THE STATUS OF GEOTHERMAL DIRECT USES IN EUROPE. PRODUCTION RELATED PROBLEM AREAS

P. Ungemach and J.L. Fouasse

GEOPHASE
P.O. 358
93153 Le Blanc-Mesnil, France

ABSTRACT

An updated status of European geothermal direct uses is presented. Production problem areas, particularly those related to (i) injection into clastic sedimentary reservoirs of the heat depleted brine, (ii) submersible pump reliability, (iii) corrosion and scaling of tubular goods and down hole pumps, and (iv) reservoir management issues, are reviewed with special reference to the Paris basin, the most recently developed resource to date. The prospective impact of the so-called hydro-energy route aimed at exploiting, via heat pumps, very low temperature sources, which contribute to diversifying the conventional geothermal heating spectrum, are also discussed.

INTRODUCTION — DEVELOPMENT STATUS

In Europe, direct uses of low grade geothermal heat, addressing resources below 90°C deposited in vast sedimentary basins (Figure 1), has become an established technology, in particular in Hungary (Panonian basin), in northern Italy (Abano thermal springs), and more recently in France in the Paris and Aquitaine basins. In the Paris metropolitan area alone, the installed capacity of the 43 schemes (Figure 2) devoted to geothermal based, retrofitted district heating was nearing 300 MWt in late 1984.

The standard exploitation system in the area consists of a deviated well pair, 1,800 m deep, associating a production and an injection hole. Maximum withdrawal rates vary between 200 and 300 m^3/h with bottom hole and rejection temperatures set at 70°C and 40°C respectively, thus yielding a power of ca 8.5 MWt. The salinity of the formation fluid, a sodium chloride dominated brine, with TDS averaging 20,000 mg/l and less than 2 percent wt dissolved gases (mainly CO_2 and H_2S), makes the injection of the heat-depleted brine an environmental necessity. As injection is completed in the reservoir, it can be turned into an asset, pressure maintenance resulting in prolonged reservoir lifetime.

A heat load of 2,500 to 4,000 equivalent dwellings, each 185 m^3 in volume, is connected to the geothermal couplet via a heat exchanger of the plate type (to ease maintenance) made of a Titane-Palladium alloy (to withstand brine corrosion). Depending upon reservoir temperatures and heating processes, heat pumps can be added to the heat exchange system. These consist of water/water, electrically or gas driven units used either to boost well-head temperature or to deplete rejection temperatures or both. Geothermal heat is used as base load, peak load being assured by back-up, fossil-fuel fired boilers, supplying at least 65 percent of the total heat consumption. On the best systems in use high well-head temperatures and low-temperature heating devices (such as floor slabs) with centralized domestic hot water, this percentage can reach 85 percent.

The overall cost of such geothermal heating couplets usually ranges from US $3.5 to 5 million (February 1985 rates) about equally shared between well and surface equipment and piping costs. Financial ratios would shape as follows: pay-back time = 10 years, internal rate of return = 10 to 15 percent (Ungemach, 1982). A Parisian couplet achieves yearly fossil-fuel savings amounting to 2,000 to 3,000 tons of oil equivalent (TOE's).

As compared to the Paris basin, contrasted development scenarios take place in the Aquitaine basin, another major geothermal province of France. Fresh waters tapped in either deep (2,000 m) or shallow (1,000 m) aquifers exhibiting carbonate or clastic lithologies do not require injection practice unless otherwise dictated at some future time by reservoir management considerations. Owing to a milder climate, lower reservoir temperatures and sparser heat loads, heat pumps and cascade uses are

