhaust gases, and (2) on turbines via exhaust gases. Heat to power ratios stand around 1.1 (engines) and 1.35 (turbines) respectively.

The co-generator must comply to the following conditions:

- 50% minimum (global) energy efficiency,
- heat to power ratio higher than 0.5,
- use (self-utilization) of produced heat,
- conformity certified by the competent authority (Drire).

The contract is passed with the utility (Edf) for a duration of 12 years. The co-generator subscribes to a guaranteed installed power and a plant utilization factor (subject to bonus/penalty) of 95%. Co-generation extends over a 151 calendar-day (from November 1st to March 31st) heating period.

The foregoing have important implications on geothermal production. Power (and heat) is generated constantly, at nominal rating over 151 days (3,624 hours) to maximize electricity sales. Therefore, co-generated and geothermal heat grids are operated as base and back-up loads respectively during winter heating. This results in a somewhat drastic drop of geothermal heat supplies. Actually, in many instances artificial lift was abandoned and self-flowing production substituted instead.

On economic grounds, the following numbers (Table 2), borrowed from two typical co-generation grids, shape quite attractive with discounted pay back times nearing five years.

Increases in natural gas prices have a penalizing impact, mitigated though, thanks to the contract passed with the utility, which compensates about 75% of gas tariff rises. In the aforementioned examples, a 40% increase in gas prices would result in additional expenditures amounting to 510 (grid 1) and 730 x 10^3 FRF (grid 2) (78 and 111 x 10^3 ε ~ 70 and 100 x 10^3 US$) respectively.

Co-generation has become a reality on many operating doublets. At the start of the 2000/2001 heating season, twelve co-generation/geothermal heating plants were online. Five other doublets are already commissioned and due to operate in 2001. Three to five sites are projected. Summing up, within the next years only 10 to 12 doublets should be exploited via the conventional heat exchange/back-up relief boilers heating mode.

CONCLUSIONS

Based on an experience dating back to the mid 1970s, the following conclusions may be drawn as to the past, present and future of geothermal district heating in the Paris Basin.

The geothermal source proved dependable with respect to reservoir extent and performance allowing easy well completions and high yields. Drillings achieved a 95% success ratio and well productive capacities currently attain 250 m^3/h - 70°C (158°F) nominal ratings.

Large residential dwelling compounds of the Paris suburban belt favored the district heating development route as a result of suitable heat loads overlying the heat source.

The doublet concept of heat mining and retrofitting were the governing rationale in exploiting the resource and heating the end users connected to the heating grid downstream of the geothermal heat exchanger.

Developments benefitted from a strong involvement of the State, following the first and second oil shocks, in favor of alternative energy sources. Relevant supporting policies addressed the areas of legal/institutional (mining law), risk coverage (exploration and exploitation sinking funds), financial backing (fiscal incentives, subsidizing), project reviewing/commissioning (ad-hoc committees) and heat marketing.

In the mid-1980s, 54 doublets were online and exploitation targets set at 360 MWt (installed capacity) and 2,000 GWht/yr (heat production) respectively. Since then, recorded figures did not match expectations. As a matter of fact, actual figures, as of year 2000, stand at 34 operating doublets, 227 MWt installed capacity and 1,200 GWht/yr heat supply. This situation reflects the learning curve phases, infancy, teenage and maturity, inherent to any new technological development, particularly in the mining field.

Paris Basin geothermal development was soon confronted by three major problems:

- **Technical problems**: the thermo-chemically sensitive geothermal brine caused severe, corrosion/scaling induced, damage to well tubulars and production equipment; these problems had been clearly overlooked at design/implementation stages,
- **Financial problems**: deemed the most critical, they resulted from a massive debt charge (no equity) aggravated by a low price and depleted energy market in the aftermath of the second oil shock,
- **Managerial problems**: they related to the lack of experience and expertise of geothermal operators, the large majority belonging to the public/municipal sector, in handling industrial installations including a significant mining segment; consequently loose monitoring and maintenance policies were the rule.

This bleak outlook could be progressively overcome thanks to innovative, State supported, chemical inhibition and well restoration technologies, debt renegotiation and sound management of geothermal heating grids. These sharp progresses were however accompanied by the abandonment of the twenty or so poorly reliable doublets.

So, everything considered, in spite of a fairly hostile, competing, economic environment geothermal district heating scored well. It demonstrated so far, its technological and entrepreneurial maturity and gained wider social acceptance.

Still economic viability proves fragile and only gas co-generation could secure the survival of a number of geothermal district heating grids. Twelve co-generation systems are operating to date and it is likely this figure will reach the twenty mark in the near future.

Where to Go Next?

A major question arises on whether the future of geothermal district heating reduces to the sole gas co-generation survival scenario in which geothermal heat no longer supplies base load.

Recent climatic disasters attributed to global warming and greater sensitivity of the public to environmental, clean air concerns could challenge this trend and turn low-grade geothermal heat into a widely accepted asset. Taxation of greenhouse gas emissions, the so-called ecotax, would in this respect be decisive in giving geothermal heating a new chance.

Prospective developments could, in the short run, address realistically two objectives. First the extension of existing (co-generated and non co-generated) geothermal grids to new users. Second the reactivation of abandoned doublets according to a revival of triplet design combining two injectors (the old wells) and one, new generation, production well.

Note: The following conversions were used:

7.30 French Franc (FRF) - 1 US$
1 Euro (ε) = 0.90 US$
6.60 FRF = 1 Euro

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GEOTHERMAL DISTRICT HEATING EXPERIENCE IN TURKEY

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ABSTRACT

Turkey is the 7th richest country in the world in geothermal potential. Most of the development of this resource is achieved in geothermal direct-use applications with 52,000 residences equivalence of geothermal heating (493 MWt) including district heating, thermal facilities and nearly 500,000 m^2 geothermal greenhouse heating. Geothermal water is used in 194 spas for balneological purposes (327 MWt). Engineering design for nearly 300,000 residences equivalence of geothermal district heating has been completed.

By summing up all this geothermal utilization in Turkey, the installed capacity is 820 MWt for direct-use and 20.4 MWe for power production; where, a liquid carbon dioxide and dry ice production factory is integrated with the Kizildere geothermal power plant with a 120,000 tonnes/year capacity.

Geothermal district heating systems (GDHS) are the main geothermal utilization in Turkey, which have an important meaning to the Turkish citizens who make use of this system; since, a clean environment and comfort has been provided to residences in an economic situation.

The district heating system applications were started with large-scale, city-based geothermal district heating systems in Turkey; whereas, the geothermal district heating center and distribution networks have been designed according to the geothermal district heating system parameters. This constitutes an important advantage of GDHS investments in Turkey in terms of the technical and economical aspects.

An annually average of 23% growth of residence connection to GDHS has been achieved since 1983 in Turkey.

INTRODUCTION

As the district heating system installation started with GDHS investments in Turkey, the GDHS are operated very economical, which is the result of optimization of geothermal resource characteristics with the consumer's characteristics, suitable system design and technology.

Turkey is a developing country. There is a continuous migration from rural areas to cities, and there is 2% population increase annually. As a result of this, apartment buildings in cities are continuously increasing vertically and horizontally. The results of the migration are some of the important subjects, which should be considered before the establishment of geothermal systems. Another case is, while some of the buildings have a radiator-heating system, some of them have not. The conversion project should take these types of systems into consideration.

TECHNOLOGICAL ASPECTS

The main units of a geothermal district heating system are geothermal water production, reinjection, heat exchangers, piping system and pumps.

By using the new approaches in determining the heat load instead of classical methods, the initial investment cost has generally been reduced.

Fifteen years of experience showed that real heat loads were approximately three times lower than the heat loads evaluated by theoretical methods. The main reasons for this are as follows:

1. Using outside design daily average temperatures causes an excess calculation of heat load by 20%, which increases the initial cost of the investment.
2. The theoretical heat load evaluation methods are considered as constant, but in reality the heat loss and gain are variable. The main differences in heat load calculations result from the variable effects that are not taken into account.
3. Besides the heating application, domestic hot water supply also exists in geothermal district heating systems. In the classical calculation methods, domestic hot water load is not added directly to the heat load. This occurs for two reasons. The way to maximize utilization of the geothermal fluid is to decrease the return geothermal water temperature to a minimum level. The return temperature from the heating (radiator) is about 40°C (104°F). The domestic hot water temperature is about 45-50°C (113-122 °F). To heat the network water from 15°C to 43°C (59 to 109 °F), no additional load is required and the energy of the discharged water is used for this purpose. The domestic hot water load occurs for a very short time in a day which does not affecting the design load.
4. In addition, heat loss occurs from the outer surface of the buildings. However, there are heat gains from the solar radiation, human beings and electrical devices. But all of them were not taken into account in calculation of the heat load.

To utilize the geothermal fluid to its maximum, the leaving temperature of the fluid should be kept to as low as possible. To achieve this goal, it is necessary to control the radiator return water of the buildings. The control of the radiator return water temperature is done with self-operating, flow, temperature and pressure difference control valves.

Radiator discharge water control means controlling the return to the Heat Center. The less the return water temperature entering the heat exchanger in the Heat Center, the more heat extracted from geothermal fluid, and the more the geothermal fluid is utilized. The circulation pump is controlled by means of a PC network that regulates pumping of the required amount of water to the city.

In the Balçova geothermal district heating system, the newest technologies are used and the operational costs are very low. This system has operated successfully since 1996 and supplies 11,500 residences of equivalence heating. Be-sides, these new approaches, the following technical develop-ments have caused a large decrease in the operational costs.

Heat consumption in GDHS is variable according to the outdoor temperature. Thus, the energy amount supplied to the consumers should also be variable. This variability could be obtained by holding the water temperature to and from the consumers constant, and providing a variable flowrate instead of variable temperature. So, this system prevents damage to the pipes due to temperature variations, and the system replies immediately and provides 100% to the different heat demands of the consumers resulting in much lower operational costs.

To save electricity, geothermal water and chemicals, the related pumps are controlled by variable speed drives. Due to a good operation plan and full automatic control of the variable-speed drive pumping system, the electricity consumption rate decreases to 63% annually.

Heat Exchangers

Heat exchangers are usually the major units of equipment for direct-use applications. All standard types of heat exchangers, shell-and-tube, plate, finned tubes, and downhole heat exchangers can be used for geothermal applications. But, there are several conditions, which must be considered when designing and selecting equipment for geothermal supplies and the different utilizations.

Usually, it is not possible to use the geothermal fluids directly in district heating systems due to their chemical composition and/or their temperature. For this reason, heat exchangers should be used. Heat transfer with a minimum approach temperature, directly decreases the initial investment and operation costs.

Plate-type heat exchangers have many advantages compared to the shell-and-tube, finned tube and downhole heat exchangers:

- Plate-type heat exchangers are especially useful for low-temperature (40-50°C)(104-122°F) heating app-lications. For example, in Kirsehir GDHS, the geo-thermal production temperature is 54°C (129°F). In this case, shell-and-tube heat exchangers could not be used to transfer the heat energy to the clean water, as the discharge temperature of the geothermal water had to be a minimum 7°C (13°F) higher than the city circuit water temperature. So, instead of having a city circuit of 50°C/40°C (122/104°F), the geother-mal water discharge temperature would have to be 57°C (135°F).
- Shell-and-tube heat exchangers have maintenance problems, require large flow volume and temperature difference compared to plate type heat exchangers.
- As the price of electricity in Turkey is high, heat pump utilization is not widespread. The plate-type heat exchangers are suitable for using low-temperature geothermal fluids. For this reason, they constitute an important component of geothermal applications in Turkey.

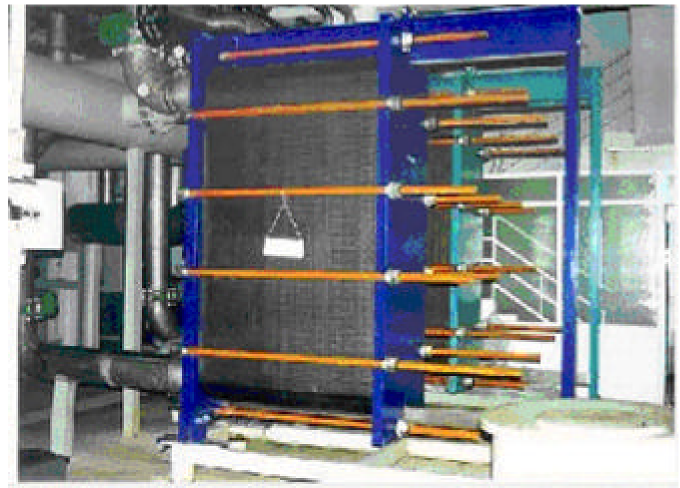

Figure 1. ***Plate type heat exchangers used in Izmir, Balcova Geothermal District Heating System.***

- By using 70°C (158°F) temperature geothermal water and using a shell-and-tube heat exchanger, the geothermal water demand would increase to 2-3 times and the city circulation flowrate 2-6 times. This case also increases the initial investment and operation costs.

Downhole Pumps

Many geothermal reservoirs are non-artesian, so that the wells will not produce without pumping. Deep well pumps are used to bring geothermal fluids to the surface, to the main heat exchanger, and to the reinjection well. In addition, there are many deep well pumps installed in artesian wells to increase the flowrate, to prevent high gas concentra-tion in the wells, and to keep the geothermal water temperature and production pressure above the boiling point pressure line as liquid phase. These pipes are used to pressurize the water so that it will not boil nor release gas.

The benefits of deep well pumps in general are temperature and production control, minimizing of scaling in the well which require less chemicals, and no steam loss or air pollutants (CO_2, SO_2, NO_x) to the atmosphere.

The benefits of the downhole pumps are better generating capacity and no reduction in production flowrate due to well scaling, increased production temperature from each well by lowering of the water level, higher production temperature with no loss to the atmosphere and surface, and better energy recovery.

Piping System

Piping systems used for transportation of the geothermal fluids and energy distribution system in the city have two main differences in comparison to conventional piping systems. The first difference is that these pipes are buried directly in the ground and no concrete anchor blocks are needed. The main advantage of this in Turkey is, as the substructure in the cities already exist, it would be rather difficult, time consuming and costly to put in a more complicated conventional system. As a result, a decrease about 10-20% of total investment cost is obtained.

The second main difference is that these pipes (fiberglass reinforced polyester and welded steel pipes) do not require any expansion joints, as the designed and applied expansion strength due to thermal stress remains below the pipe resistance. The engineering design and application of these pipes requires an expert knowledge about this subject. Fiberglass reinforced pipes are produced 100% locally (except raw material). Fiberglass reinforced resin (FRP) composite material technology has developed very fast in the world.

Figure 2. Pre-Insulated Steel Pipes (Casing is FRP) for geothermal heating network distribution.

Optimization is necessary to select the inner pipe material and the resin types. Up to 90°C (194ºF) temperature, local produced FRP can be used. In the cases where the FRP utilization is not suitable due to temperature and optimization reasons, inner pipes, insulation material and the jacket pipe can be used in different combinations.

Figure 3. Pre-insulated FRP pipes for geothermal water transportation.

In order to prevent corrosion in closed circulation water networks in steel pipes, a special corrosion inhibitor is used. The insulation is covered with a strong jacket pipe. To protect the pipes and the insulation material from leakage, these pipes are installed with a detecting system and controlled continuously from the Heat Center. Also, the insulated steel pipe system requires less maintenance.

CONVERSION OF CONVENTIONAL HEATING SYSTEM TO GEOTHERMAL HEATING SYSTEMS IN TURKEY

The people in Turkey usually live in apartment houses in cities and villages. In these buildings, the heating system is formed by means of a boiler–radiator system for each building or each flat with its own heating system. In Turkey, the heating systems, other than geothermal heating systems, are designed with a 90/70°C (194/158ºF) temperature interval. Local or imported coal, fuel oil or natural gas is usually used in these heating systems. The prices of these fuels are determined in international market conditions and passed on to the consumers.

District heating systems are now being converted to geothermal use in Turkey. Below are the important points related to this conversion:

1. Since the price of geothermal heat is held constant for the entire year, geothermal heating projects are, thus, supported by the consumers.

2. The existing heating systems are connected to geothermal district heating systems directly.
3. The radiator area designed according to 90/70°C (194/158ºF) temperature interval, has not caused any problem at temperature intervals like 80/40°C, 80/45°C and 70/50°C (176/104, 176/113, and 158/122ºF). The result is that the radiator areas have been designed larger than necessary.

The amount of energy required in geothermal district heating systems is determined according to the parameters such as regional meteorological data, physical characteristics of the buildings, and system design temperature.

In Turkey, the main design criteria for heat loss calculations in buildings are expressed by standards TS 825 and TS 2164. According to these norms, Turkey is divided into three main climate regions. The values of the outdoor design temperatures have been given for all the settlement units of these three regions. Dimensions of the heating system should be determined in accordance with these values. Generally, this leads to large radiator surface areas. The velocity of water circulating in the radiator is one of the parameters that determine the radiator heat transfer constant. Thermodynamically, heat flows from a high to a low-temperature state. For buildings, that is, heat loss is a function of difference between inside and outside temperatures. To determine the heat loss of buildings individually, the average of the lowest temperatures is taken into account. This average value compared to the outdoor temperature of the district heating systems is a much lower value. This over design provides an advantage in conversion of classical heating systems to geothermal heating systems. On the other hand, the number and the usage of electrical devices show an increase due to the design of conventional systems. This might be an advantage for the conversion process. The best example for this is Kirsehir geothermal district heating application.

ECONOMICAL ASPECTS

The factors, which lead to more economic geothermal district heating investments, are as follows:

- Using of heat demand based on experimental results.
- Temperature control in the supply and return lines for energy saving.
- Utilization of plate type heat exchanger.
- Utilization of buried pre-insulated piping system networks.
- Utilization of production and circulation pumps with the variable-speed drive.
- Utilization of deep well pumps.

As a result of suitable technology selection and professional application, the investment amount per residence of the GDHS is about 1,500--2,500 US$ in Turkey (radiator installation in the residence excluded). The geothermal district heating investments are paying back in 5-8 years in the conditions of Turkey. Moreover, they have a relatively low initial and operation costs and low selling price of heat in comparison to conventional fuels (coal, lignite, fuel-oil etc.). As an example, the heating price of geothermal is only 1/4-1/7 of heating with natural gas in Turkey.

By applying these technical developments to the GDHS in Turkey, the heating fees (2001 heating season) varies from 14 US$ - 29 US$ (February 2001).

The construction costs for a heating system is 300 US$/kW (installed capacity) in the conditions of Turkey.