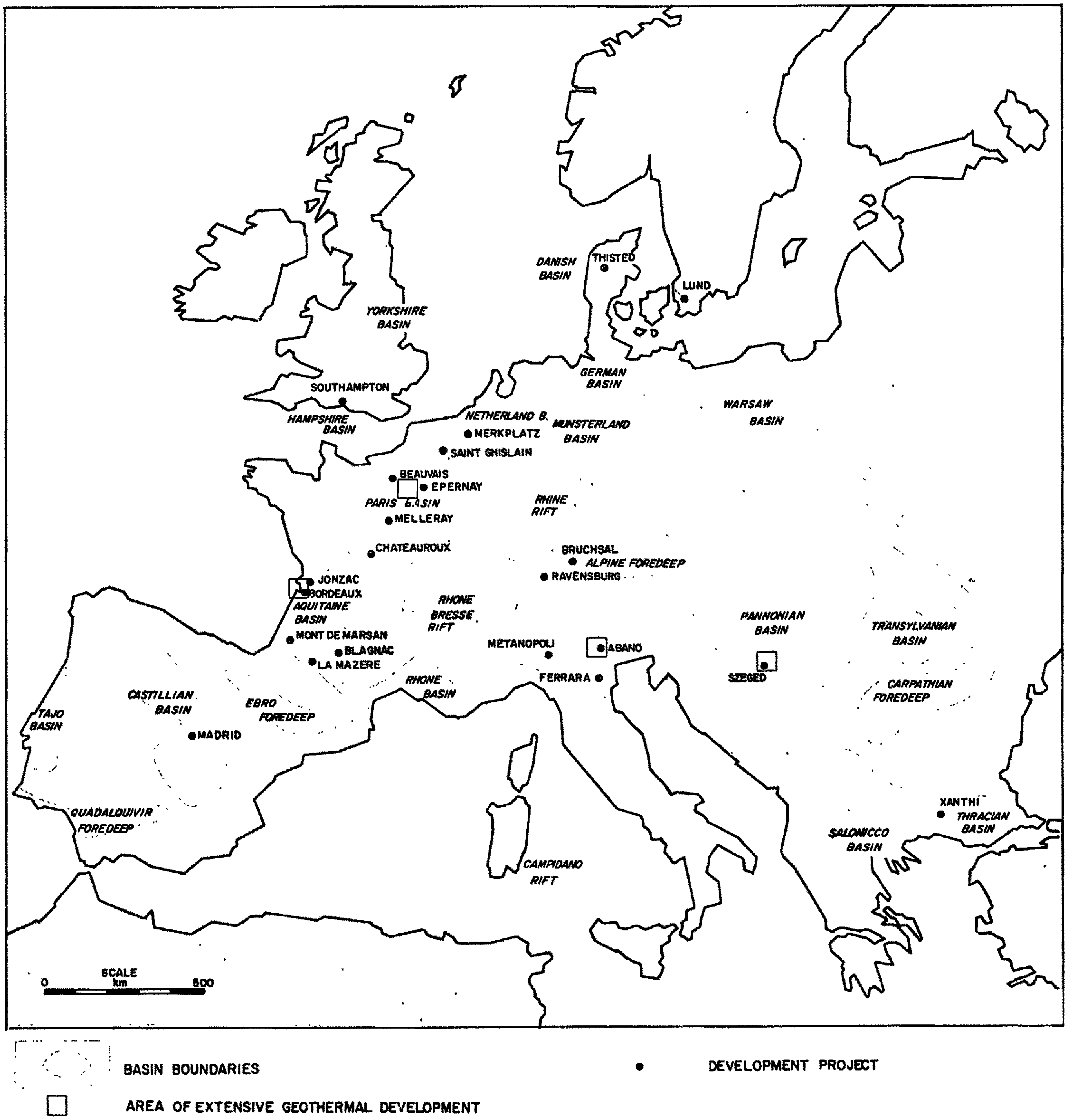

Figure 1. Major European sedimentary basins and proven low enthalpy geothermal reservoirs

sought to upgrade the economics of systems already partially enhanced by the lack of injection costs (Ungemach, 1982).

By the fall of 1985, 50 couplets and 10 singlets are due to operate in France, thus saving yearly 130,000 TOE's. A target of 250,000 TOE's is projected for the late 1980s according to the latest (and realistic) forecast issued to date.

In northern Italy, following a tradition dating back to Roman times, the Abano springs have long been exploited by local hotels and medical establishments for heating, hot water supply and thermal baths. Several hundred springs and shallow wells of this hydrothermal convection system, fed by a deep-rooted fault, extract this hot water resource whose temperature varies between 40 and 80°C. Various estimates (Brianza and others, 1984) agree on an installed capacity of 250 MWt depending upon the average rejection temperatures (close to 40°C) and moreover discharge rates among the many individual geothermal ownerships.

In other areas of Europe, development is being commissioned at a limited number of sites (Figure 1) in the