About 30-50% of the investment has been paid by the consumers as a connection subscription fee, like a capital investment. As a result, the economy of GDHS investments is in a better position.

RESULTS

Geothermal space heating capacity reached 52,000 residences equivalence (493 MWt) today, with 23% average annual growth, since 1983. This development depends on the following important factors:

- Development and realization of suitable geothermal district heating systems according to Turkey's conditions.
- The participation of the consumers in the geothermal district heating investments by about 30 to 50% without any direct financing refund. No foreign credit has been used in geothermal district heating investments in Turkey yet.
- The introduction of environmental friendly, cheap and comfortable geothermal district heating to the Turkish people.
- The transition from brown lignite stove heating utilization to geothermal district heating systems has increased the social living standard of the people. Therefore, it is a kind of a revolution in Turkey.
- Geothermal heating is about 65% cheaper than natural gas heating in Turkey.
- In Turkey's conditions, the amount of existing district heating investments is equal to three years saving of imported oil.
- 31,500 MWt geothermal heat potential is estimated for Turkey.
- 170 geothermal fields exist in Turkey, which 500 MWe power production and 3,500 MWt (500,000 residences) space heating is targeted for the year 2010.
- With the existing geothermal wells 2,600 MWt geothermal heat capacity is proven.
- Government, municipalities and the people know geothermal energy as an environment-friendly type of energy.
- Due to the reinjection failure in Kizildere, geothermal power plant has created a negative outlook in Turkey for geothermal power production.
- The geothermal district heating investments are supported by the consumers and the people are applying pressure on municipalities to realize and organize geothermal district heating systems in Turkey.

- It is expected that the geothermal power production investment starts and achieves developments with the geothermal law which is expected to be effective this year.
- Turkey's main target is to heat 30% of the residences in Turkey to save imported oil, natural gas and coal.
- Turkey's goal is to be one of the first three countries in the world in geothermal heating applications in the year 2010.
- The number of the existing wells is not enough for Turkey, which has 170 geothermal fields. A minimum of 100 wells yearly should be drilled in Turkey. Turkey is ready for international cooperation and finance for geothermal exploration and field development projects.
- By using experimental results instead of constant heat load values, the initial investment and operation cost is being reduced.
- By heating 52,000 residences equivalence geother-mally in Turkey 516,000 tons of CO_2 emission has not been discharged to the atmosphere. It is equal to canceling 310,000 cars from traffic (as peak emission amount in January).
- Usually in Turkey, the people are using brown lignite coal stoves for heating purposes in their houses. With the geothermal district heating system, which brings radiator heating to their houses, their living standard has been improved.

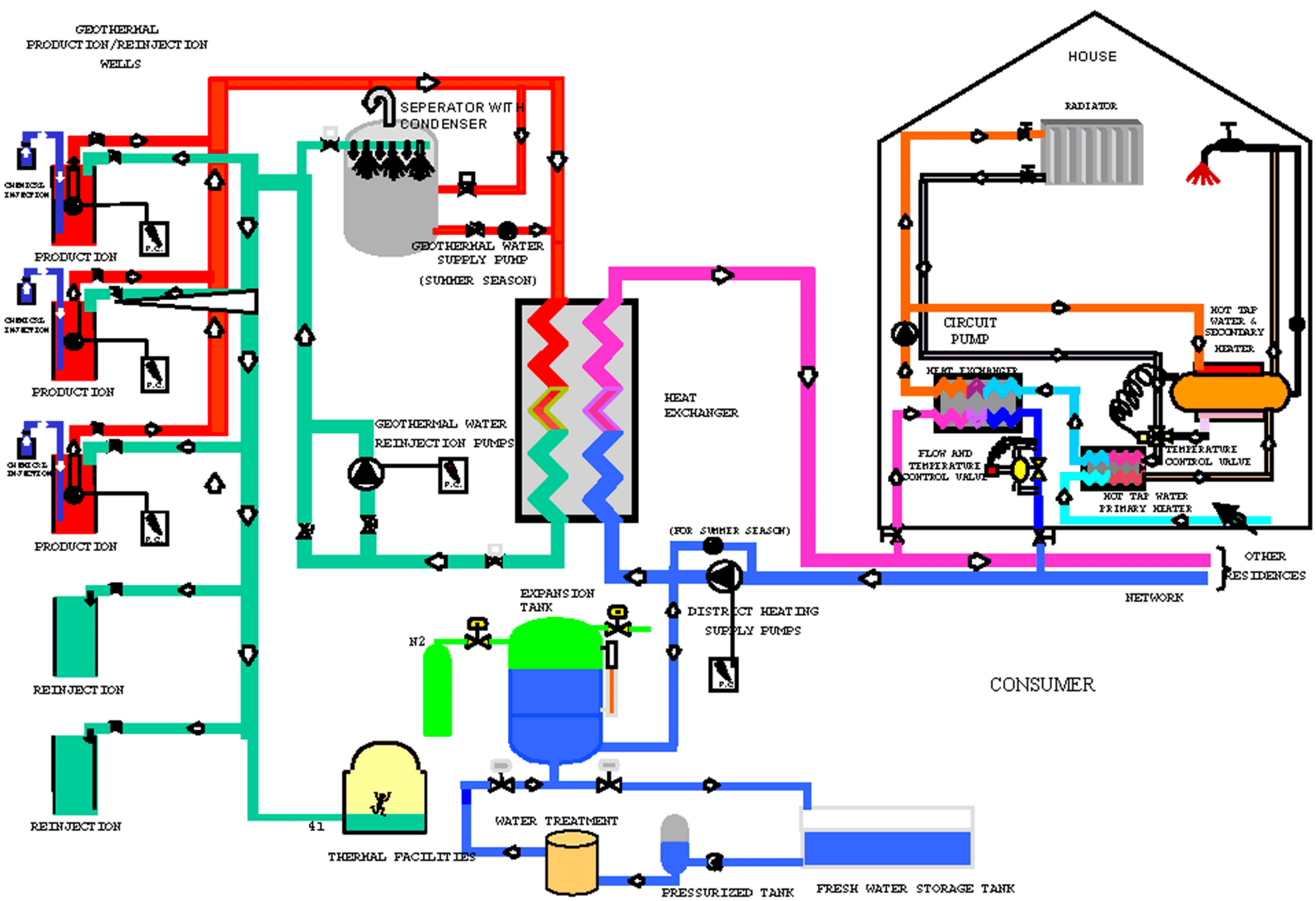

Figure 4. Example of a geothermal district heating system flow diagram (Izmir).

SHALLOW GEOTHERMAL ENERGY

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Justus-Liebig University, Giessen, Germany

The underground in the first approx. 100 m is well suited for supply and storage of thermal energy. The climatic temperature change over the seasons is reduced to a steady temperature at 10-20 m depth (Figure 1), and with further depth temperatures are increasing according to the geothermal gradient (average 3°C for each 100 m of depth).

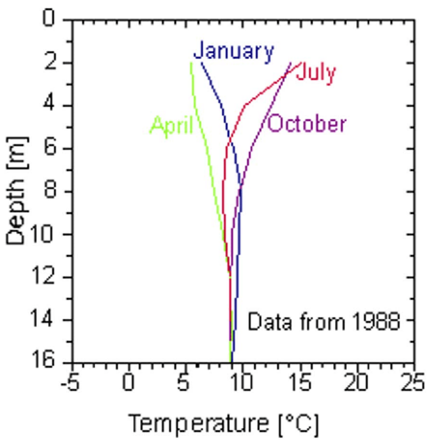

Figure 1. ***Underground temperatures from a borehole south of Wetzlar, not influenced by the heat pump operation.***

The main methods to make use of this energy are:

- Ground-Source Heat Pumps (a.k.a. Geothermal Heat Pumps)
- Underground Thermal Energy Storage (UTES)

This presentation will give an overview of these methods, possible application and systems, and some successful examples.

GROUND-SOURCE HEAT PUMPS

The basic principle of a ground-source heat pump is shown in Figure 2. Heat can be extracted from the ground at a relatively low temperature the temperature is then increased through the heat pump and used in a heating system. For each kWh of heating output, only 0.22-0.30 kWh of electricity are required to operate the system (i.e., the seasonal performance factor is 3.3-4.5). For cooling in summertime, the system can be reversed, and heat from building cooling can be injected into the ground for highly effective space cooling.

The ground system links the heat pump to the underground and allows for extraction of heat from the ground or injection of heat into the ground. These systems can be classified generally as open or closed systems:

- **Open systems:** Groundwater is used as a heat carrier, and is brought directly to the heat pump.
- **Closed systems:** Heat exchangers are located in the underground (either in a horizontal, vertical or oblique fashion), and a heat carrier medium is circu-lated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa).

The system cannot always be attributed exactly to one of the above categories. Examples of exceptions are use of standing column wells, mine water or tunnel water.

To choose the right system for a specific installation, several factors have to be considered: geology and hydro-geology of the underground (sufficient permeability is a must for open systems); area and utilization on the surface (horizontal closed systems require a certain area); existence of potential heat sources like mines; and, the heating and cooling characteristics of the building(s). In the design phase, more accurate data for the key parameters for the chosen technology are necessary, to size the ground system in such a way that optimum performance is achieved with minimum cost.

Open Systems

The main technical part of open systems are ground-water wells, to extract or inject water from/to water bearing layers in the underground (“aquifers“). In most cases, two wells are required (“doublette“)(Figure 3), one to extract the groundwater, and one to reinject it into the same aquifer from which it was produced.

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, ground-water wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. The main requirements are:

- Sufficient permeability, to allow production of the desired amount of groundwater with little drawdown.
- Good groundwater chemistry (e.g., low iron content, to avoid problems with scaling, clogging and corrosion.

Open systems tend to be used for larger installations. The most powerful ground source heat pump system world-wide uses groundwater wells to supply ca. 10 MW of heat and cold to a hotel and offices in Louisville, Kentucky, USA.

Closed Systems

Horizontal

The closed system easiest to install is the horizontal ground heat exchanger (synonym: ground heat collector, horizontal loop). Due to restrictions in the area available, in Western and Central Europe the individual pipes are laid in a relatively dense pattern, connected either in series or in parallel (Figure 4).

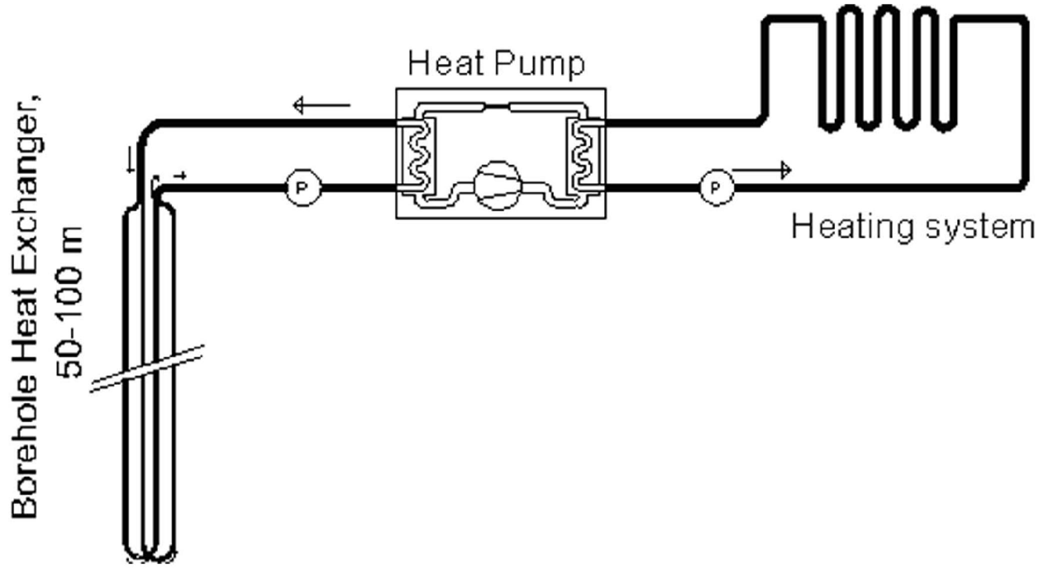

Figure 2. Schematic of a ground-source heat pump.

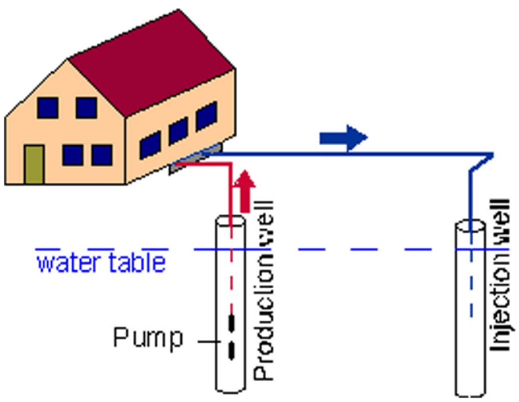

Figure 3. Groundwater heat pump (doublette).

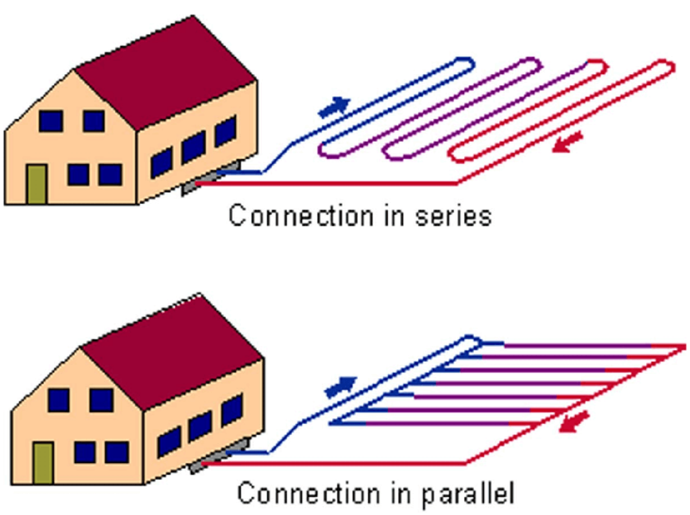

Figure 4. Horizontal ground heat exchanger (European style).

To save surface area with ground heat collectors, some special ground heat exchangers have been developed. Exploiting a smaller area at the same volume, these collectors are best suited for heat pump systems for heating and cooling, where natural temperature recharge of the ground is not vital. Spiral forms (Figure 5) are popular in USA, mainly in the form of the so-called "slinky" collectors (placed horizontally in a wide trench like in the figure, or vertically in a narrow trench).

The main thermal recharge for all horizontal systems is provided for mainly by the solar radiation to the Earth's surface. It is important not to cover the surface above the ground heat collector.

Vertical

Because the temperature below a certain depth (ca. 15-20 m) remains constant over the year, and because of the need to install sufficient heat exchange capacity under a confined surface area, vertical ground heat exchangers (borehole heat exchangers) are widely favored. In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining room in the hole is filled (grouted) with a pumpable material.

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are (Figure 7):

- U-pipes, consisting of a pair of straight pipes, connected by a 180°-turn at the bottom. One, two or even three of such U-pipes are installed in one hole. The advantage of the U-pipe is low cost of the pipe material, resulting in double-U-pipes being the most frequently used borehole heat exchangers in Europe.
- Coaxial (concentric) pipes, either in a very simple way with two straight pipes of different diameter, or in complex configurations.

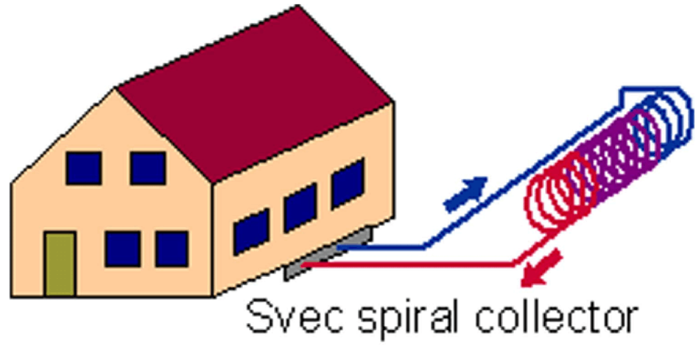

Figure 5.   Spiral-type ground heat exchangers (North America).

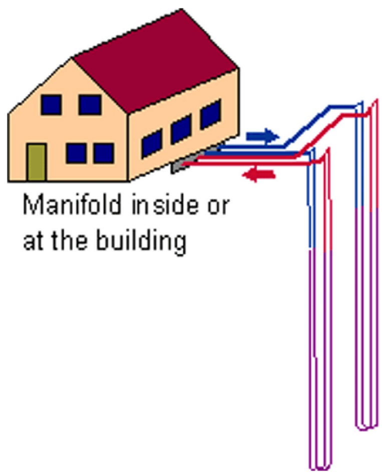

Figure 6.   Borehole heat exchangers (double U-pipe).

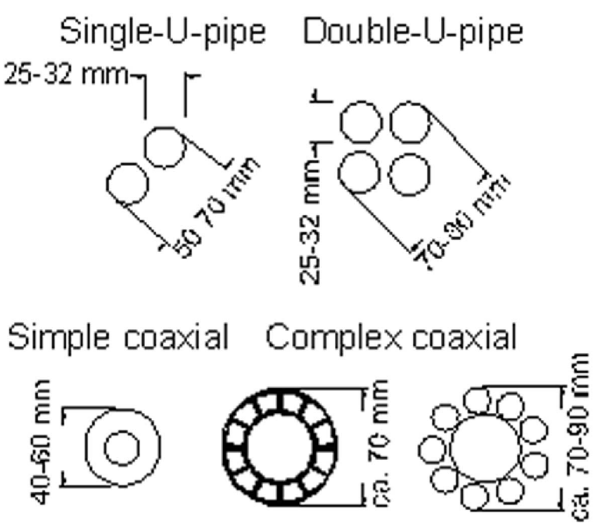

Figure 7.   Cross-sections of different types of borehole heat exchangers.

The borehole filling and the heat exchanger walls account for a drop in temperature, which can be summarized as borehole thermal resistance. Thermally enhanced grouting (filling) materials have been developed to reduce this losses.

Ground-source heat pump plants of every size have been used with borehole heat exchangers, ranging from small houses with just one borehole to large buildings, requiring a whole field of borehole heat exchangers. The highest number of boreholes for a single plant in Europe may be the head office of the German Air Traffic Control (Deutsche Flugsicherung), with 154 borehole heat exchangers each 70 m deep. The largest single plant in the world heats and cools the Richard Stockton College in New Jersey and comprises 400 boreholes each 130 m deep.

Another trend are residential areas with heat supply from ground source heat pumps; an example with ca. 130 houses with individual ground source heat pumps and one or two borehole heat exchangers for each house can be found in Werne, Germany, over an area of ca. 50,000 m^2 (Figure 8).

A perfect example for the total integration of ground source heat pump systems is the use for filling stations. The first plant was installed for the Philips 66 chain in Prairie Village, Kansas. The heat pump used for space heating and cooling is coupled to ten borehole heat exchangers each 99 m deep. The convenience store appliances (14 kW walk-in cooler, freezer and icemaker) have their own separate water-cooled compressors, and waste heat from the appliances is discharged into the same ground loops used by the space conditioning system (Figure 8). This installation has reduced electricity consumption by 40% compared to air-cooled equipment of the same size. For the wintertime car wash operations, the ground-source heat pump is coupled to radiant floor heating in the car wash bays and below the concrete at the car wash entrances and exits.

Further Philips 66 stations use ground source heat pumps in Colorado, Oklahoma and Texas, and another example is Conoco's "Skunk Creek" Service Station in Sandstone, Minnesota. Similar systems have been tested for fast food chains (e.g., McDonalds).

The design of borehole heat exchangers for **small, individual applications** can be done with tables, empirical values and guidelines (existing in Germany and Switzerland). The most important guideline currently in use is issued by the German Association of Engineers (Verein Deutscher Ingenieure, VDI) with the title "VDI 4640: Thermal Use of the Underground." This guideline consists of four parts (the first three published by the date of the EGS), dealing with:

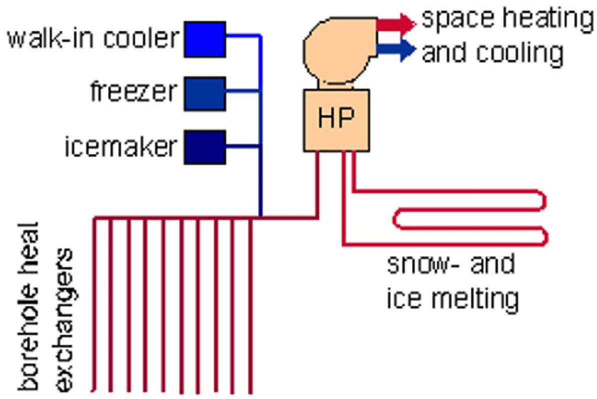

Figure 8. ***Schematic of ground-source system for filling station in USA.***

- Fundamentals, environmental aspects, licensing
- Ground-source heat pumps
- Underground thermal energy storage
- Other uses, direct uses

A popular parameter to calculate the required length of borehole heat exchangers is the specific heat extraction, expressed in watts per meter of borehole length (Figure 9). Typical values range between 40-70 W/m, dependent upon geology (thermal conductivity), annual hours of heat pump operation, number of neighboring boreholes, etc.

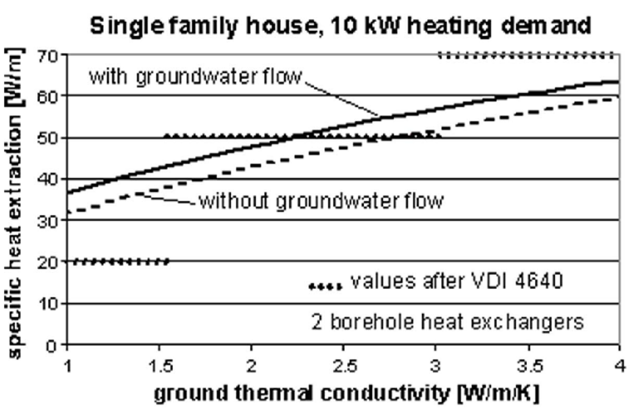

Figure 9. ***Example of specific heat extraction values for a small ground-source heat pump, no domestic hot water (heat pump operation time 1800 h/a).***

For **larger borehole heat exchanger plants**, calculations have to be made to determine the required number and length of borehole heat exchangers. Programs for use on PC exist in USA and Europe, and for difficult cases, simulation with numerical models can be done. The design tool mostly used in Europe is the "Earth Energy Designer" (EED), developed by the universities of Lund, Sweden, and Giessen, Germany. A demo version of the program and further information can be found on the website of Lund University under:

http://www.buildingphysics.com (goto "Software")

Numerical simulation can help to solve even the most difficult design problems, in particular if the influence of groundwater flow has to be considered. An example of the temperature development around three borehole heat exchangers is shown in Figure 10, modeled with the code TRADIKON-3D developed in Giessen.

To get reliable input parameters for such calculations, the Thermal Response Test has been developed (Figure 11). This test allows determination of thermal parameters of the underground on site.

A special case of vertical closed systems are "energy piles" (i.e., foundation piles equipped with heat exchanger pipes) (Figure 12). All kind of piles can be used (pre-fabricated or cast on site), and diameters may vary from 40 cm to over 1 m.

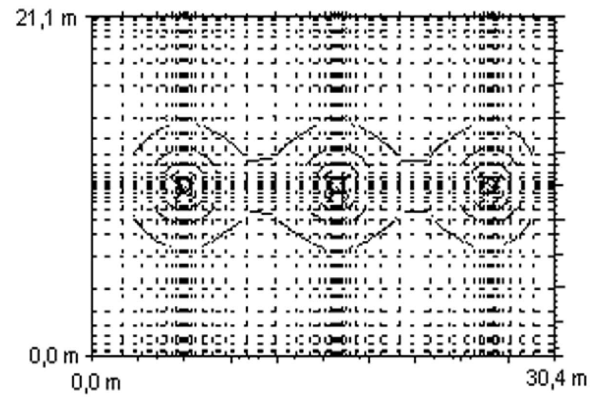

Figure 10. ***Isotherms around 3 borehole heat exchangers, calculated with TRADIKON-3D.***

Other Systems

There is a number of ground systems which are not categorized as open or closed.

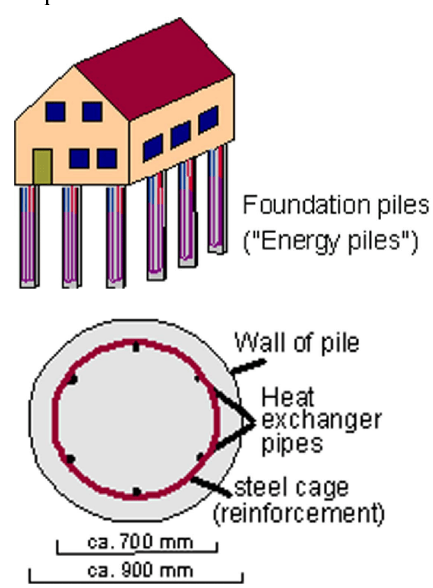

Figure 12. ***Energy piles and cross-section of a pile with three loops.***

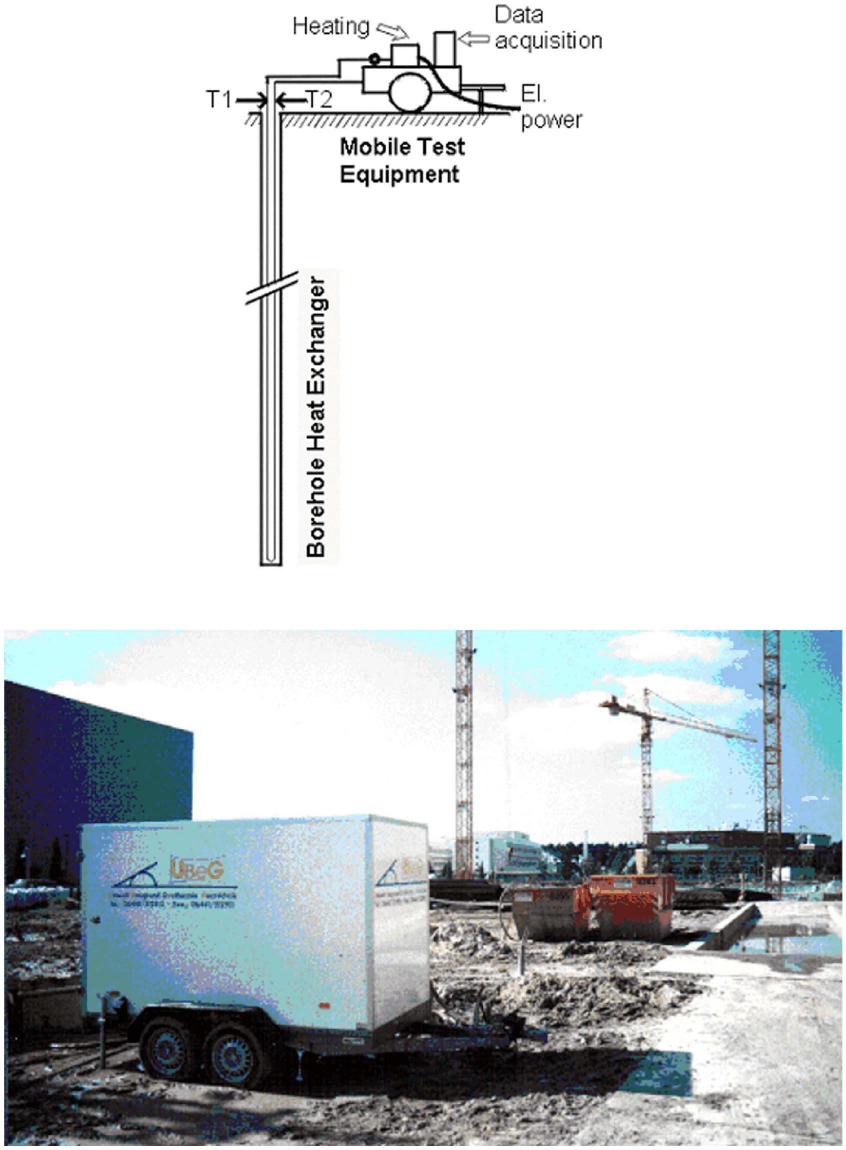

Figure 11. ***Schematic of Thermal Response Test and the equipment on site.***

In a standing column well, water is pumped from the bottom of the well and, after leaving the heat pump, percolated through gravel in the annulus of the well. Standing column wells need a certain depth to provide enough power without freezing the water, and thus most plants have boreholes several hundred meters deep. Examples are known from Europe (Switzerland and Germany) and from USA. With the expensive borehole, the technology is not suited to small installations.

A very promising concept is the use of water from mines and tunnels. This water has a steady temperature the whole year around and is easily accessible. Examples with mine water use exist in Germany (Saxonia, Figure 13) and Canada. Tunnel water is used in the village of Oberwald at the Western entrance of the Furka rail tunnel in Switzerland and in Airolo, where water from the Gotthard road tunnel provide
the heat source for a heat pump in the road maintenance facility. With the huge tunnel constructions ongoing in the Alps, new potential for this type of heat source is developing.

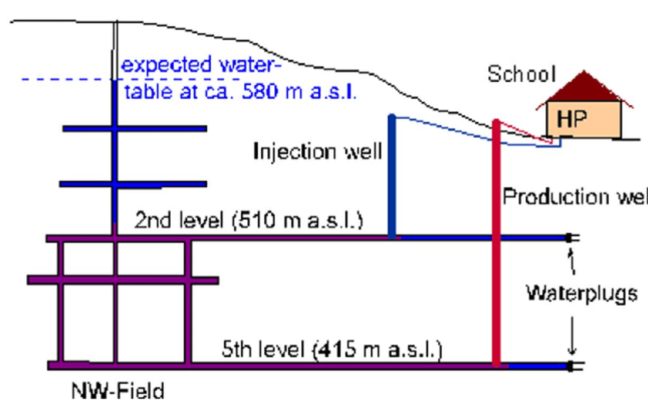

Figure 13. Heat pump using mine water (example of Ehrenfriedersdort, Germany, with abandoned tin mine).

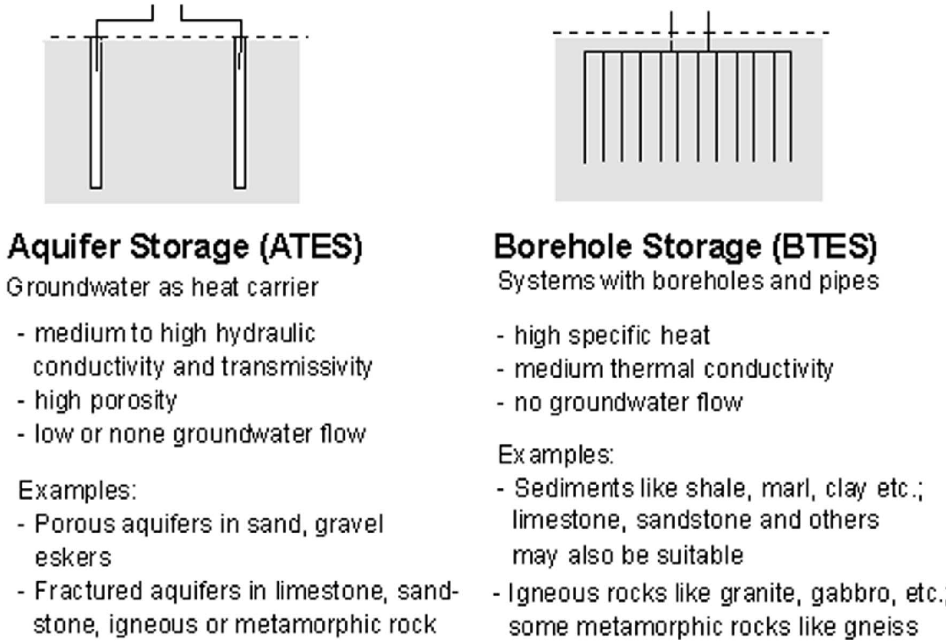

Figure 14. Types of underground thermal energy storage and geological preferences.

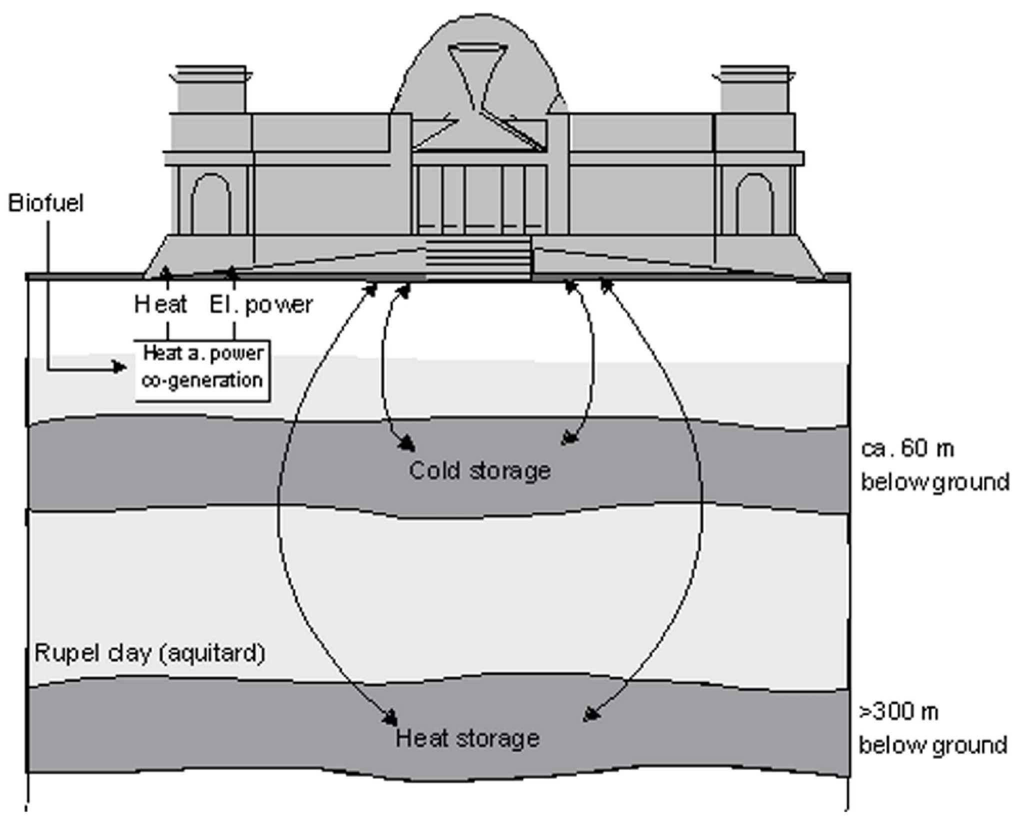

Figure 16. Schematic of Berlin Reichstagsgebäude ATES (not to scale).

UNDERGROUND THERMAL ENERGY STORAGE (UTES)

In UTES, heat, cold or both are stored underground. The methods of ground coupling (Figure 14) are essentially the same as for ground source heat pumps, with open systems (ATES) and closed systems (BTES).

Cold storage is starting to become very popular, because the cost for space cooling normally is rather high. Cold air in winter is used to cool down the underground store and this cold is used again in summer. In the 60s, China was a major pioneer in this field, with a number of plants in the Shanghai area. Today, the main activity on seasonal cold storage is in Belgium, the Netherlands, and Southern Sweden.

A combination of heat and cold storage UTES is used for road surfaces (Figure 15). Heat from solar radiation on the surface can be stored and used in winter for de-icing and snow melting on that surface. The system is used mainly on bridges, but can also be applied to any other road surface, airport runway, etc.

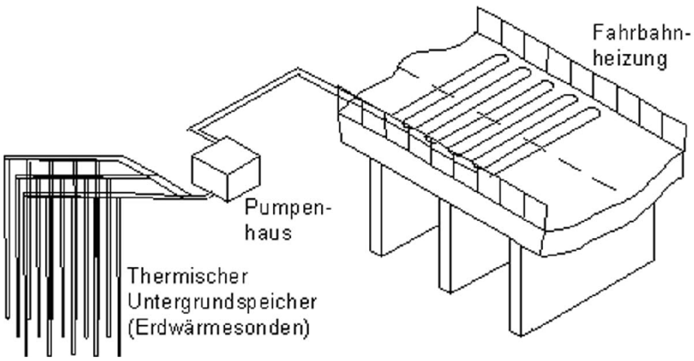

Figure 15. UTES for de-icing of road surfaces.