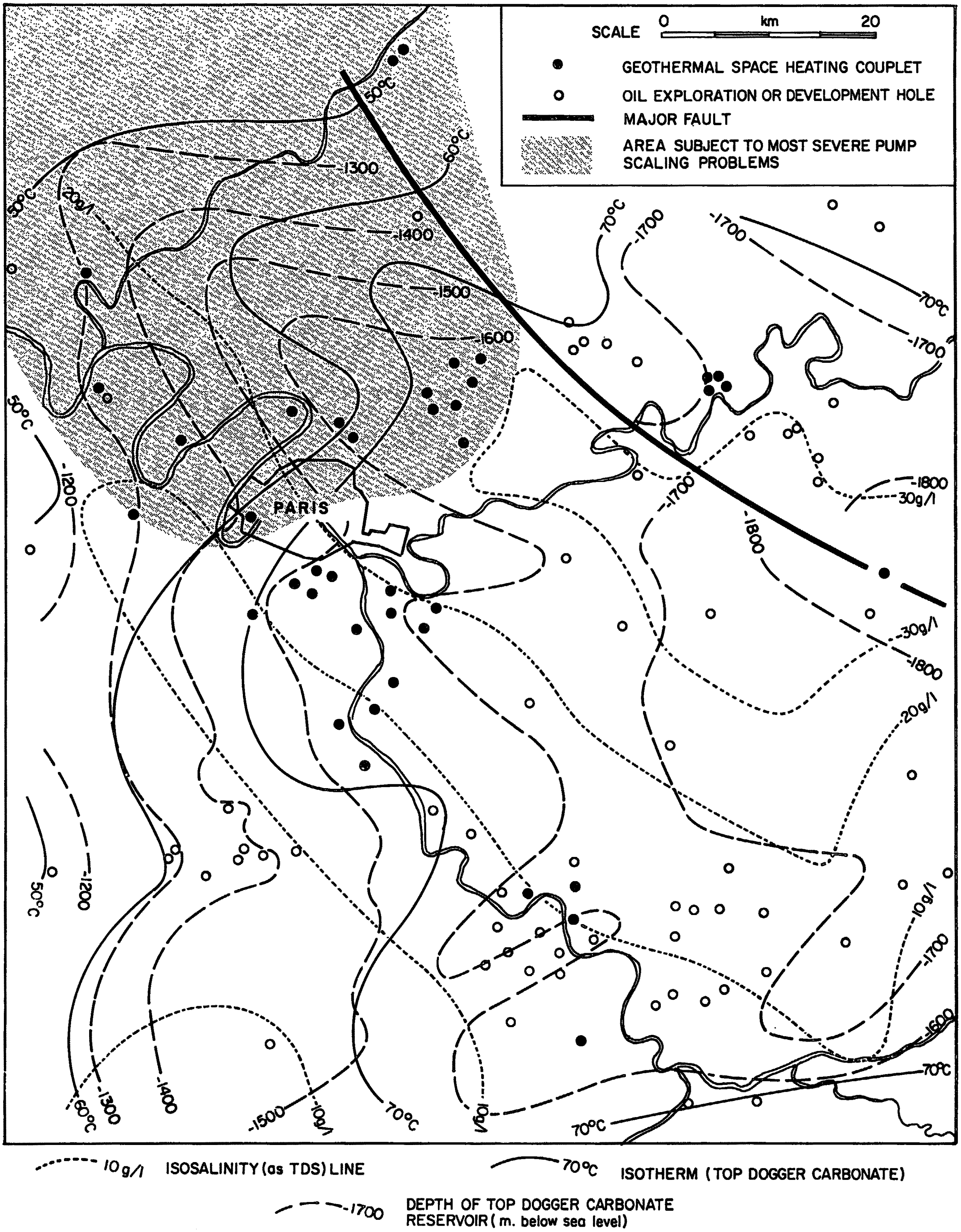

Figure 2. Composite geothermal map of the Dogger reservoir, Paris metropolitan area

United Kingdom (Southampton), Sweden (Lund), Denmark (Thisted), Belgium (St-Ghislain, Merkplats), Spain (Madrid), Italy (Milano, Ferrara), western Germany (Ravensburg, Bruchsal) and Greece (Xanthi-Macedonia). The idea here is to prove the feasibility of the geothermal process on selected pilot sites before exploiting the resource at a wider scale as is the case in the Paris suburbs, an area indeed favoured by the coincidence of a prolific hot aquifer and of a massive heat load.

Summing up, apart from thermal resorts of the Abano type, most direct uses in Europe deal with geothermal gradients close to normal, thus exploiting deep seated resources calling on fairly sophisticated mining technologies similar to those used in the oil industry. Utilization in western Europe, as opposed to Hungary, which displays a more diversified spectrum (Gudmundsson and Palmason, 1981), is chiefly concerned with district heating a reliable market that allows for depreciating the high captial investment implied by well and piping costs. This obviously restricts low enthalpy geothermal development to large urban areas.

The presently installed capacity (including eastern Europe) totalizes ca 2,000 MWt (sources above 40°C). It could ultimately reach 5,000 MWt if potential candidate sites were equipped. This figure would likely be increased should other resources and utilization areas, particularly shallow, tepid and fresh water aquifers, cascade uses and low temperature heating processes, be commercially exploited at fairly attractive economic ratios, say 5 years pay back time and 20 percent rate of return. It is the authors' opinion that such potential exists in the form of cheap resources and small size heat loads, in particular in Italy and France where there are numerous hot springs, karstic systems and medium depth aquifers that could bring on line an additional capacity of 1,000 to 2,000 MWt.

At production level, problem areas may be subdivided into four main categories, namely:

Reservoir Related Problems. They are presently more critical for sandstones than for carbonate reservoirs because of sand control and well plugging, which emphasize well completion, injection, solid treament and filtering processes.

Reliability of Down Hole Production Systems. Most wells require production to be sustained via down hole pumps of either the electric submersible (ESP), line-shaft (LSP) or even turbine (TP) type to be profitable. The experience acquired for 5 years over a representative sample of 50 pump sets suggests that no such system developed by the oil industry and the water supply and irrigation sectors has yet demonstrated the desired reliability under geothermal service conditions.

Thermochemistry of the Formation Fluid. Corrosion, erosion and scaling of tubular goods, down hole pumps and surface facilities are some of the many shortcomings encountered by geothermal operators. In the Parisian area, H_2S combined corrosion and scaling is believed to have caused almost one half of submersible pump failures.

Reservoir and Resource Management. It is thought that lack of pressure maintenance of a massively withdrawn aquifer might be one of the major reasons for the hydraulic interferences and subsequent loss in productivity noticed in Hungary, in the Szeged area. Such situations could occur in France, in Aquitaine and even in the Paris basin, unless adequate management policies be devised in due time.