Heat Storage can make use of solar or waste heat in summertime for heating in winter. Major plants in Germany are at Neckarsulm, were a BTES system is charged with heat from solar collectors and heats a housing district, or in Berlin, were waste heat from heat-and-power-co-generation in summer is stored in an ATES for heating in winter (Figure 16). The Berlin plant supplies heat and cold to the German Parliament buildings (Reichstag building and surrounding offices), and for the first time incorporates two ATES systems at different levels, the upper for cold storage, and the lower for heat storage (up to 70°C). System parameters are:

The total energy demand is as follows:

- power: 8,600 kW 19,500 Mwh/a
- heat: 12,500 kW 16,000 Mwh/a
- cold: 6,200 kW 2,800 Mwh/a

To meet the heat and cold demand, several units are installed within the Reichstag building and the surrounding buildings:

- 2 heat- and power co-generation plants
- 3 absorption heat pumps (heating/cooling)
- 1 boiler (for peak heating)
- 2 compressor chillers (for peak cooling)

All excess heat from power generation is stored in the lower ATES system, and a big part of the cooling is provided from the upper ATES.

CONCLUSION

Shallow geothermal energy applications can be used in a variety of sectors, from house heating to process cooling and road de-icing. Design and construction is well understood and done routinely, however, skill and knowledge is required to guarantee successful installations. Ground-source heat pumps in some of the countries have a wide application in simple cases of heating a residential house (Table 1). In the future, further good opportunities for use of this technology can be seen within Europe mainly in the commercial sector (offices, factories, department stores, etc.), where heating and cooling is required.

Table 1. Estimation of GSHP-Numbers in Europe by the End of 1998, Using Published Information (with year) and Extrapolation According to Published Rates of Increase

	Number of GSHP-plants	Remarks
Austria (1996)	ca. 13000	annual increase ca. 1600
Germany (1995)	14 000-22 000	240-450 MW thermal capacity, annual increase ca. 2000
Netherlands (1997)	ca. 900	market development is about to begin
Sweden (1998)	more than 60 000	ca. 330 MW thermal capacity
Switzerland (1998)	more than 20 000	ca. 300 MW thermal capacity, annual increase ca. 10%
France (1999)	10 000 - 20 000	mainly horizontal GSHP heating capacity < 15 kW
Rest of Europe	NA	Growing market in Great Britain
Total Europe (extrapolated to end of 1998)	110 000-140 000	almost 1,300 MW thermal capacity, ca. 1,950 kWh heat per year

POWER GENERATION FROM HIGH-ENTHALPY GEOTHERMAL RESOURCES

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ABSTRACT

In this article, I shall address high-temperature (high-enthalpy) development, concentrating on electric power production. We live in a modern world, however, where awareness of the environment is ever on the increase. This is clearly manifest in greater demands being made of the engineer, the scientist and the developer to observe care in power development, which is by many considered the main culprit and contributor of pollution both liquid and gaseous. I will therefore touch upon integrated energy development, both because it is very close to my heart and it meets the aforesaid demands most admirably.

The task I was given is quite complex and demanding –I can thus only execute it in outline and will undoubtedly leave out many aspects that are important to some and address aspects that are of less importance to others.

One of the drawbacks is a lack of good compre-hensive references that I regret.

SOME BASIC DEFINITIONS

Before delving any deeper into the utilization of high-enthalpy (temperature) geothermal resources, it is important to define a few of the basic terms used in this presentation to categorize the resource.

High temperature	fluid temperature in excess of 250°C
Medium temperature	fluid temperature between 150°C & 250°C
Boiling low temperature	fluid temperature between 100°C & 150°C
Low temperature	fluid temperature between 50°C and 100°C

These are not the scientific definitions normally used but rather more practical engineering terms. Other more specific definitions are defined as they appear.

DEVELOPMENT STRATEGIES

Very early on the road to geothermal development, a basic strategy needs to be thoroughly studied and agreed. Such strategy strongly affects future exploration, feasibility, financing, design and construction work. Three basic strategies prevail in the world today:

Tailored Development – Electric Power and Industrial Use:

The development is tailored to the 30-50 year yield of the reservoir that has been estimated using volumetric methods. Examples are Lardarello, Wairakei, The Geysers, Tiwi, Cerro Prieto, Ahuachapan, Hatchubaru, and Olkaria.

This type of tailored development was conventional during the early years of geothermal development that was heavily biased towards electricity production. The plant output was decided on the basis of an estimated reservoir volume, average formation temperature, and porosity. This usually lead to an overestimate of yield and useful life span.

Main advantages:
- Maximum size of development steps
- Benefits of scale(i.e., lower cost per unit installed power)
- Larger initial power capacity widens choice of markets

Main disadvantages:
- Large initial capital investment required
- Long development time
- Under capacity operation reduced earnings
- Serious reservoir depletion problems
- Less operating security

A study carried out in Iceland and reported at the 5th-annual Energy Congress held in Iceland 1991 by Valgardur Stefánsson, Benedikt Steingrímsson and E.T. Eliasson found that the standard volumetric reservoir capacity methods predicted capacities three to four times greater than methods using reservoir simulation techniques.

ADVICE: IN CONTEMPLATING DEVELOPMENTS TAILORED TO A RESERVOIR CAPACITY, BE VERY CAREFUL IN ADOPTING A CAPACITY BASE ARRIVED AT SOLELY BY VOLUMETRIC ASSESSMENT.

Stepwise Development – Electric Power and Thermal Energy Production:

The reservoir is developed in 10–30 MW steps with a 2-3 year interval between each development step during which time you study the reservoir response etc., for the next step. This new idea, which first was put forward by Dr. V. Stefansson in 1990, has now been adopted in Iceland.

The development is divided into several manageable steps, and often more than one geothermal field may be under parallel development at the one time. The step size is decided on basis of local specifics such as needs of local energy market, economic minimum size, preliminary assessment of reservoir capacity etc.

The basic idea is that each step be only a portion of the pre-assessed reservoir capacity using for instance volumetric assessment methods.

Main advantages:

- Development can be made to suit available finances
- Earnings start early
- Minimum initial investment
- Better possibility for low environmental impact
- Investigate as you develop

Disadvantages:

- Smaller development units reduces size benefits
- Development spread to more than one area at the one time to ensure high rate of development

Integrated Development – Multi-Use Applications:

The reservoir is developed for multiple use right from the start. This strategy was pioneered in Svartsengi 1976 and is widely adopted in Iceland.

Integrated development ensures the best o/a conversion efficiency, typically the highest earnings per kWh from the development and also the minimum gaseous emission into the atmosphere per produced kWh. Figure 1 shows development of a multiple use boiling low temperature source.

Figure 2 shows a combined heat and power development, producing electricity combined with steam to heat fresh water for district heating. The source is a high temperature resource and the output is currently some 60 MWe and 150 MWt.

Figure 3. on the other hand depicts a very interesting CPH solution adopted in the year 2000 for the new addition to the Svartsengi Plant. It features an energy system that is new in geothermal development though it is well tried in the chemical and divers process industries.

Instead of deploying a back-pressure turbine as is quite common, steam is here tapped off the turbine at two points and used with cooling water from the condenser as the energy source for the cascaded uses to improve overall efficiency of conversion.

ENERGY CONVERSION SYSTEMS

High temperature developments of this type comprise five basic subsystem components:

- Steam/fluid supply
- Energy and/or power production
- Effluent disposal
- Energy and/or power transmission or distribution
- Control systems

The steam/fluid supply subsystem comprises:

- Geothermal wells complete with mufflers and control valves
- Fluid collection pipelines, flash/separator units, steam mains and vapor eliminators

Energy and/or power production subsystem comprises of:

- Power turbine/generator units
- Condensing facility and/or heat exchanger banks and pumping units
- Control systems
- Monitoring systems

Effluent disposal subsystem comprises of:

- Gas evacuation and gas disposal facility
- Liquid effluent collection and disposal
- Control systems
- Monitoring systems

Energy/power transmission or distribution subsystem comprises:

- Electrical power transformers
- High tension power lines and switch gear
- Steam or hot water transmission pipelines and pumping plant
- Pressure control and/supply compensation tanks

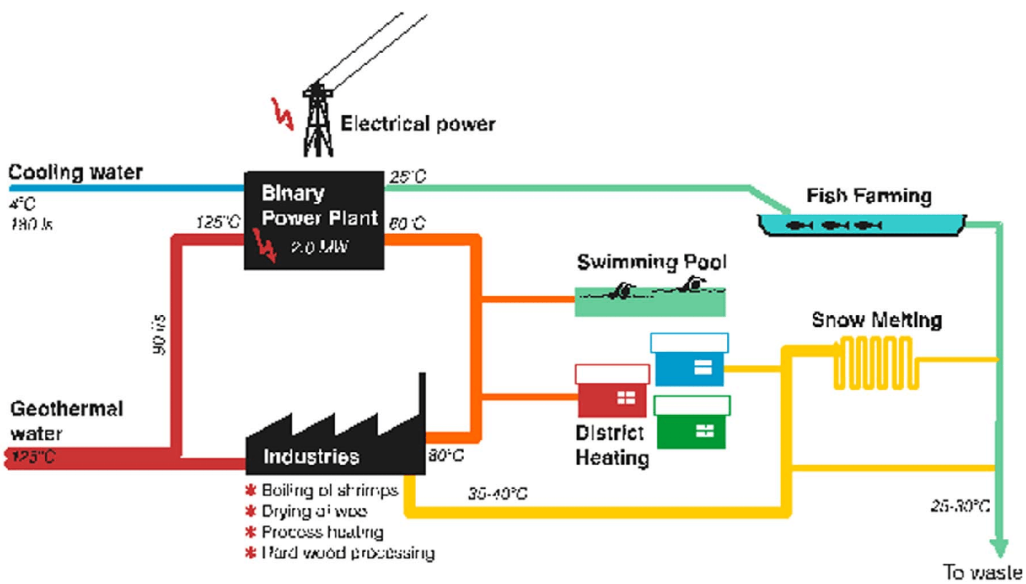

Figure 1. Húsavík, Iceland energy development.

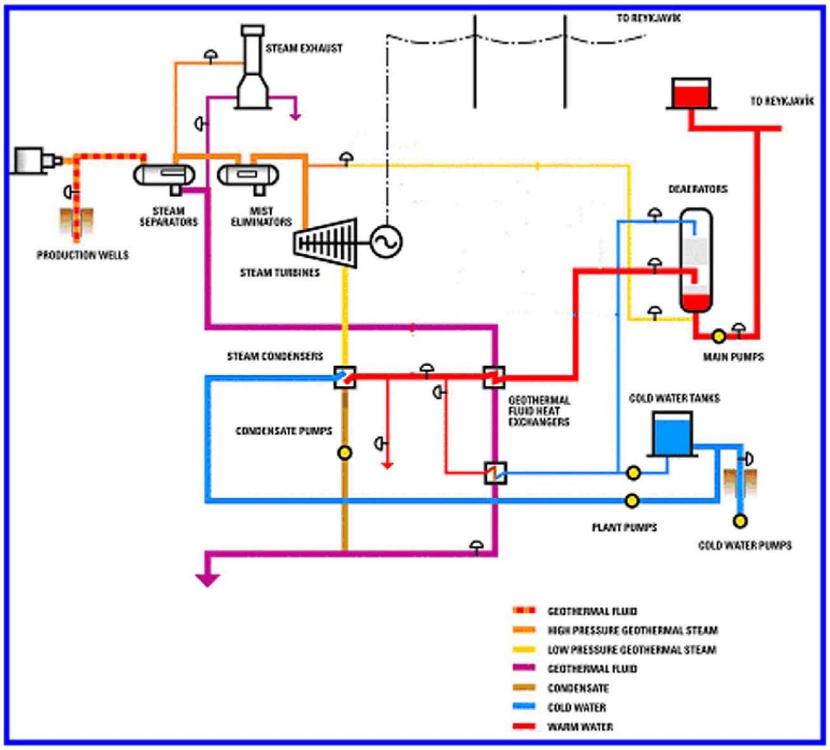

Figure 2. Nesjavellir, Iceland energy development.

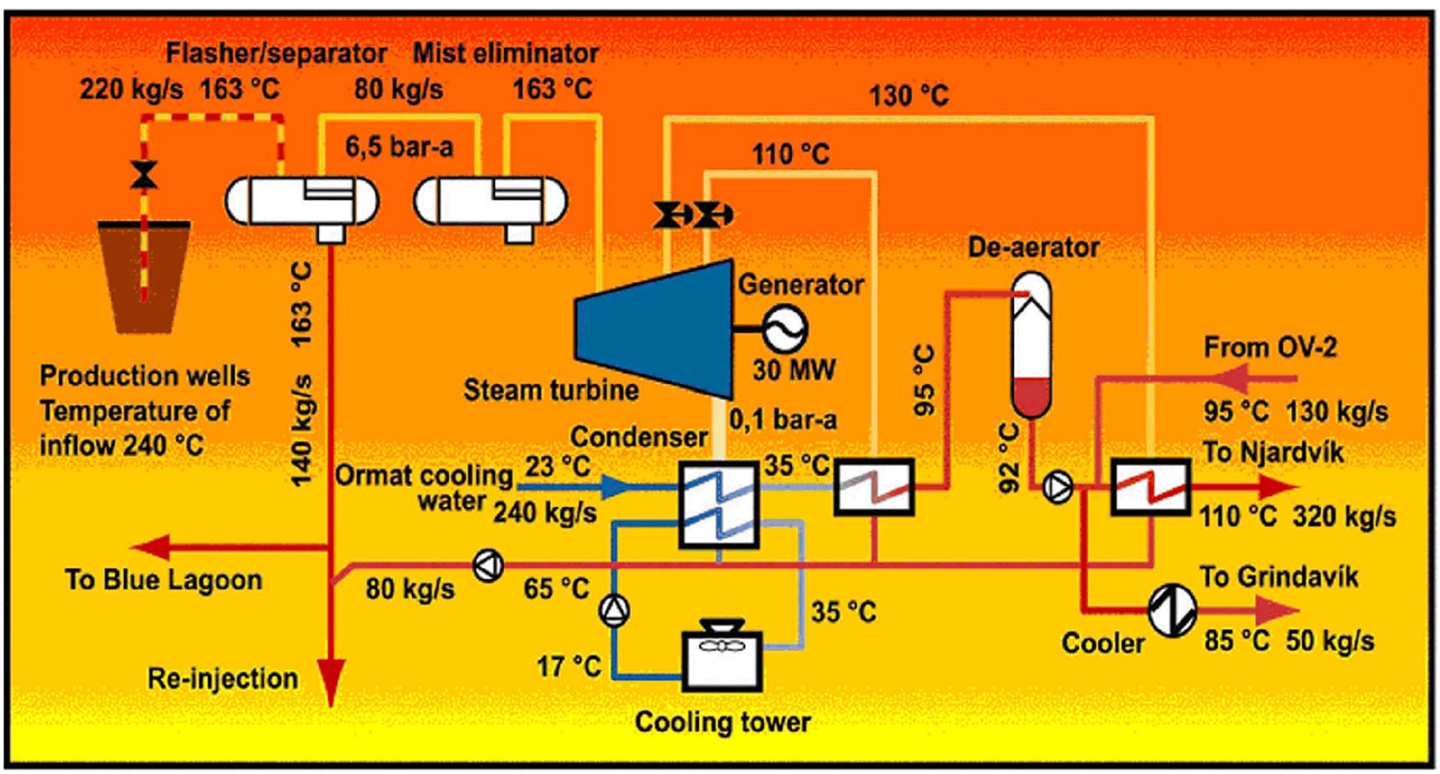

Figure 3. Production diagram for the newest Svartsengi Energy Facility (OV-5).

Control subsystem comprises of:

Miscellaneous automatic and computer aided system controls frequently remote.

In the following, it will be endeavored to outline each of these conversion components, the problems and some of the aspects that have to be considered to arrive at an acceptable solution.

HIGH-TEMPERATURE WELLS

They are typically drilled in four stages:

- A wide hole to a depth of 50-100 m into which is cemented the surface casing.
- A narrower hole to a depth of 200-600 m into which the anchor casing is cemented
- A narrower hole still to a depth of 600 to 1,200 m which carries a cemented casing called the production casing
- Finally the production part of the well is drilled into and/or through the active aquifer. This part carries a perforated liner that is hung from the production casing reaching almost to the well bottom.

On top (wellhead) the well is fitted with expansion provisions and a sturdy sliding plate valve (master valve). It is also connected to a muffler, usually of a steel cylinder fitted with an expanding steam inlet pipe to slow down the fluid on entry. Steam capacity of these wells commonly range between 3-30 kg/s (1.5 MWe -15 MWe).

The wells are often enclosed in a lightweight enclosure to keep the wellhead warm, free from dirt and curious visitors both animal and human.

Typical Wells Types

Geothermal wells are in principle either straight or directional. The drilling programs are of two types:

Standard:

- Surface casing 18” nominal diameter in a 20” hole
- Anchor casing 13 3/8” nominal diameter in a 17 ½” hole
- Production casing 9 5/8” nominal diameter in a 12 ½” hole
- Liner 7” nominal diameter in an 8 ½” hole.

Wide:

- Surface casing 22” nominal diameter in a 24” hole
- Anchor casing 18” nominal diameter in a 20” hole
- Production casing 13 3/8” nominal diameter in a 17 ½” hole
- Liner 9 5/8” nominal diameter in a 12 ½” hole

The wide configuration may give as much as twice the yield of a standard one for the same formation resistance

Typical Well Casing Programme

The types of well casings, which are all cemented to the formations, are depicted on Figure 4. They have the following denotations:

- Conductor
- Surface casing
- Intermediate or anchor casing
- Production casing.

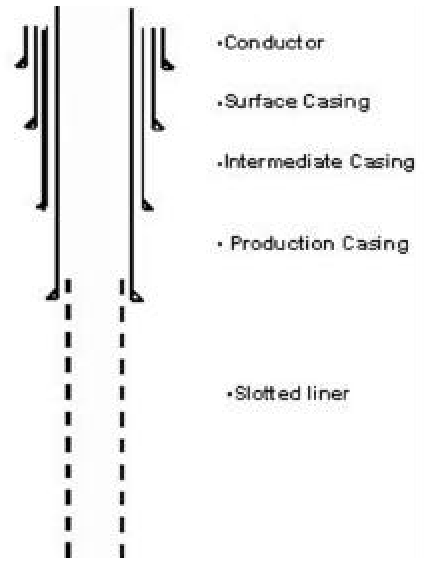

Figure 4. Casing types.

In addition to those there is the production liner, which is slotted/perforated and not cemented to the formations but hung from a special casing hanger usually placed some 20 m or so from the shoe (bottom) of the production casing. The liner ends some 20 – 30 m above the bottom of the well to allow for thermal expansion.