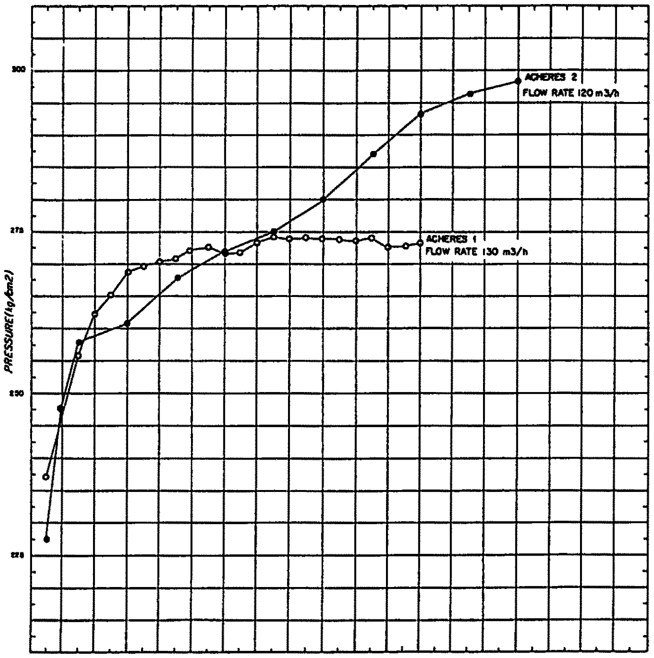

Figure 3. Summary of well injectivity testing (district heating couplet west of Paris)

PROBLEM AREAS

Injection of Cooled Brines (Ungemach, 1984)

Three injector wells drilled on two different sites in a sandstone reservoir of Triassic age have experienced severe injectivity problems. The first well (M2), drilled south of Paris, completed with a wire wrapped screen, was partially plugged soon after start up of a commercial couplet aimed at heating 15 ha of greenhouses. Here the measured injectivity index proved to be, after temperature correction, half the initially determined productivity index. Further to production testing, using artesian free flow, initial well productivity was restored. This irreversibility suggested the build up during injection of a mechanical damage removable by backwashing the well. Workover confirmed this early diagnosis by evidencing a strongly positive skin displaced after switching to production. The source mechanism of this near wellbore removable damage has been attributed to the displacement in the nongravel packed annular space of solid clay particles and, possibly, of iron hydroxides and debris settled down hole. These particles are expected to form a filter cake partially bridging pore entries, a mechanism known as sandface bridging (Barkman and Davidson, 1972). A semi stabilized pressure pattern is noticed for each injection step (analogous to that indicated in Figure 3 for well A1) with a trend towards damage increasing proportionally to injection rates. Restoration, by backwashing, of productive capacities suggests that these particles do not invade the formation whatever the injection pressure gradient, e.g. their size

Table 1. Down hole pump data base — Paris Basin

Well Site	WHT (°C)	Setting Depth (m)	Power (kWe)	Pump Type	Date Installed	Number of Failures	Running Times (hrs) (*)
PNC1	54	260	200	ESP	1977 10/1983	1 1	N.A. 8,000 - 6,000
PNVG	54	260	320	ESP	10/1977	1	6,000
PNCS	60	245 310	260	ESP	1981	2	2,000 - 5,500 - 6,000
PEC	84	190 300	250 380	ESP	1981	3	15 - 4,500 - 18,000 - 5,000
PNWCP	60	30 250	70 210	ESP	1982 1984	1	16,500 10,000
PNCL	72	130	120	ESP	6/1982	1	14,500 - 6,000
PEM1	79	110	160	ESP	8/1982	1	11,500 - 10,000
PSM	74	210 300	180 240	ESP	1980 11/1983	2 3	N.A. 7,000 - 1,500 - 3,500
PNCN	59	230	240	ESP	1/1983		11,000
PNB	46	160 210	130	ESP	9/1982	2	11,500 - 5,500 - 1,000
PEE	60	450	275	ESP	2/1983	1	8,500 - 5,500
PES	69	250	320	ESP	7/1983		12,000
PSE	72	220	200	ESP	10/1983		11,500
PEM2	79	225	320	ESP	9/1983	1	6,500 - 5,000
PEM3	79	280	370	ESP	10/1983	1	8,000 - 3,000
PNEBM	68	200	230	ESP	10/1983	1	8,000 - 2,000
PSRO	72	235	275	ESP	9/1983	2	5,000 - 7,000 - 500
PNEA1	71	190	220	ESP	9/1984	1	500 - 2,500
PWA	59	150	160	ESP	11/1983	2	3,500 - 6,000
PSF	73	420	300	ESP	10/1983		8,000
PWCS	63	254	210	ESP	3/1983	1	6,500 - 6,000
PSC	68	230	220	ESP	10/1984		4,000
PNEA2	71	200	260	ESP	9/1984		3,500
PNG1	66	200	260	ESP	9/1984	1	2,000 - 1,000
PWPS	59	140	150	ESP	10/1984		3,500
PNET	74	200	265	ESP	10/1984	1	500 - 2,000
PSCM	68	365	340	ESP	9/1984	1	3,000 - 1,000
PSEE	74	130	150	ESP	10/1984		3,000
PNC2	57	115	90	LSP	1/1984	1	5,000 - 4,500
PSEM	72	130	120	LSP	11/1983	3	2,000 - 2,500 - 1,000 - 1,500
PEB	66	140	165	LSP	11/1984		3,000
PSES	77	200	190	LSP	11/1984	1	150 - 1,000
PEM4	78	207	290	TP	5/1984	1	3,500 - 4,000

(*) last figure indicates running time since last failure largely exceeds pore throat diameters; neither do they obstruct screen slots when moving to production.

On the second (and third) hole, drilled west of Paris, specifically injection-oriented experiments were conducted on a commercial development prospect designed to cope with the questionable reliability of the Triassic sandstone target. In other terms, both wells were completed so as to switch to the overlying Dogger limestone in case of poor Triassic reservoir performance. The first well (A1) was partially gravel packed, thus allowing for particle entrainment in the free annular space. The second hole (A2) was completely gravel packed over a thin (9 m) net pay interval of clean conglomerate. Injectivity testing showed two distinctive trends depending on the tested well. On A1, a trend similar to that shown by the well M2 south of Paris was noticed, e.g. an injectivity index fast stabilizing to a figure two times lower than the temperature-corrected productivity index. This converging trend could be attributed to the same cause, odd completion and subsequent sandface bridging. On well A2, bottom hole pressures were far from stabilized after 21 hours injecting and the injectivity index was much lower than on A1. The origin of this progressive plugging trend could be found in the high injection pressures (over 100 bars at well head), relevant fluid velocities at sandface and moreover formation invasion by fine particles of micrometric size. Actually particle monitoring indicated that the amount of suspended solids of the 3 to 5 μm size had undergone a two-fold decrease whereas in the 0.2 to 1 μm range they increased by two times.

The foregoing had led French authorities to postpone development of clastic aquifers until injection of cooled brines is thoroughly mastered. Many proven and potential geothermal reservoirs in Europe include fluvio-deltaic clastic despositional sequences. The particle invasion problem is thought to become critical for matrix-dominated reservoirs with transmissivities in the 5 to 20 darcy-meter range and injection velocities above 1 cm/s at a screened well face. Two projects, in Spain at San Sebastian de los Reyes (Madrid outskirt (Ungemach and Economides, 1984)) and in Denmark at Thisted (North Jutland), dealt with testing, in the field and in the laboratory on cores, of both well injectivities and formation injectabilities. It seems that the high formation permeabilities noticed at these sites and the design of adequate filtering facilities have inspired the go-ahead decision for these projects.

Down Hole Pumps

This is undoubtedly the most critical problem area hitherto encountered in production of Paris basin geothermal heating systems. It has been clearly overlooked since the very beginning of commercial exploitation, when it was first decided to (a) sustain withdrawal rates above already substantial artesian free flows, and (b) boost well head pressures far above bubble point pressure, a notion often misunderstood by geothermal operators. Discharge was rated at 200 to 250 m^3/h and pumps submersed at 100 to 250 m depth. Taking advantage of high (up to 200 m^3/h) free flows, pump manufacturers were requested to supply high-flow, low-head pump sets. Recently, although a number of operating wells have undergone repeated pump failures, as shown in Table 1, new pumping flow and head requirements have been set at 275 to 325 m^3/h and 250 to 350 m respectively, the record being held by a 520 kWe unit (320 m^3/h, 350 m). This trend, which defeats elementary resource conservation standards, is a consequence of routine district heating practice. To augment the installed power capacity, thus improving the geothermal load factor, thermal engineers tend to increase flows (heat exchangers operate in equalized flow-rate mode) rather than deplete rejection temperatures by means of heat pumps, low temperature heating devices, heat storage or simply optimized system regulation.

Table 2. Down Hole Pumps Failure Record—Paris Basin

Number of down hole pumps, including replacements: 59
ESP (54); LSP (4); TP (1).(*)

Number of (reported) failures: 38
ESP (32); LSP(5); TP(1).

Maximum (continuously) running times (hrs):
ESP (18,000); LSP (5,000); TP (4,000 still running).

Average (continuously) running time (hrs):
ESP (5,900); LSP (2,100); TP (p.m.).

Maximum running time (hrs) since last failure or since pump installation:
ESP (11,500); LSP (4,500); TP (4,000).

Failure (presumed) causes (number of failures):

ESP	cable, connection	6
	motor (insulation, flash, lubrication)	4
	thermochemical (pump scaling)	15
	installation	4
	other (hazard, industrial defect)	3
LSP	shaft bearing wear(**)	4
	thermochemical	1
TP	surface boost pump	1

(*) ESP = electric submersible pump; LSP = lineshaft pump; TP = turbine pump.

(**) As a result often of misfunctioning lineshaft protection.

Pump history for the Paris basin may be found in Table 1 and the failure record is summarized in Table 2. Only six systems produce in nonsustained flow mode.

Initially, in the late 1970s, standard ESP units of the type used in the oil industry were installed. None of them was capable of operating continuously over more than a few thousand hours e.g. less than the 6 months oil industry average. Corrosion and motor breakdown were the main failure causes. Pumps were running at constant speed and neither were motors thermally insulated nor hydraulics and materials specifically designed for geothermal service.