The functions of the casings and liner are basically as follows:

- Conductor and surface casing are used to facilitate drilling through unconsolidated surface formations.
- The intermediate or anchor casing prevents breakthrough of steam up through the surface during drilling, protecting rig and crew.
- The production casing closes off cold aquifers and provides a conduit for the fluid up the well.
- The liner is not cemented and prevents the well wall from collapsing into the well during operation.

Typical Liner Perforations

As previously recounted, the liner is perforated or slotted. Thorough studies carried out in Iceland and elsewhere indicate that the degree of perforation needed to ensure adequate flow area without undue restriction to inflow corresponds to some 3% to 6% of the surface area of the liner.

In other words, the periferal slot/perforation area per meter of liner is usually kept within this range. Another factor that affects the choice of the actual number of slots per meter of casing is the weakening of the liner’s tensile strength caused by the slots. The longer the liner, the lower must be the ratio. Axial staggering of the slots should also be considered to minimize nonuniformity of strength along the liner’s length.

The basic shapes and mode of perforating the liner and depicted in Figure 5. are:

- Rectangular slots (flame cut or milled)
- Oval shaped slots (flame cut)
- Rectangular inclined slots (flame cut or milled)
- Circular holes (drilled, flame cut, shot)

Figure 5. ***Typical liner slots.***

Boiling Point with Depth

The boiling curve, the overburden, the cold water pressure, mud pressure and boiling pressure variation with depth in the well. All these parameters are important in designing the casing, the cementing program and drilling sequence for the well.

Typical Icelandic Well Yields

Typical well capacities obtained in Iceland expressed as saturated steam at 7 bar absolute and water at 170°C are depicted in Figure 6.

SCALING IN GEOTHERMAL

The type of deposition (scaling) most commonly encountered in surface equipment are those of silica, sulphite and calcite.

The diagram in Figure 7 shows how the solubility of silica in water varies with temperature and the degree of boiling.

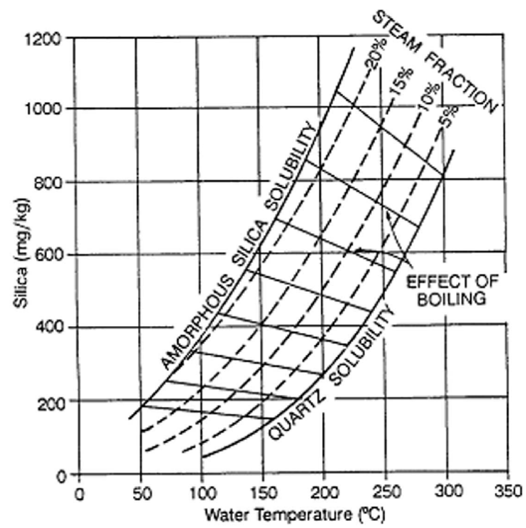

Figure 7. ***Solubility of silica.***

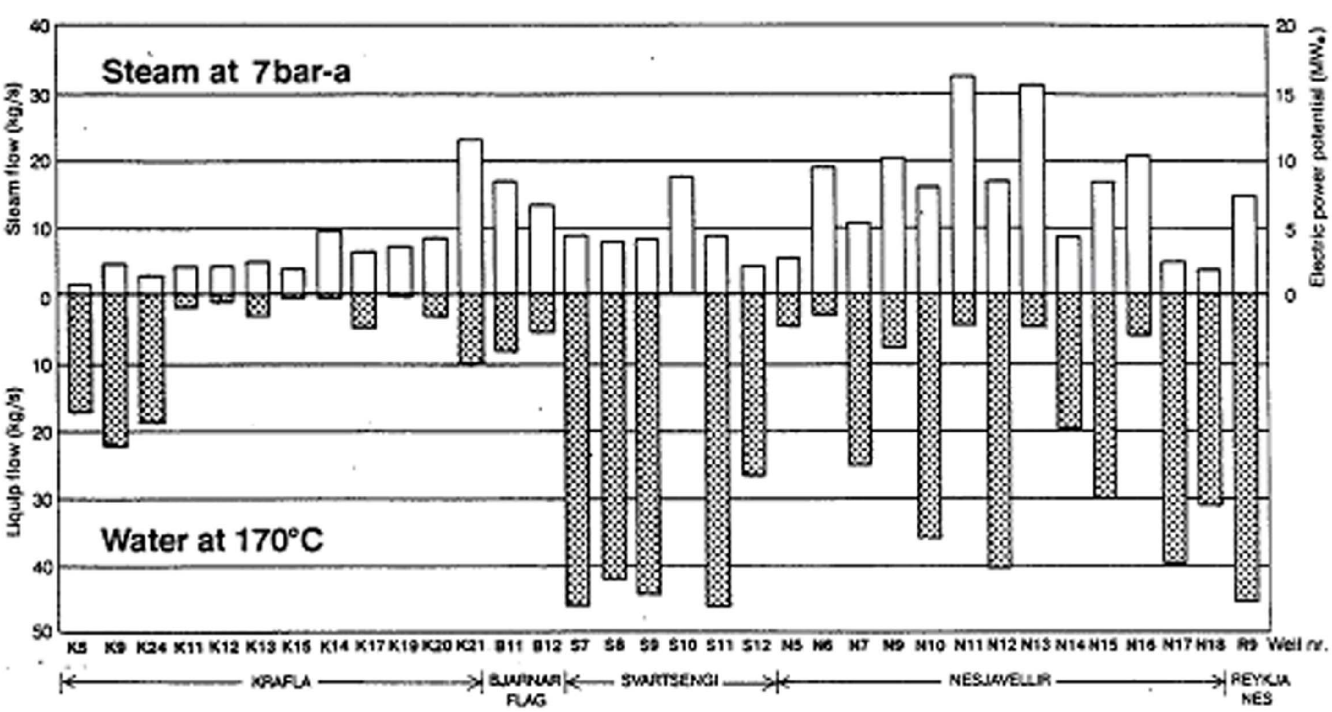

Figure 6. ***Typical Icelandic well yields.***

Deposition of silica is a common occurrence in high temperature geothermal systems. It is, therefore, important to realize the disposition potential at various sensitive points of the conversion system so that appropriate and timely measures can be taken to alleviate and/or side-step deleterious effects.
Silica scaling has a time factor that is temperature and salinity dependent and can be made to work in ones favor (i.e., it can be used to delay the onset of scaling) and thus select the place where in the system the scaling takes place. Surface pipeline to be cleaned of calcite scaling by the use of high-pressure jet washing technique is depicted on Figure 8. This shows the condition of the steam collection pipe some 50 m after the well in the Reykjanes field. The pipeline requires cleaning about once every four years. See also calcite scaling in a well liner Figure 9.

Figure 8. Calcite scaling in surface pipes.

Figure 9. Calcite scaling in Krafla, Iceland well liners.

Calcite is deposited largely through carbon dioxide coming out of solution in fluids that are rich in calcium. Calcite does, however, have reverse solubility, which means the solubility is increased as the temperature falls. It is, therefore, always preferable to keep the CO_2 gas in solution in heat exchange situations and remove first after the heat exchanger when the fluid has cooled down.

STEAM FLASH/SEPARATORS

Steam is separated from the geothermal fluid using the forced vortex principle. The fluid is introduced into a cylinder via a tangential or a streamlined inlet. Two basic designs are in use; based either on a vertical or a horizontal separator vessel.

- The former admits the fluid via a streamlined inlet and is fitted with a central vertical pipe for tapping of the steam, whereas, the liquid fraction is discharged radially low on the vessel's body via an orifice arrangement. The steam and liquid phases separate mainly via centrifugal action.
- The latter admits the fluid via a tangential inlet into a wide horizontal vessel fitted with a curved horizontal vane and a droplet filter in front of the steam outlet port. The separation is chiefly through gravity effects. The liquid discharge is tangential low on the vessel's body via an orifice as before.

Separation efficiency is very important because all dissolved solids carried over as droplets from the separator result in scale deposition in the attached energy conversion system such as on turbine vanes/blades, in heat exchanger tubing etc.

All separators constructed and installed in Iceland 1967-1995 were of the vertical design, the horizontal type fitted with droplet elimination mats gaining popularity in later years.

Mist eliminators are generally installed in the steam mains just before it enters the building. Steam traps are also fitted to long steam mains to tap of condensate.

Vertical Separator Design

Advantages:
- Sharper cut-off
- Cleaner steam
- Wider pressure range
- Maintenance easy

Disadvantages:
- Size limitations
- Height of construction

Horizontal Separator Design

Advantages:
- Size not a constraint
- Greater throughput/unit

Disadvantages:
- Needs mist eliminators to ensure good quality steam
- Greater maintenance
- Generally less expensive

Steam dryness needs to be kept better than 99.995% to ensure low scaling rate in equipment. Steam quality is highly sensitive to control of liquid level in separators, more so the vertical design.

Fluid Separation

Steam is generated from the geothermal fluid by sharply changing the fluid pressure for instance via a plate orifice. This changes the fluid state by increasing the relative portion of vapor. The following thermodynamic equation and Figure 10 illustrate the phenomenon.

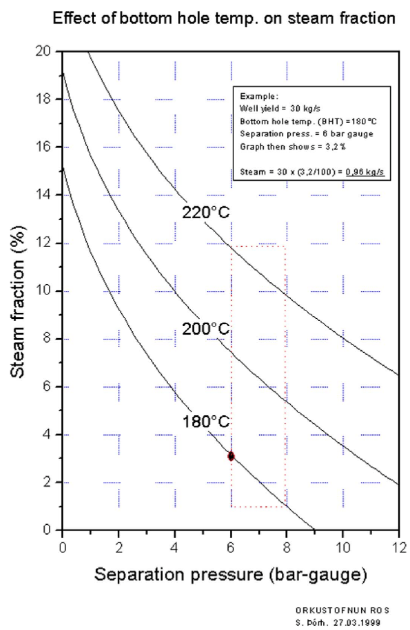

Figure 10. Fluid separation.

Steam fraction in the fluid $\boldsymbol{x}$ depends upon total enthalpy of fluid ($\boldsymbol{h_0}$) and the separator pressure expressed by the equation of state:

$$x = (h_0 - hv_2)/r_2$$

Where:

- x: portion steam (portion liquid = 1-x)
- h_0: total enthalpy of well fluid (kJ/kg)
- hv_2: water enthalpy at separation press.
- r_2: ($r_2 = hg_2 - hv_2$): latent heat at separation pressure
- hg_2: steam enthalpy at separation press.

Chemicals Dissolved in the Geothermal Fluid

The hot geothermal fluid interacts with the geological formations and dissolves both solids and gases. Since the gases do not condense in the conversion system, they are mutually denoted non-condensable gases or NCG.

Non-Condensable Gases

The gas content in the geothermal fluid depends chiefly on the following:

- Temperature of the geothermal system – the higher the temperature the higher the gas content
- The geology of the reservoir affects strongly the relative composition of the non-condensable gas (NCG)
- The physical properties of the reservoir fluid:
  > Steam field typical gas concentration 3% to 4% by weight
  > Boiling reservoir gas content 0.5% to 2%
  > Liquid dominated reservoir 0.2% to 0.5%

The gas follows the vapor phase in the flashing process. The pressure at which the flashing takes place thus affects the amount of gas present in the flashed steam:

- The lower the separation pressure the lower the gas content in steam.
- Double flashing gives virtually zero gas in second flash,

Typical Steam Composition

Table 1 shows the typical NGC content in the steam flashed off the geothermal fluid from Icelandic high-enthalpy reservoirs. This is fairly typical of other liquid dominated and boiling two phase geothermal fields.

Table 1. Typical Composition of High-Enthalpy Flashed Steam in Iceland

Component	Separator Liquid	Steam Mains	Heat Exchangers
Conductivity uS/cm	32.6	46.20	
Silicate (SiO_2)	869	0.60	0.70
Sodium (Na)	12,587	0.09	1.39
Potassium (K)	1,905	0.21	0.67
Magnesium (Mg)	1.16	0.03	0.02
Calsium (Ca)	2,263	0.35	0.69
Chloride (Cl)	25,030	0.94	2.34
Sulphate (SO_4)	36.4	1.07	1.61
Iron (Fe)	0.47	0.02	0.02
Total dissolved solids (TDS)	45,120	4.60	6.20

The solids content and composition is more varied, however, particularly as regards chloride and various trace elements, some of which may be highly polluting (e.g., boron, fluoride, mercury, etc.). Geothermal fluids containing as much as 130 g/kg (130,000 ppm), mostly sodium chloride, are known. In Iceland, the maximum TDS is about 30 g/kg (30,000 ppm) in the Svartsengi field.

FLASHED STEAM SYSTEMS

Flashed steam is most common in all types of geothermal energy conversion systems whatever their type, such as with:

- **Back pressure units** – common as well-generation-units also used in integrated CPH type geothermal plants.
- **Flash steam electric power condensing turbine generator units** – single flash/double flash.
- **Hybrid electric power plants** – flash plant combined with binary.

Binary units - most commonly in difficult fluid chemistry environments. The binary converter is adopted for many reasons the most significant ones being:

- To isolate chemistry related problems such as from high TDS.
- Simplicity of operation.
- A method well tried and established.

Hybrid Systems

Commonly constitute combined back-pressure unit and binary unit in cascade. Sometimes also condensing steam plant in parallel with a binary plant. Hybrid plants potentially have greater conversion efficiency than its conventional flashed steam condensing or pure binary equivalent.

Hybrid energy conversion systems are particularly suited to medium temperature geothermal resources where the fluid properties are not unduly difficult.

Binary Energy Converters

Purely binary systems come best to their own right in the utilization of:

- Boiling low-temperature reservoirs for electricity production.
- In harnessing geothermal resources of very high TDS and difficult chemical compositions

It must be realized, however, that a purely binary plant is a low-efficiency conversion equipment that is, therefore, best used in cascade in a multi-use or hybrid type situation in a way that benefits the o/a efficiency of utilization.

There are two distinct systems of the binary type on the market:

- The Organic Rankine Cycle type energy converter commonly called the ORMAT type energy converter after the company that has been in the forefront of its commercial development. Available from:
  > ORMAT Industries Ltd of Israel
- TURBODEN Ltd of Italy
- Mitsubishi Heavy Industries Ltd and others from Japan
- The Kalina Cycle named after its inventor prof. Kalina. It is available from:
  > Exergy Inc. of California, USA

Of the two binary converter types the latter is more efficient within the temperature ranges featured in this discourse but also more complex.

The binary conversion system is based upon a two fluid system; where, the geothermal fluid is the primary energy source and transfers thermal energy via heat exchangers to a second low boiling-point fluid in a closed system. The second fluid, normally one of the carbon hydrates (butane or pentane), in turn drives the turbine generator. From the heat exchangers the geothermal fluid is disposed of and often returned back to the reservoir.

CONDENSING PLANT

The greatest preponderance of high and medium temperature areas are found in relatively arid locations or where cold surface water is scarce. The most commonly adopted condensing systems in geothermal are, thus, the so-called jet condensers coupled with forced ventilation cooling towers. The NCG is exhausted from the condenser either via steam ejectors (NCG<2%-3% of steam by weight) or by mechanical means using miscellaneous vacuum pumps (often liquid ring extractors). The cooling cycle is usually "closed", the condensed water is circulated through the cooling tower and sprayed into the condenser.

Mechanical problems:

- Cooling tower fill
- Icing
- Fouling

Chemical problems:

- Sulphur deposition
- Corrosion due to low pH and oxygen

Other problems:

- Bacteria growth
- Flaking of pond walls
- Disposal of NCG exhausted

CHEMISTRY SPECIFICS

The most commonly encountered chemical type problems in geothermal development are:

- High non-condensable gas contents
- High total dissolved solids (TDS) contents
- Difficult chemical compositions

They affect the operating part of a geothermal utilization system, the gaseous effluent disposal and liquid effluent disposal (e.g., via reinjection).

High NCG Content

The most commonly encountered problems with regard to high gas content in the geothermal steam are:

- To meet legislative pollution criteria as regards atmospheric pollution.
- High NCG content tend to lower conversion efficiency particularly as regards the evacuation of condensing plant and heat exchanger equipment.
- High H_2S content generally promotes metallurgical problems such as corrosion, stress corrosion cracking and metal fatigue.
- High CO_2 content in geothermal fluid below about 200°C accelerates calcite scaling and may promote corrosion.

High TDS Content in Fluid

High content of dissolved solids causes numerous problems. The most serious of these are various types of solids disposition problems that plug up flow conduits.

Table 2 shows the type of chemical composition that may be encountered in the fluids in energy conversion circuitry. The fluid in question is from a high TDS field in Iceland.

Table 2. Example of Chemical Composition of Fluid in Conversion System

High-Pressure Reservoir	Pressure (bar a)	H_2O %	CO_2 %	H_2S %
Reykjanes	10.0	99.30	0.672	0.019
Svartsengi	5.5	99.80	0.196	0.003
Hveragerdi	5.5	99.84	0.138	0.006
Bjarnarflag	11.0	99.70	0.060	0.060
Krafla	8.0	98.70	1.140	0.070

REINJECTION OF FLUID AFTER USE

Reinjection of the geothermal liquid used back into the reservoir has a number of purposes. The most important ones being:

- Disposal of the used liquid without polluting the environment.
- Sustenance of the reservoir pressure to counteract draw down and surface subsidence.
- Mining of heat stored in the hot formations simultaneously extending the useful life of the reservoir.

The Associated Problems Are Mainly:

- Chemical deposition of silicates.
- Loss of injectivity due to properties of formations injected into, particular in the case of sandstone.
- Coldwater breakthrough from injection wells to production wells.

Many different methods are used to overcome the deposition problem. They depend upon the type of deposition encountered, the geological situation and the economic environs. The more important ones are:

Calcite Deposition:

- Thermodynamic countermeasures coupled using the reverse solubility characteristics of calcite coupled with keeping the CO_2 in solution until the under saturated state is reached.
- Introduction of calcite scaling inhibitor chemicals into reinjected fluid.

Silicate Deposition:

- Keeping the reinjected fluid at a temperature above the silica deposition point and keep out of contact with atmospheric air.
- Control the pH of the reinjected mixture using plant condensate and/or acidification.
- Use scale inhibitor admixtures in effluent liquid.
- Promote polymerization of silica in the effluent liquid and letting it settle out in special settling ponds prior to reinjection.
- Treatment with special acid admixes with additives to protect casing.