The second generation, in the early 1980s, consisted still of ESP's mainly manufactured for water production (ground and surface water supply, irrigation, water-flooding, desalinization, etc.) purposes. Substantial improvements were implemented such as (a) variable

Table 3. Figures of Merit of Various Down Hole Pump Concepts

Pump Type	Advantages	Disadvantages
ESP[1]	Acceptable efficiencies (60 percent). Great depth of submersion. Easy handling and maintenance.	Down hole motor. Insulation in a saline water environment. Reliability.
LSP[2]	No down hole motor. Higher efficiences (65 percent). Reliability. Possibility of manual pump restart.	Limited submersion depth. Shaft bearing (wear and lubrication). More complicated maintenance.
TP[3]	High reliability. Great depth of submersion. Compact packing allowing for high quality materials. Lighter maintenance.	Low efficiencies (35 to 40 percent). Large diameter required for high flow rates (13⅜" above 200 m^3/h) forbidding dual completion. Anchoring via "retrievable" packer in single completion.

[1] Electric submersible pump. [2] Line shaft pump. [3] Turbo pump.

Table 4. Mineralogic Analysis of Scale Deposits Sampled on Geothermal Wells in the Paris Basin

X-Ray Diffractometry (Code: A = abundant, P = poor, Tr = trace)

Sample A - West of Paris	
Deposits collected on surface pipe close to well head	
Mackinawite (Fe_9S_8)	A
Pyrite (FeS)	P
Akaganeite (β FeOOH)	P
Goethite (α FeOOH)	Tr
Lepidocrocite (γ FeOOH)	Tr
Pyrrhotite (Fe_7S_8)	Tr
Oxydes in cubic phase (Magnetite Fe_3O_4; Maghemite γ Fe_2O_3)	Tr
Sample B - North of Paris	
Deposits collected on impellers of down hole pump	
Pyrite (FeS)	A
Pyrrhotite (Fe_7S_8)	P
Marcasite (FeS_2)	Tr
Hematite (Fe_2O_3)	P
Calcite ($CaCO_3$)	Tr

speed through frequency variators to adjust to the daily and seasonal changes in demand inherent to district heating and to minimize power consumption, (b) improved thermal insulation of motors for fluid temperatures above 70° C, (c) use of higher grade materials (aluminium-nickel bronze, SS 316 L, K Monel) substituted for the standard Niresist for vital hydraulic parts (impellers, diffusers, shaft) to withstand the added effects of corrosion, erosion and wear, (d) increasing statorrotor clearances of hydraulics to reduce blockage by scale, and (e) new elastomer design for bearings and pressure equalizing (between motor cooling and down hole ambient pressure) membrane for combating excess material fatigue.

The failure record displayed in Tables 1 and 2 is based on a data set of more than 50 cases including a large majority of ESP's, four LSP's and one TP. LSP and TP systems appeared during the 1983-1984 heating period as a possible alternative to ESP units. It can be seen in Table 1 that, as long as the production target has been kept at reasonable levels, say below 250 m^3/h, the reliability shaped rather fine with an average (continuous) running time, between consecutive incidents, nearing 9,000 hours, e.g. over 1 year, an acceptable figure by economic standards set for the operation-maintenance item (ca US $75,000 per year). The striking feature indicated by Table 2 is that almost one half of the reported failures (many of them occurred in 1984) are attributed to pump binding as a result of scaling, chiefly metal sulfides. Although causes are not yet precisely diagnosed, it is thought that high velocities and subsequent turbulences induced at pump suction level have favoured H_2S and CO_2 degassing with formation of sulfide and carbonate scale.

LSP's are still on the learning curve. Many mechanical problems associated with lineshaft cooling and bearing wear have been experienced so far. However, it seems the most attractive concept for geothermal service in the Paris area, provided that shaft length does not exceed 200 m and that a (hollow) shaft cooling lubricating system, using either geothermal water or oil as lubricant and more resistant bearings, can be designed. Figures of merit of three production concepts are outlined in Table 3. For the time being ESP systems exhibit the best reliability record. In the future, their use could be limited to wells requiring submersion depths greater than 200 m. However, they could still prove competitive for net (global) conversion efficiencies of say 60 percent and continuous running time over 15,000 hrs. LSP sets should logically prevail due to their higher efficiency (65 percent) and life time despite disadvantages inherent to submersion depths (150 to 200 m) and more tedious maintenance. TP's are intrinsically more reliable, although the pump can be equally affected by scaling. However its low efficiency (40 percent at the best) limits its use to highly productive wells where energy costs are minimum. For example, extra energy costs for a 20 to 30 darcy-meters hole and 250 m^3/h can be estimated yearly at US $30,000. On the other hand, the anchoring of the pump down hole via a "retrievable" packer may be a severe problem after several years running as reported in IFP-BEICIP (1984) for a similar outfit.

A production-injection configuration recommended by the authors is sketched in Figure 4. It associates an ESP

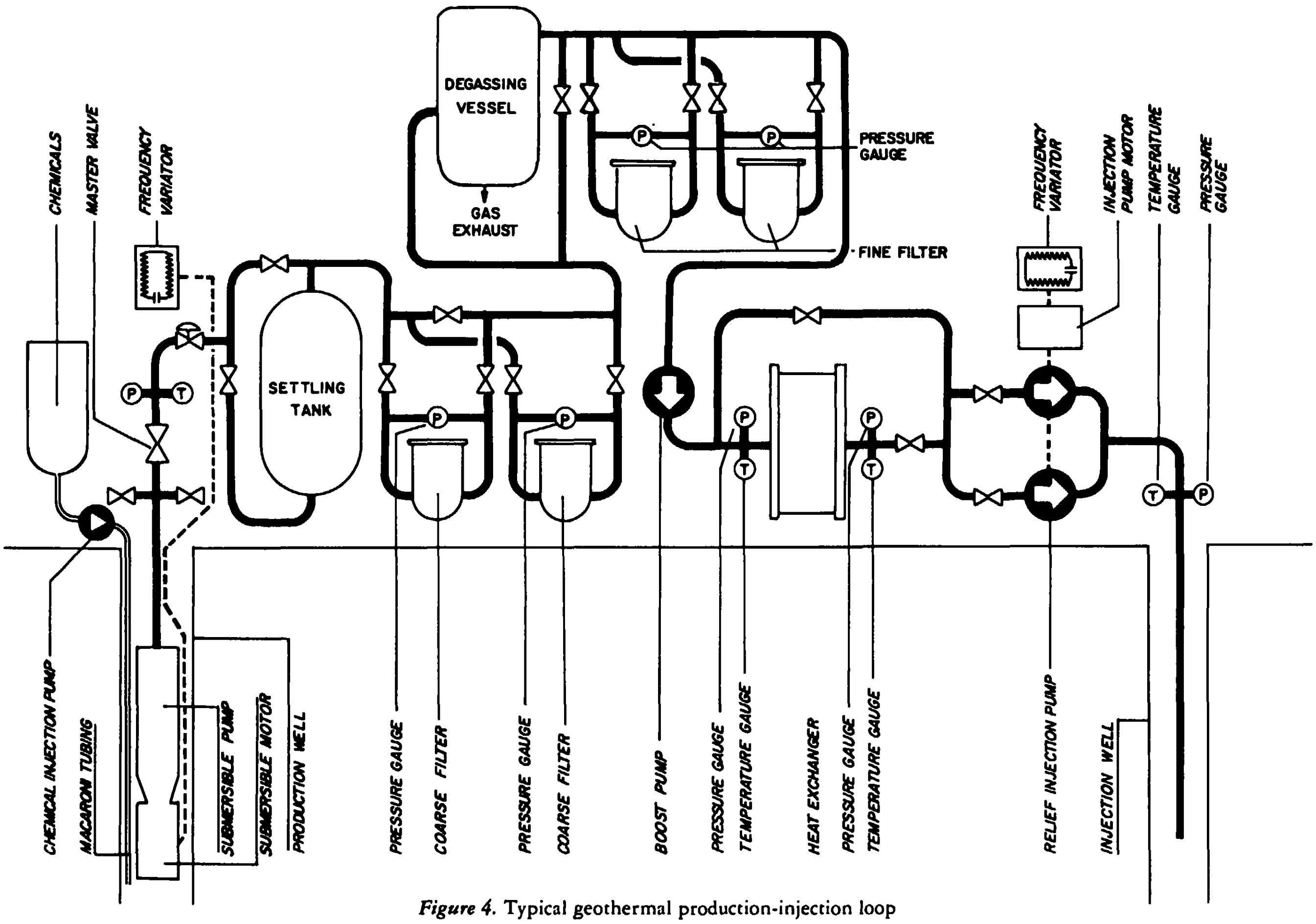

Figure 4. Typical geothermal production-injection loop

(or a LSP) unit and a dual injection pump set, a main unit in high grade materials and a (cheap) standard metallurgy relief pump. Injection pumps are of the horizontal type for practical space and maintenance reasons and are driven by an asynchronous motor, which can better cope than DC motors with humid and saline environments. Here the role of the surface feed pump is essential when dealing with a free flowing well, which is generally the case; it secures production when the down hole pump is out of order and during the summer period when supply is limited to domestic hot water. It boosts fluid pressure above bubble point pressure. During the heating period it can contribute 20 up to 35 percent of total manometric head, thus achieving, because of its efficiency that is higher than that of the down hole pump, a gain of 2 to 3 percent in overall net efficiency. Over the whole year this gain can reach 6 to 8 percent. Mechanical (settling, coarse and fine filtering) and physical (degassing) treatment is applied to the produced fluid upstream of the pump suction and the geothermal heat exchanger.

The injection of a pressurized inert gas (nitrogen) in the pumping chamber to prevent fluid degassing and (or) air contamination is deemed inadequate. The problem will be removed to the surface and by all means require the inert gas to be displaced. Instead, the association of a boost pump and of a degassing vessel would appear more appropriate.