Reinjecting Into Sandstone:

- Superfine filtration of effluent combined with friction reducers.
- Periodic reversals of injection well.
- Ream-out of injection zone of well to increase injection area.

Location of Injection Wells to Avoid Coldwater Breakthrough:

- Depth at which to inject effluent.
- Policy of reinjection at circumference of production area .
- Do careful injectivity tests and chemical tracer tests to determine production/injection well distance that ensures a breakthrough time commensurate with acceptable reservoir life, if reinjecting within production area.

OTHER LOCALITY SPECIFICS AFFECTING TECHNOLOGICAL SOLUTIONS

The important ones are:

Environmental Issues

These are gaining importance and seriously affect the feasible solutions that can be adopted. Issues like:

- Effluent disposal - gaseous as well as liquid.
- Selection of sites for wells, collection pipelines, access roads, mufflers, power transmission line sites, mast types etc.
- Noise criteria (short- and long-term).
- Tourism.

Accessibility

- Topography at development site.
- Access to water – climatic conditions.
- Proximity to centers of population.

Local Technological Status

- Access to technological competence locally, regionally, nationally.

Energy Market

- Type, versatility and stability of energy market

Political Constraints

- Is geothermal part of national energy plan?
- Financial, taxation and legislative constraints.

Geothermal fluid has a low-specific energy content and all solutions adopted for its utilization must be simple and inexpensive.

It also sometimes has chemical problems associated with it that preclude the use of high tech refinements. The hydrogen sulphide in the steam phase, though quite insignificant for all sense and purpose, is quite sufficient to play havoc with some of the modern sensors, control equipment and computer systems; which means that, highly special and often costly equipment is required to ensure the required degree of reliability.

Material selection for the parts in direct contact with the geothermal fluid is also quite important.

POWER GENERATION FROM LOW-ENTHALPY GEOTHERMAL RESOURCES

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INTRODUCTION

After a briefly presentation of power generation from geothermal energy, this paper presents the binary power plant at the University of Oradea as an example of geothermal low- enthalpy utilization for power generation.

POWER GENERATION FROM GEOTHERMAL ENERGY

The total worldwide installed electric power capacity exceeds 8 GW as far as geothermal sources are concerned (Sanner, 1998). This installed capacity is not equally distributed around the world. The United States is first, followed by the Philippines, Mexico and Italy. Japan, New Zealand and El Salvador are others worth mentioning as places of geothermal electricity production. Certain geological locations provide high enthalpy resources that are best adapted for power production. These are the so-called plate boundaries which take the form of subduction zones, spreading zones, or rift zones. These zones will remain the main areas of interest until the time when HDR (hot dry rock) technology might allow geothermal production virtually everywhere in the world. Consequently, the countries that are positioned within these zones may become more independent from oil import because of the possibility of using indigenous energy.

The technology of geothermal binary fluid has been researched and developed for the purpose of generating electricity from low-to-medium temperature resources and of utilizing the thermal resources through the recovery of waste heat. A well known source of waste heat in geothermal fields is the waste water from flash separators (Hudson, 1998).

The Figure 1 presents a simplified schematic of a binary system. A secondary working fluid has a low boiling point and a high vapor pressure at low temperatures when compared to steam and this is the fluid that the binary system utilizes. This secondary fluid is operated through a conven-tional Rankine cycle. Temperatures in the range of 85 to 170°C (185 to 338°F) are the values at which the binary system can be designed to operate through the selection of appropriate working fluid. The upper temperature limit is restricted by the thermal stability of the organic binary fluids.

The lower temperature limit is restricted by practical and economic considerations, as the heat exchanger size for a given capacity becomes impractical and the parasitic loads (from well and circulating pumps for example) requires a large percentage of the output. Before being expanded through a turbine to some lower pressure temperature, heat is transferred from the geothermal brine to the binary cycle via heat exchangers where the binary fluid (or working fluid) is heated and vaporized.

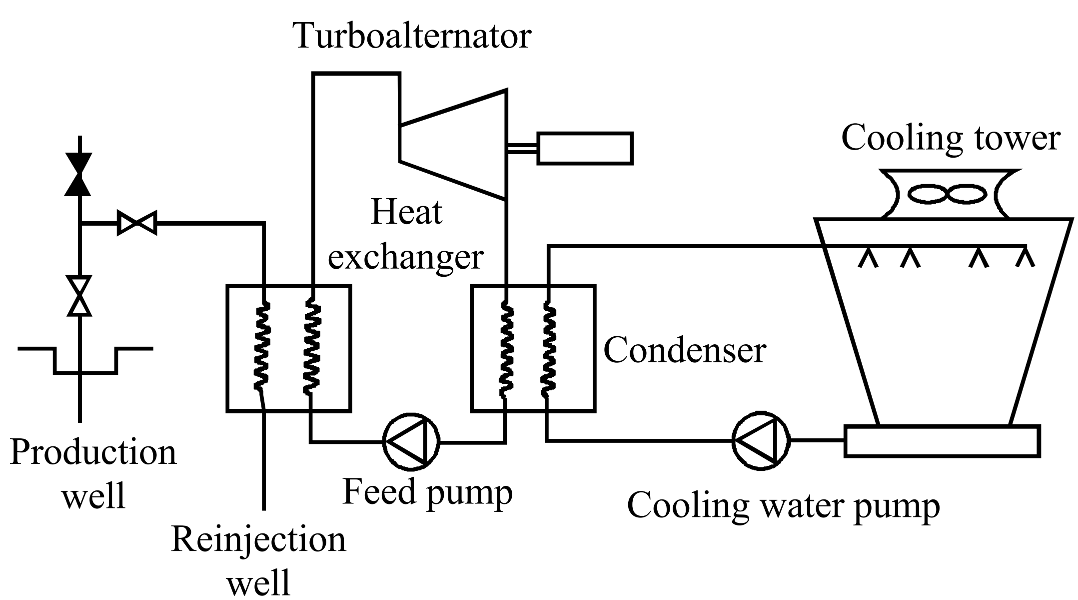

Figure 1. ***Simplified scheme of a binary system.***

The binary plants have been small modular units varying in size from hundreds of kilowatts to several megawatts. The small development linked to modular con-struction is cost effective and facilitates short manufacturing and installation times. The problem of larger power project in the 10 to 50 MW range, is solved by bringing a number of modular units together in a common development.

Down hole pumps may be used where wells do not flow spontaneously, or where it is advantageous to prevent flashing of the geothermal fluid (to prevent calciting for example), in order to keep the fluid in a pressurized liquid state. Binary units can then be used to extract energy from the circulating fluid.

THE BINARY POWER PLANT FROM THE UNIVERSITY OF ORADEA

The University of Oradea initiated a research program for producing electricity by using geothermal energy. Due to the fact that the geothermal water temperature is less than 100°C (212°F), only a binary cycle could be considered for power generation. According to Maghiar (1995), the first pilot power plant was completed and tested in 1984 and had an installed capacity of 100 kW. The research program continued and two other pilot power plants were designed and completed: one 2 x 250 kW in 1986 and the other 1MW in 1988. Based on the experience gained and the encouraging results obtained with these pilot plants, the research program has been increased and, at present, a team of researchers and teachers have implementing a new pilot power plant with increasing output capacity, estimated at under 2 MW. A programmable logic controller (PLC 2), connected to the SCADA system controls and monitors the operation.

The binary power plant transforms the thermal energy of the water into mechanical energy and then, by a generator, into electric energy. Basically, the working fluid runs in a closed circuit according to a thermodynamic motor cycle, between two heat sources, water at high temperature and cooling water. Usually, the working fluid is hydrocarbon, such as isopentane, or refrigerant, such as R12. For environmental reasons, the working fluid used at this binary power plant is carbon dioxide. There are some advantages in using it, such as no explosion danger, it is non-inflammable, non-toxic and available at low cost. In Figure 2, the thermodynamic cycle of CO_2 in a pressure-enthalpy diagram is presented. Line 1-2 corresponds to the flow of the working fluid in the engine; line 2'-3 is the evolution for transferring heat from CO_2 to the cold water; line 3'-4 shows the passage of the working fluid through the piston pump for increasing the pressure of CO_2; and, line 4-1 shows the flow through the shell and tube heat exchangers where geothermal water transfers heat to the working fluid.

In order to obtain the maximum rated power, it is necessary to maintain the optimal thermodynamic cycle for every operation regime of the power plant and it is necessary to maintain optimal CO_2 parameters when disturbances occur. In a certain steady-state operation regime of the power plant, some disturbances may occur resulting in changing of CO_2 parameters. These changes can be due to fluctuations in

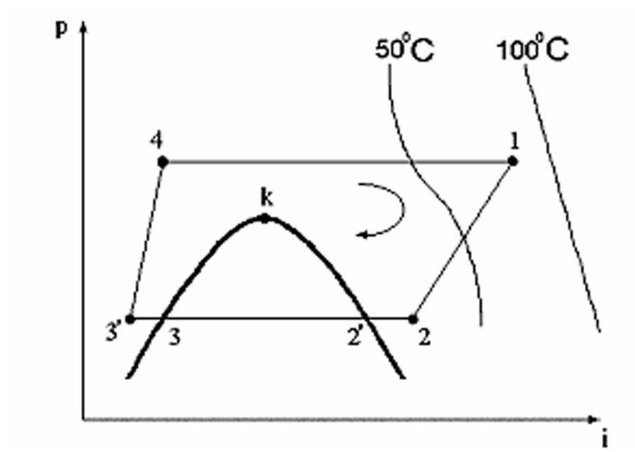

Figure 2. ***The carbon dioxide thermodynamic cycle in pressure-enthalpy diagram.***

geothermal and cold water parameters and geothermal engine parameters (i.e. pressure and temperature fluctuations of CO_2, flows and temperature fluctuations of the geothermal water and cooling water and variations of geothermal engine speed, etc.). To maintain this optimal thermodynamic cycle, the automation of the power plant is required. As mentioned above, this will be accomplished by using a programmable logic controller, PLC2 (Antal, 1995).

The schematic diagram of the binary power plant is presented in Figure 3. Corresponding to the thermodynamic cycle presented above, it comprises a turbine (engine), a condenser with a buffer tank, a CO_2 liquid pump and an evaporator. In order to maintain the optimal thermodynamic cycle, sensors and devices were installed, such as pressure transmitters, temperature transmitters, flow transmitters and control valves (CV). A general view of the binary power plant is shown in Figure 4.

CONCLUSION

The technology of geothermal binary power plant has been researched and developed in the purpose of generating electricity from low-to-medium temperature resources and of utilizing the thermal resources through the recovery of waste heat.

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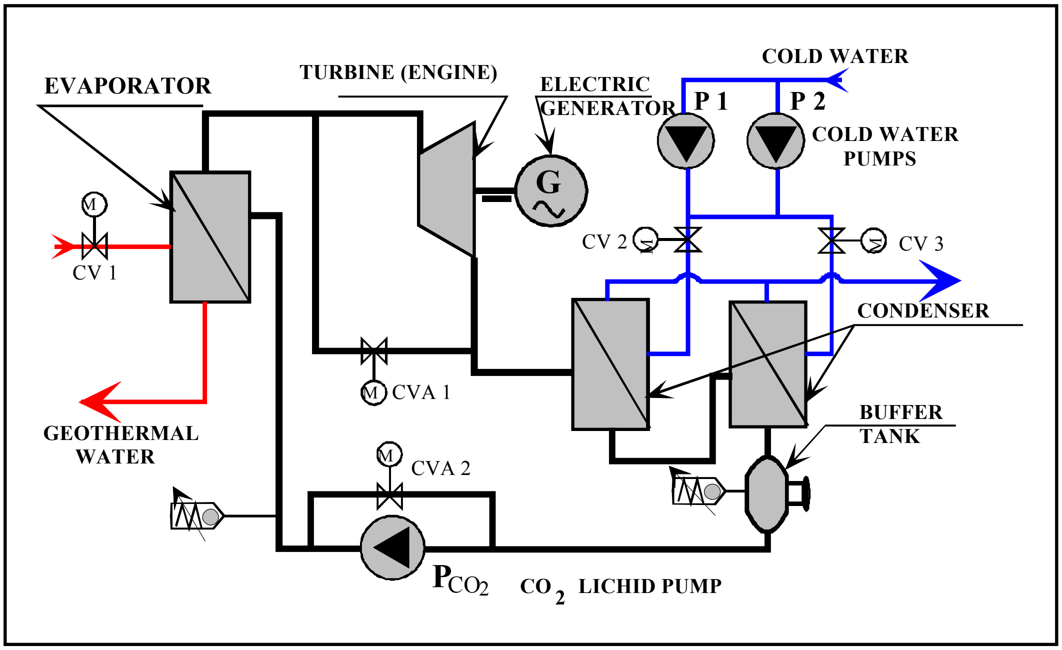

Figure 3. Diagram showing the binary power plant.

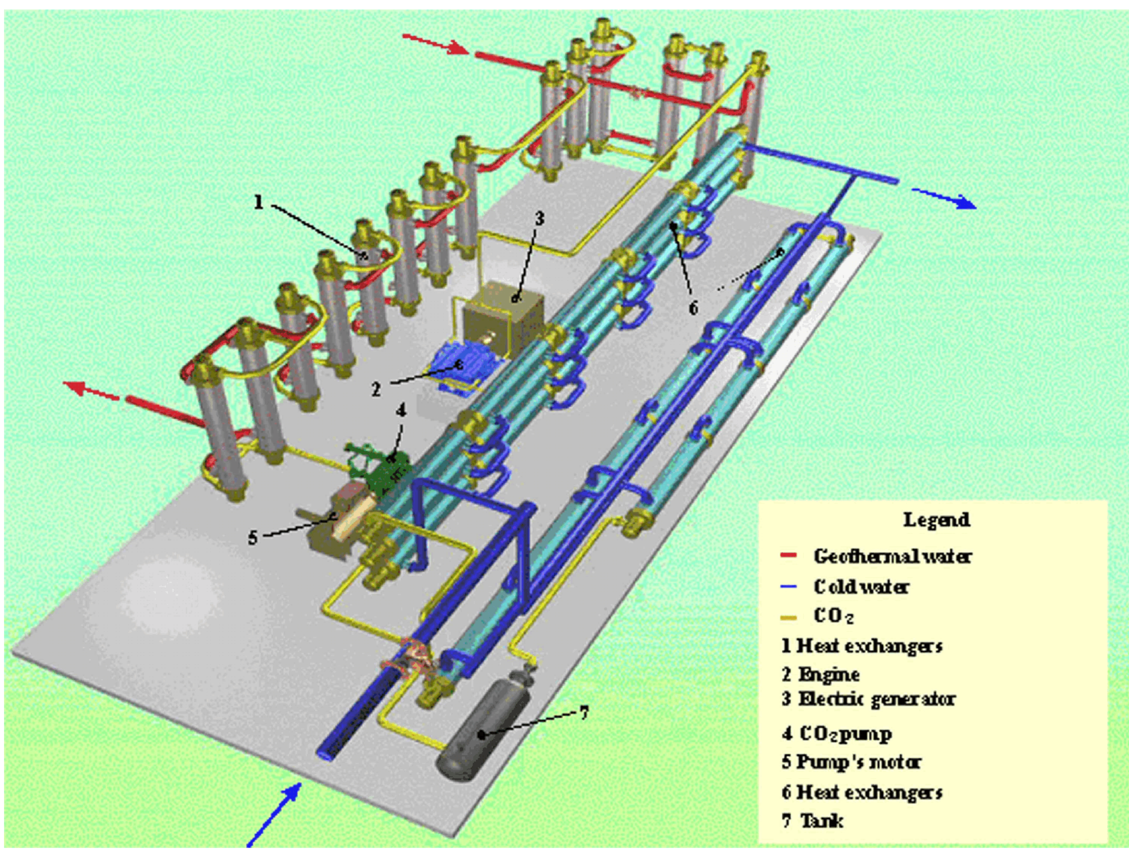

Figure 4. Binary power plant – general view.

FEASIBILITY OF GEOTHERMAL AGRICULTURAL PROJECTS AT THE BEGINNING OF XXI CENTURY

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SUMMARY

An intensive process of development of new technologies for direct application of low-temperature geothermal fluids in agriculture during the 70s has been significantly slowed during the 80s and nearly stopped during the 90s. However, that was a period long enough for development of a large number of commercially feasible technologies, offering a rather large field of use of low-temperature brines at the end of the previous century.

To plan for the possible development of geothermal projects with direct application in the beginning of this century, a review of the available technologies is made and proposals for their technical and economic consideration for use in different market conditions is presented.

Some of the conclusions have a broad interest. The most important one is that direct application projects are feasible in most of the regions where geothermal energy is available. Even under very stiff competition with fossil fuels, it appears that geothermal energy is going to consolidate its position as the best alternative resource in many regions of the world.

INTRODUCTION

The so called "energy crisis" of late 70s and early 80s showed that it was worthwhile to develop an energy source available just below our feet. This offers the advantage of being independent of the international market of fuels, where powerful countries are playing a game that does not always benefit the small ones with weak economies.

Unfortunately, favorable conditions for geothermal development were too short to enable a real and wide introduction in all possible life sectors where it is available. Today the lowered exploration activities in many developed countries are discouraging development. However, development has not stopped. Slowly and continually, the number of improvements, new uses and new sources are increasing. This is probably the last of the so-called "alternative energy resources" which can be and in many cases is economically competitive with the cheap fossil fuels of today.

An attempt is made in this paper to present a short description of important improvements of direct application of geothermal energy in agriculture, achieved in recent years, in order to stimulate further interest and development of this particular energy source. It can be of major importance for a number of developing countries in the world.

POSSIBLE USES AND LIMITATIONS

Theoretically, the number of possible uses of geothermal energy is large. Where hot or warm fluids, or steam are required, geothermal water or steam can be used for agricultural production in protected conditions, aquaculture, mushroom growing, heating of dwellings and animal farms, washing, pasteurization, sterilization, etc.

Unfortunately, a number of limitations discourage development:

The first and most important is of an economic nature. Rather high investment costs influence the composition and kind of users for a known resource. Sometimes gradual development is not possible because it results in great money losses during the initial years of exploitation and always presents a rather high level of risk during the same period. That is an obstacle for large capital investment that is necessary to develop the final project.

The second limitation is the multidisciplinary character of the problem. A rather high level of knowledge of different scientific disciplines is necessary to provide an economic and easy technical solution to development.

The third limitation is the characteristics of the energy resource site, as it controls the location and composition of the users.

The fourth limitation is the need for a high level of organization (i.e., users have little freedom to choose the way and terms of energy use) which is particularly true for small users.

The fifth (and not the least) limitation is the need for environmental protection. For a long time, it has been considered as a clean energy--but it is not. Geothermal brines can pollute the environment both chemically and thermally. This limitation is not taken seriously in many locations around the world, but the problems can be resolved.

These limitations are one of the major reasons for the application of very simplified solutions to projects all over the world. They give short-term benefits to the users, but are not always favorable to the long-term development of geothermal energy as a viable energy source. The public remembers an unsuccessful experience more than a positive one.

REAL EXPERIENCE

Without pretending to be complete, the list below illustrates the commercial geothermal experience gained in:

- Electricity production;
- Heat pumps use in combination with different uses of geothermal energy for heating purposes;
- Drying of wood, fish and agriculture products (rice, tobacco, etc.);
- Milk and vegetable processing;
- Paper production and other industrial uses;
- Heating of greenhouses;
- Heating of animal farms;

- Heating of dwellings, hotels, offices, hospitals and other public houses;
- Heating of hot beds;
- Heating of aquaculture farms;
- Hot irrigation;
- Heating of thermal and public swimming pools; and
- Open field heating, heating of streets, parking lots and sidewalks.

Most of the listed uses were known during the previous periods of development, but the difference now is that it is possible to speak about commercial development, and not just research and development.

Not all the problems are solved, but a certain level of technological development has already been achieved. The problem at the moment is that the concentration of knowledge and production possibilities is in a very limited number of countries; unfortunately not always where the geothermal possibilities are abundant and where they are needed. A number of developing countries could derive significant benefits from a wider use of geothermal energy in agriculture, but up to now, the situation was not very satisfactory. The main constraints can be attributed to the lack of knowledge, money, and organizational problems.

TECHNICAL ASPECTS

Heat Exchangers

Probably the most important advances in the use of low-temperature geothermal waters during the recent years are in heat exchangers. They are characterized by a variety of new configurations and materials, closely adapted to the requirements of users. The most common, economical, versatile, and simplest type is the plate heat exchanger.

Greenhouse Heating

Greenhouse heating is among the most interesting and widespread application of geothermal energy as a heat source. Over 300 ha of glasshouses and plastic houses were geothermally heated in Europe in 1986 (Duda), with a continuous increase by tens of hectares each year. That is somewhat surprising, because it is a rather poor heat consumer when considering the annual heat load factor. The explanation lies probably in the possibility to install the projects near the geothermal sources, without disturbing the organization of the production and marketing of the products.

The large introduction of cheap plastic materials for the distribution of geothermal brines and heat exchangers is the most significant development of the last ten years for this particular energy use. Thus, direct use is possible, as the corrosion problem is eliminated, which is very convenient for small artesian wells; and where it is difficult to justify the installation of expensive equipment and materials such as for heat exchangers, etc.

The rather wide variety of installations can be divided into four main groups:

Soil heaters: Usually made of smooth or corrugated plastic pipes (Figure 1), located 30-50 cm below the ground level for cultivation in soil or directly in the concrete floor for soil-less or cultivation in pots. It is convenient for a rather low-temperature heating medium and for base heating. The large inertia of the soil material will not allow a precise regulation to follow the changes of outside climate. However, it is a good energy-saving technique, having a large influence on plant development, but it cannot be taken as a unique system to cover the total heat demands, particularly in cold climates.

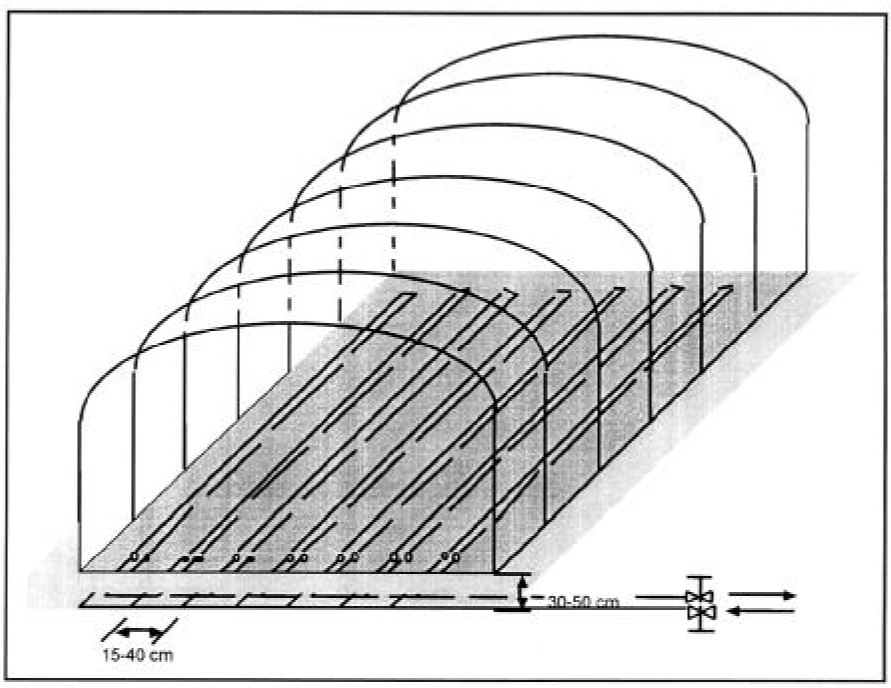

Figure 1. Soil heating installation for greenhouses.

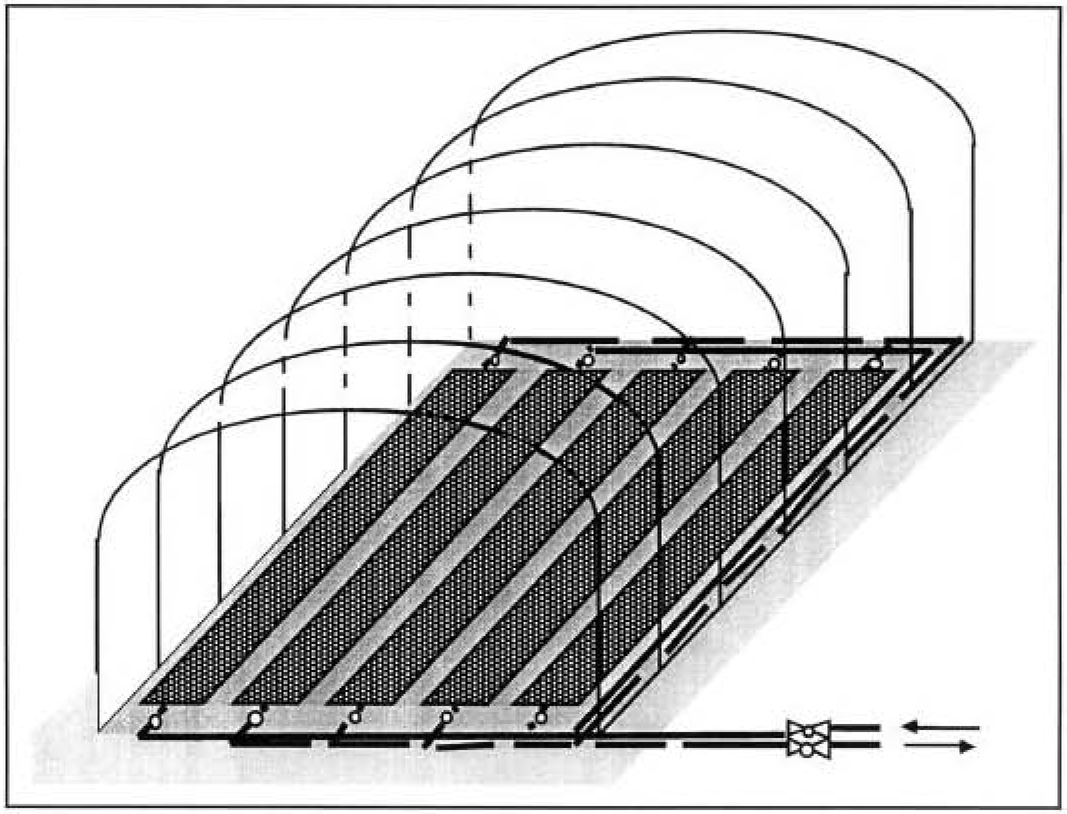

Figure 2.   Heating installations laid on the ground.

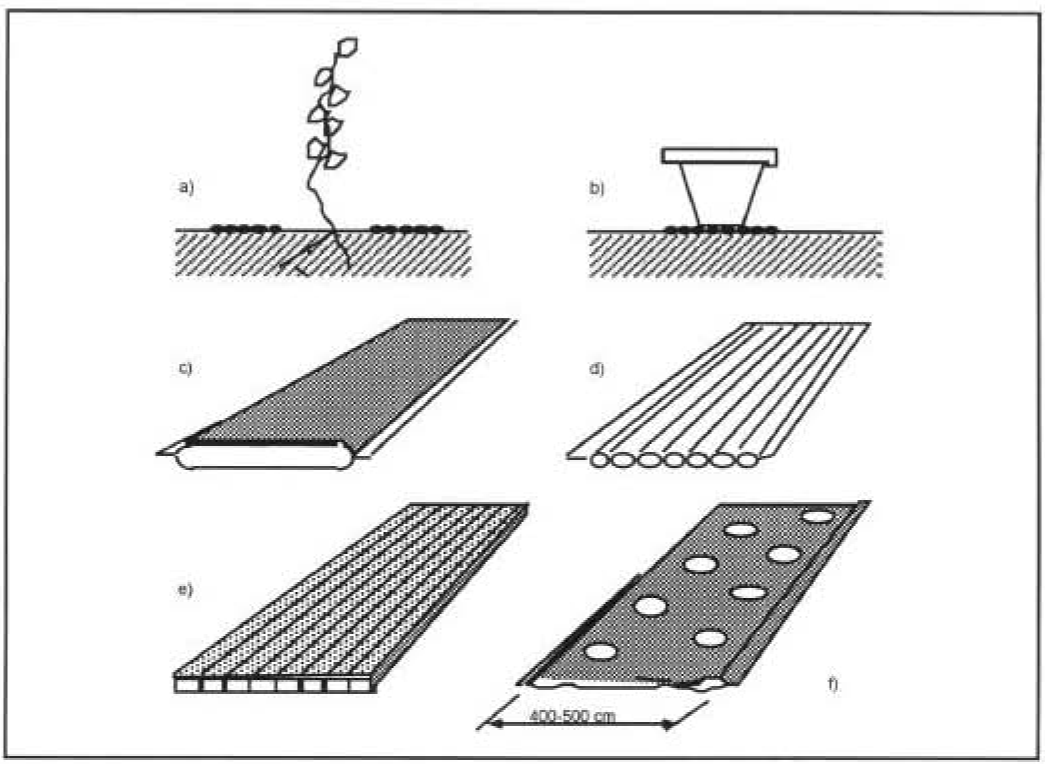

Figure 3.   Different heat exchangers for ground surface heating installations.

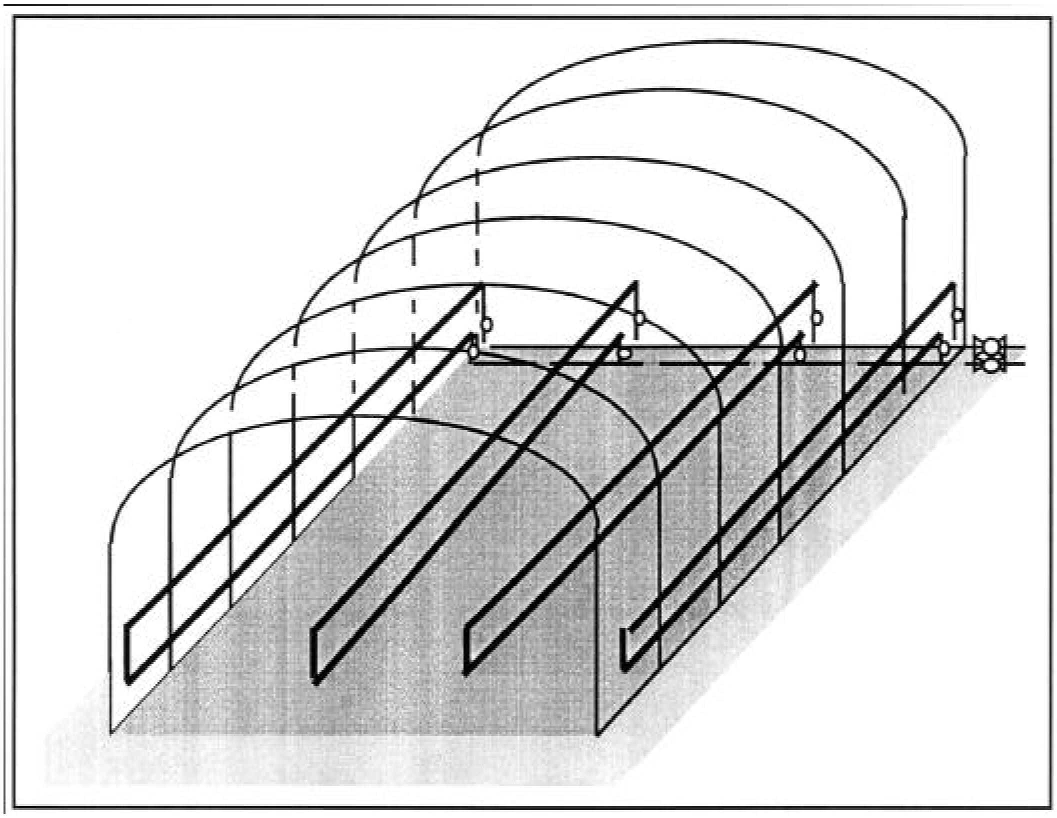

Figure 4. Free convection pipe heating installation.

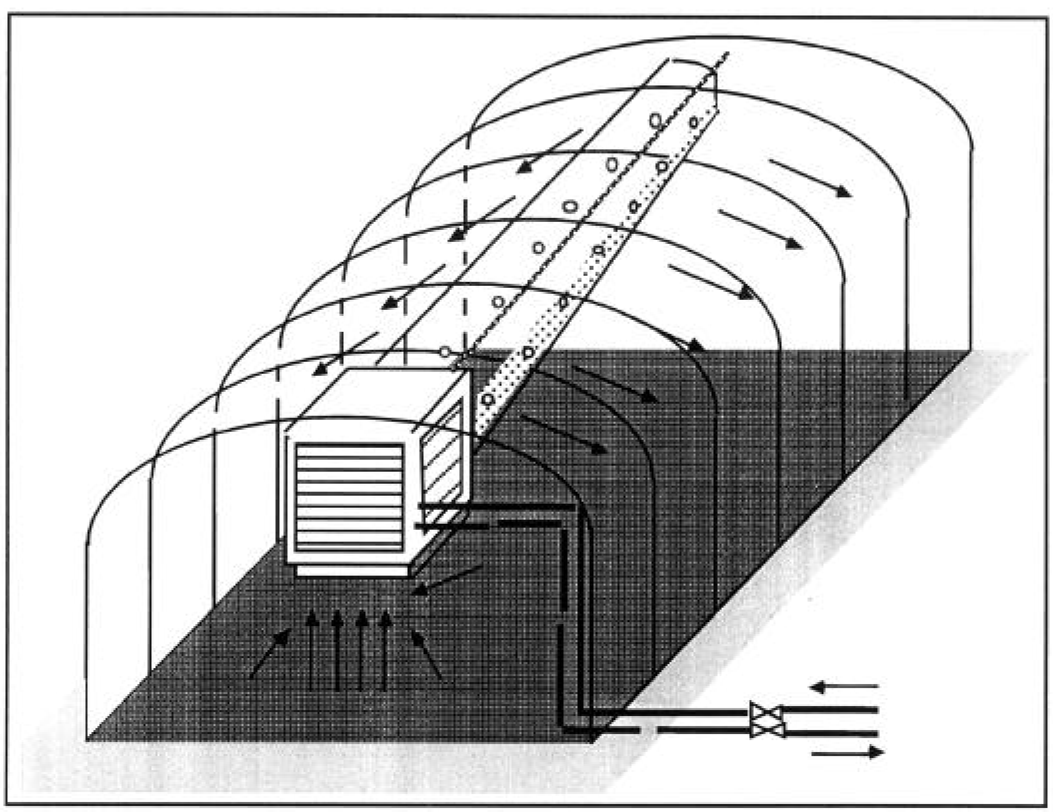

Figure 5. Fan-jet heating installation.

On-the-soil-heaters: They play two roles: to heat at the same time the soil and the air in the greenhouse (Figure 2). Excellent influence on the inside climate and production results in combination with low price; easy and simple installation, making this type of heating the most popular in Mediterranean countries in recent years. Mainly thin-pipe heating and large-plastic tube heating is widely used, as also are plate-type heat exchangers (Figure 3)(El Golli).

Free convective air heaters: This is generally the oldest type of heating installations for greenhouses, with the difference that for low-temperatures new finned pipes and special profiled aluminum pipes have been introduced (Figure 4). New experiments have improved the characteristics of heating elements in greenhouses. In addition, many good references are available (Popovski; and De Murtas). High investment costs hamper their wide spread use in countries with mild climates. In the central European, this type of installation is in wide use (Karrai: Popovski; and De Murtas).

Convective air heaters with forced air movement: the classical "fan-jet" system (Figure 5) is still in wide use, although the negative side is poor temperature distribution in the heated space. Using warm air distribution tubes solves this problem. New convector units ("hortitherm") along the sides of the greenhouses (Figure 6) are very promising. Excellent results are achieved even with a very low temperature roof heating source (Figure 7). Positive and negative sides of the various types of heating installations are the reason for using them in combinations depending on the types and placement of crops.

Heating of Animal Farms

Surprisingly enough, farm heating with geothermal energy is experienced only in two countries (Hungary and Serbia). Simple air heating installations are reliable and are often combined with greenhouse's heating (Figure 8). The relatively small demand explains probably why this type of use is not common in other countries.

Aquaculture

Some aquaculture plants heated with geothermal energy have been already tested in geothermally developed countries. The best known are the simple technical solutions in Hungary and Bulgaria (already at commercial stage).

The technical characteristics of these installations show that this type of use can be the last step in geothermal cascading, thus reducing the thermal pollution of the

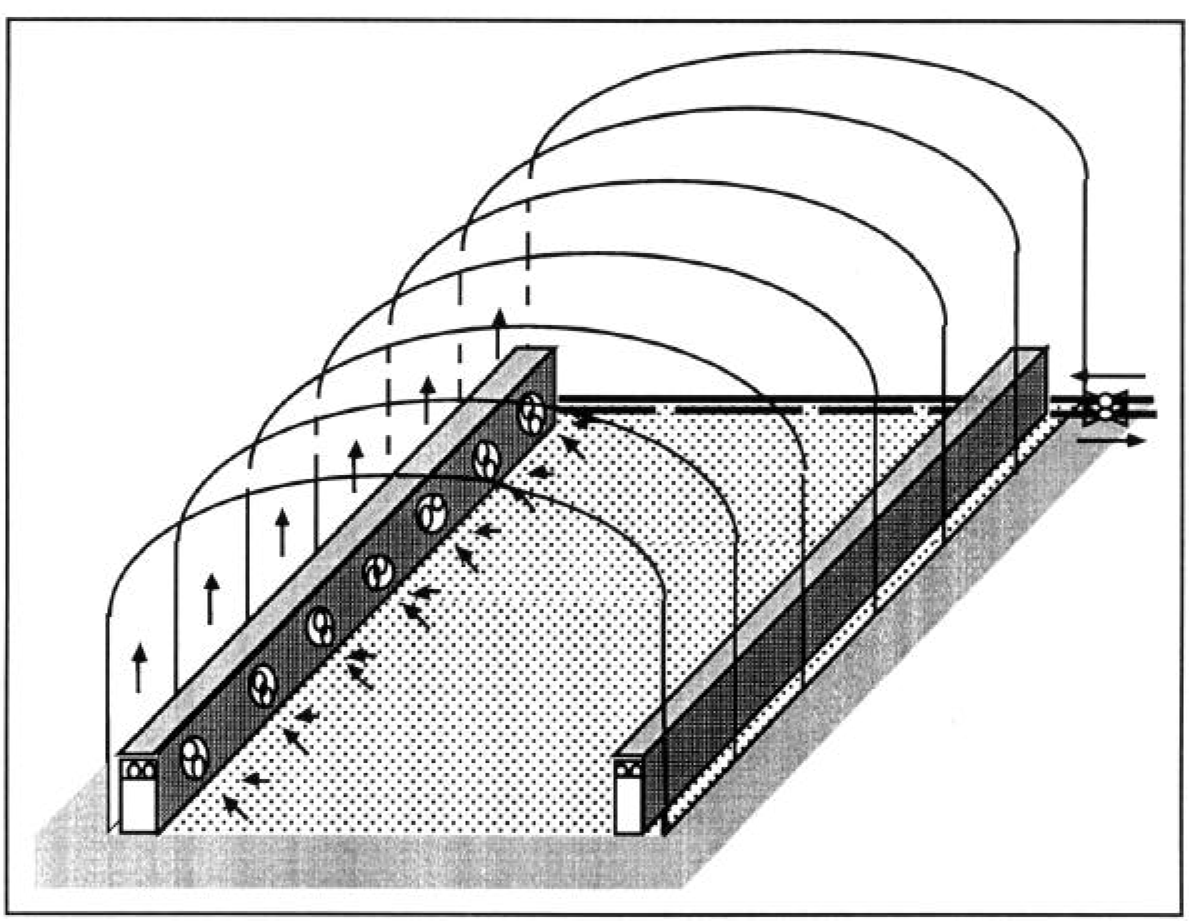

Figure 6. Hortitherm heating system.

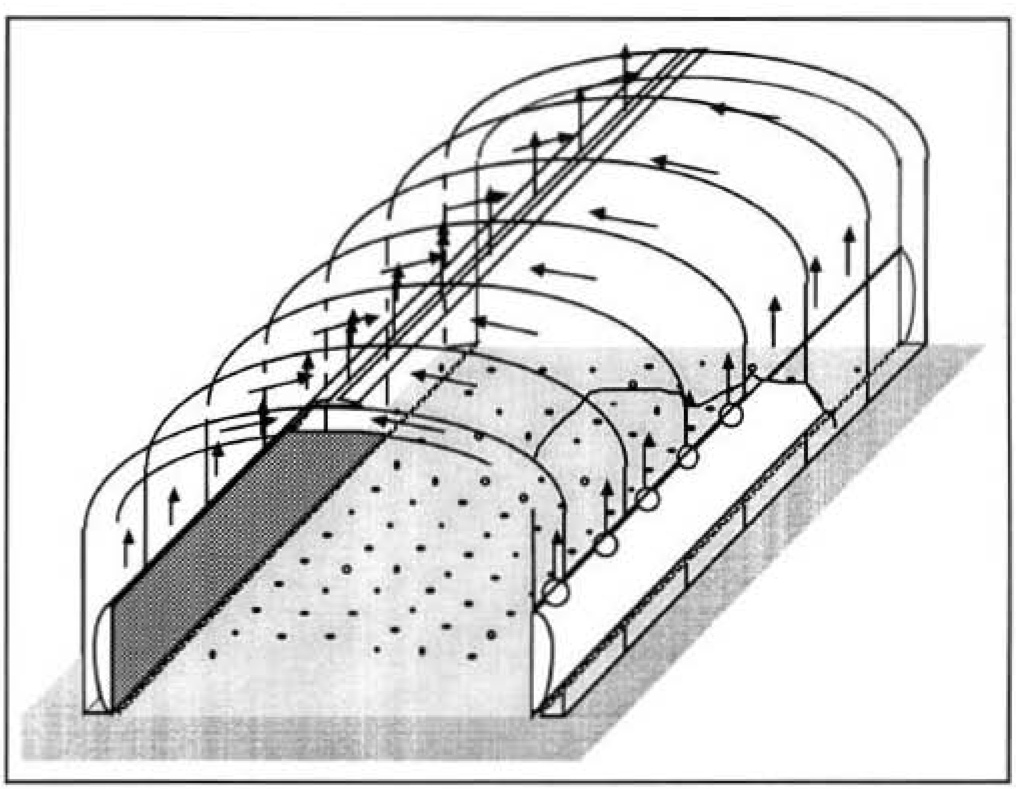

Figure 7. Low-temperature roof heating system.

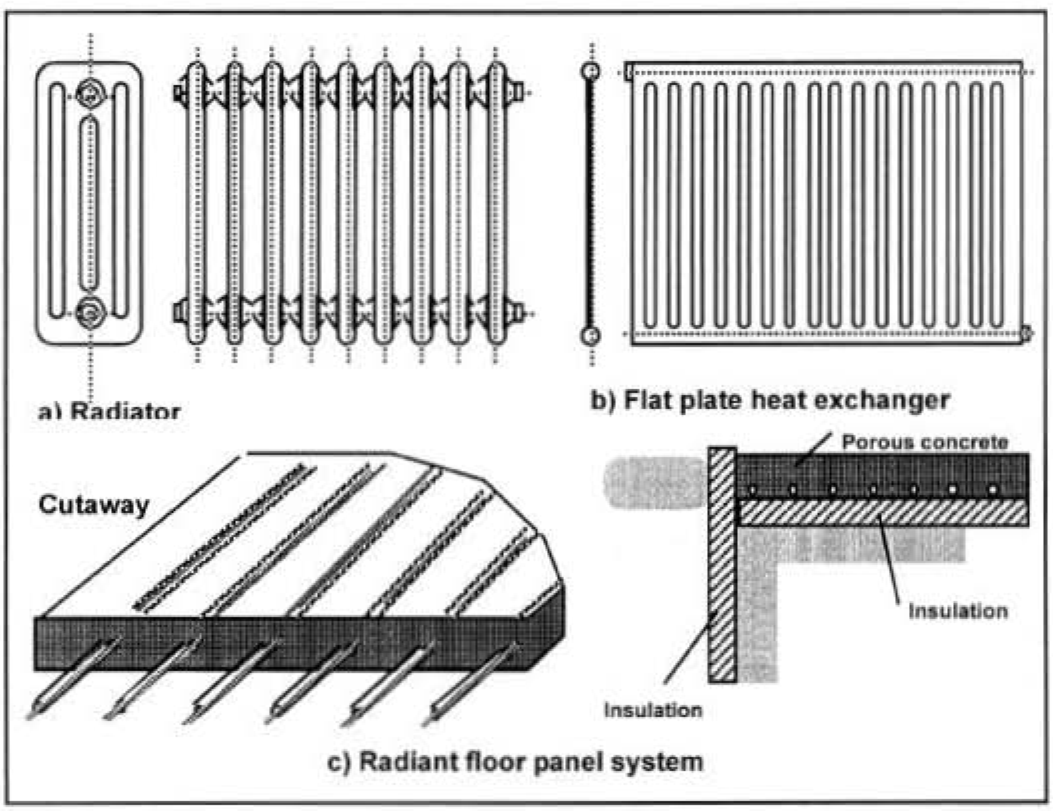

Figure 8. Elements of room heating installations for animal farms.

environment. Simple, very often hand-made heat exchangers placed in the ponds are the "heart" of the installations, offering easy exploitation and quick return on investments.

Irrigation

Two types of irrigation are of interest. One is so called "hot irrigation" for plants cultivated in protected conditions, the second is the normal irrigation in dry areas (El Golli). For the latter use, additional measures should be taken to cool the water to the proper temperature (by greenhouse heating, special cooling towers, etc.).

The Ministry of Agriculture in Tunisia, using simple corrugated plastic pipes hanging in series has developed an interesting and effective technical solution.

Other Agricultural Applications of Geothermal Energy

The list of users given in the introduction part of this paper does not exhaust the possibilities of geothermal energy applications in agriculture. It is reported that attempts have been made to introduce it also in the food processing industry, but there is still no technical data, except for drying of agricultural products (rice, tobacco, etc.) (Figure 9) and the paper industry.

ECONOMIC ASPECTS

The changeable situation of the fuel market and of the world economy during recent years influenced to a great extent the development of geothermal energy as a possible alternative energy source. The constant decrease of fuel prices, together with the constant increase of equipment prices totally changed the preconditions for its wider introduction 10 years ago. In spite of this, geothermal use has survived and continues to contribute to the energy mix. Depending on the composition of energy users, the nature of the geothermal source locally, the climate, technical, economic and social conditions; two types of development approaches gave positive economic results during the recent years. These are:

- The orientation towards a greater simplification of all the elements of a geothermal plant and the use of cheaper plastic materials. Users estimate the optimal inside climatic condition better and, this is more significant than other technical improvements. As a result, investment costs are minimized and the economics even favors poor managers.

  Greenhouse heating in Mediterranean countries is a typical example of such an approach to the problem. Mild climatic conditions allow the use of simple constructions and heating installations. Principally, the task is not the total conditioning of the inside climate of the greenhouse, but its optimization. Excellent results are reported in Tunisia, Greece, Spain and Israel.

- The orientation towards the improvement of the annual heat load factor through the combination of different heat users. The rise of investment costs and the expensive exploitation of geothermal sources are compensated by minimizing their influence on the price of used heat (Figure 10). Peak load can be covered by reject heat users (accumulation of heat), careful composition of heat users and the use of cheap fossil-fuel boilers.

Typical examples of such an approach are the geothermal complex Bansko in Macedonia and combined heating schemes in Hungary.

The problems posed by such geothermal plants are the need for a very high level of multi-disciplinary knowledge, centralized management, and resource development, which can be very difficult to be obtained in most of the developing countries. The influence of stable market conditions should not be minimized in relation to the risk for high investment costs. A stable market can be difficult for developing countries.

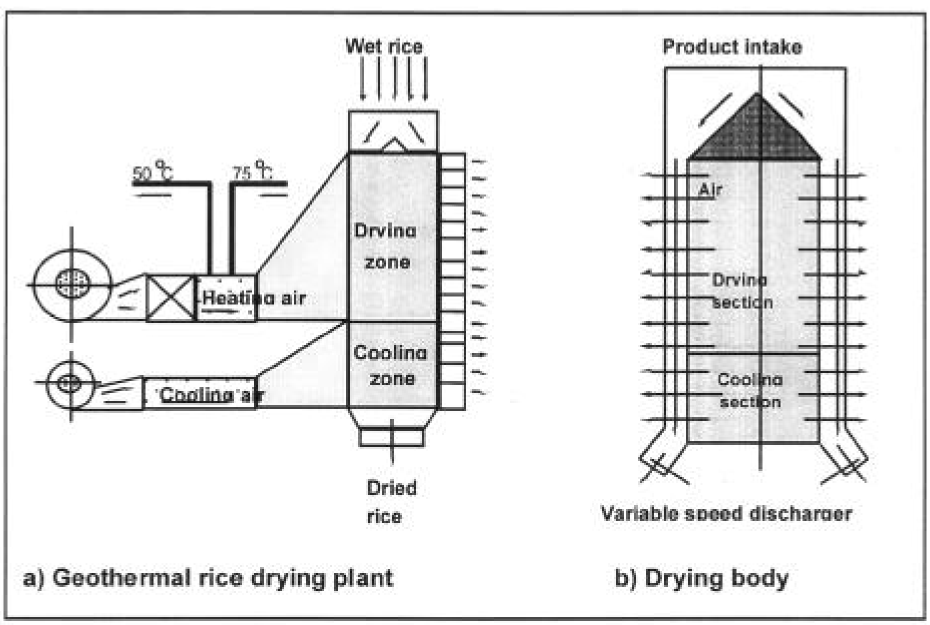

Figure 9. Geothermal rice drying plant in Macedonia.

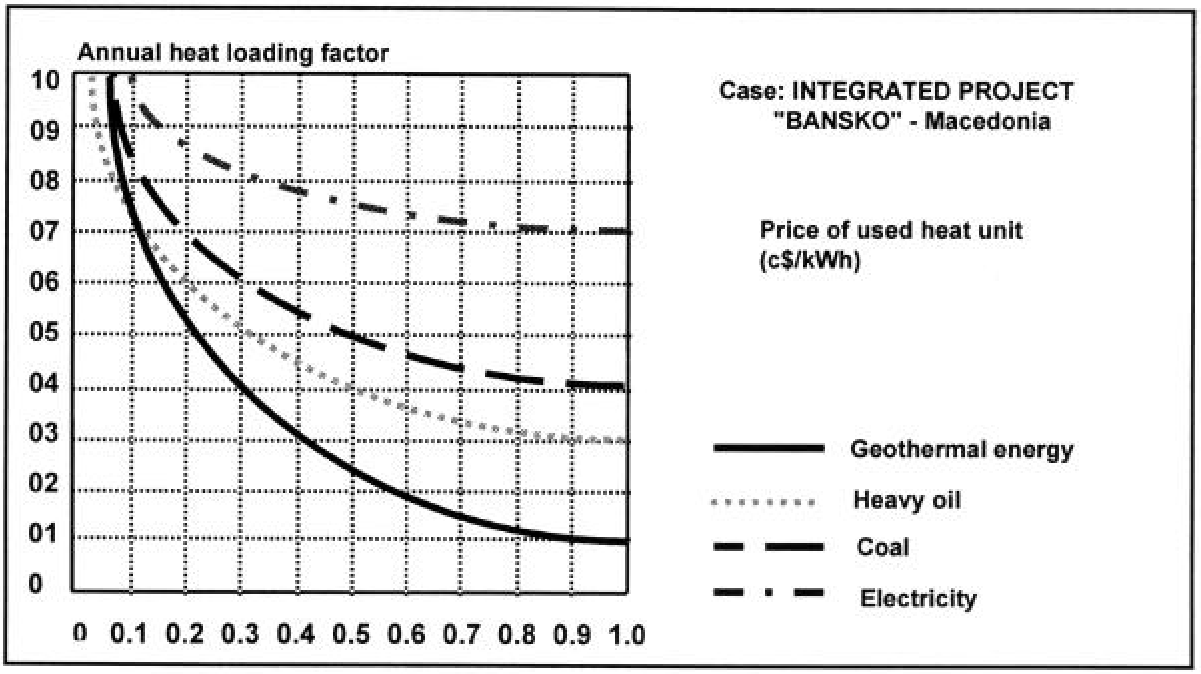

Figure 10. Changes of the used heat price depending on the annual heat loading factor.

During the last 10 years, a combined approach became predominant (i.e., the use of simple elements) where possible and justified (in order to minimize the investment costs) but also combinations of heat users in order to lower the price of the energy. That was made possible by the introduction of high productive technologies in the greenhouses of southern countries, which enabled repayment of higher investment costs, but also owing to the need to be competitive with cheap fossil fuels in northern ones.

When considering the introduction of geothermal energy as a possible energy source in many countries, it is necessary to stress the importance of initially obtaining strong support from the State.

Information exchange and international cooperation should also be underlined as extremely important economic aspects for the development of geothermal energy. The complex nature of their energy source entails a risk of making mistakes. Any money "saving" in this field during the initial period of development (when multidisciplinary "know-how" is not available) may results in expensive mistakes and negative impacts on the project.

CONCLUSIONS

The main characteristic of geothermal energy direct application development during the recent years is that it has been introduced as a commercial energy source, if not every-where, at least in a number of countries. The field of appli-cation has been significantly enlarged, particularly for direct applications. Design of different combinations of users is feasible and has improved the competitive with other energy sources improved in comparison with the period before.

If the above statement holds true, it should be very easy to draw useful and important conclusions for an accelerated development and a much wider introduction of this energy source in the world economy. Unfortunately, at least at this stage of development, it is still more useful to ask questions than to provide conclusions. We are still far from having a firm grip on this energy source because:

First: it is known that there is no common technology for geothermal energy application as each case is unique. If economy is desired, each case should be treated separately and in a multi-disciplinary way. In other words, the concentration of knowledge is the most important link in the technical chains for geothermal energy use in any possible field.

Second: it is known and confirmed that an international exchange of information and experience is extremely important for the establishment of high-level (and local) "know-how." Many international organiza-tions are actively engaged in providing technical assistance.

Third: a number of technical advances are available for all the links of the geothermal energy use technology chain, providing excellent accommodations to the local climatic, economic and social conditions.

In how many countries is the above really understood? If the State supports the development of geothermal energy in its own economy, does this support relate to all the parts of the total factors influencing the economy of geothermal energy use? How many countries have really defined the strategy for the development of geothermal energy use with the necessary legal, economic and organizational support?

A list of similar questions can be put anywhere in the world. Although there are differences in the treatment and approach to development of geothermal energy use between countries, in no one are all the answers available. One should not be misguided with the rather good situation in some countries (Italy, Iceland, New Zealand, etc.). They are also faced with serious problems.

As the final conclusion, it should be underlined that it is already confirmed and proved that geothermal energy can be commercially competitive with other energy sources in many locations in the world. It can be of a strategic importance for many countries of the world.

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