Corrosion and Scaling

The corrosion impact of Dogger warm brines has long been noticed in the Paris basin. At Melun l'Almont to the southeast, the first geothermal heating doublet completed in 1967, a total corrosion of the steel heat exchanger occurred in less than a year. It led incidentally to the design of Titane-Palladium alloyed plate exchangers, currently used in the area and whose lifetime has proved to extend over 10 years. Destruction of a carbon steel (N 80 grade) production tubing at Villeneuve la Garenne in 1976 occurred in a matter of months. At Creil, north of Paris, in 1978, bacteria were presumed to have caused pump corrosion and further failure. There has been also some evidence from hole inspection by wireline logging (ETT, CETX and microcaliper) and video camera, although results have not been released to the public, of damaged casings. Casings consist of K 55 carbon steel adequate for service in an H_2S stress corrosion environment. Pumping chambers are uncoated, at the difference of production tubings, rubber coated "recto-verso." Ironically, at Villenueve la Garenne, casings were of fiber glass, which remains an exception.

However, most severe problems resulted from scaling of down hole pumps and, possibly, scale debris progressively have plugged a few injector wells north of Paris, although this has not yet been clearly ascertained. The

Table 5. Pay Back Times for Various Low to Very Low Geothermal Configurations
(Source: GEOTHERMA — O.E.T.)

a) Shallow depth (< 100 m) aquifer

Source Temperature and Depth	Water Supply Taxes(*) (FF/m³)	Number of Connected Dwellings					
		50		100		150	
12°C - 20 m	L 0.11	5.3	8.2	4.6	6.3	4.4	5.7
	H 0.38	8.1	14	6.2	9.8	5.6	8.6
	N 0	7.9	11.4	5.5	7.4	4.8	6.4
13°C - 80 m	L 0.11	6.3	9.1	4.8	6.3	4.4	5.9
	H 0.38	9.0	16.3	6.6	10.5	5.9	9.1
	N 0	8.7	12.6	5.9	8	5.9	6.9

b) Medium depth (< 1,000 m) geothermal resource

Source Temperature	Water Supply Taxes(*) (FF/m³)	Number of Connected Dwellings							
		250		500		1,000		1,500	
25°C	L 0.23	8.4	10.9	6.2	8.1	5	6.4		
	H 0.50	10.1	13.9	7.4	10.2	5.9	8.1		
	N 0	12	15.4	8.2	10.4	6.1	7.8		
30°C	L 0.11	8.6	11.1	6.2	9	4.8	6.2	4.3	5.5
	H 0.38	9.4	12.4	6.7	8.9	5.2	6.8	4.7	6.1
	N 0	13	16.8	8.4	10.8	6.0	7.7	5.2	6.6
35°C	L 0.11	8.6	11	6.1	7.8	4.7	5.9	4.2	5.3
	H 0.38	9.4	12.2	6.6	8.6	5.1	6.6	4.5	5.8
	N 0	13.2	16.8	8.5	10.7	6	7.5	5.1	6.4

(*) L = low H = high N = none (well couplet)

PBT (years)

floor slabs : 50 - 30	radiators : 80 - 60

Fuel : domestic fuel oil)

formation fluid contains dissolved gases, by decreasing importance CO_2, H_2S and CH_4, though in limited quantities. However, very seldom would a PVT analysis detect any H_2S whatsoever, in spite of olfactive evidence some 5 km away from a drilling site. In fact PVT is most questionable (no surface separators are yet used) in assessing bubble point pressure, especially when dealing with less than 2 percent GWR's due among others to sampling conditions, sample contamination and preservation of such a volatile compound. However disputed this matter may be, it is out of the question that the predominantly metal (mainly iron) sulfide scale (see qualitative analysis in Table 4) be native. So far calcium carbonate scale has been identified on one site only to date. Therefore it is a generally accepted fact that iron sulfide scale is corrosion generated by interacting H_2S and tubulars. The origin of H_2S—degassing versus sulfate reducing bacteria—and consequently the design of countering procedures are still a subject of debate. There is nevertheless some indications, even if no correlation can be firmly stated yet, of a trend geographically located northwest of Paris (see Figure 2) associating cooler and saline zones with major pump scaling effects. In those areas possibly could H_2S degassing occur even in small quantities, in relation with (turbulent) flow singularities and its effects can be amplified by the significant discharge of these wells. Bacterial contamination generated by well-killing practice using heavy brines has also been hypothesized (A. Bradelle, personal communication, 1985). These problems are presently being systematically investigated by French authorities.

Reservoir Management Implications

The high enthalpy Ahuachapan field in El Salvador is a well known case history of over exploiting a prolific, but limited, liquid-dominated resource. It has emphasized severe interferences between production wells and also problems of modelling and implementing injection of the separated liquid phase in a fractured reservoir context.

A low enthalpy replica of this case could be found in the Szeged area in southern Hungary, where a long produced hot water aquifer has apparently undergone losses in well productivities as long as the waste fluids have not been injected to compensate massive withdrawals. This could be the case in the Bordeaux area (Aquitaine basin) where no injection of the cooled brines is yet practised, or even contemplated, to sustain reservoir pressure and avoid compaction or crushing of mechanically weak, clastic, water-bearing rocks.

In the Paris metropolitan area, where injection is the rule, the problem might soon become critical as a consequence of anarchic proliferation of production-injection couplets causing faster than expected thermal interferences and breakthroughs. This would result in irreparable damage to system and reservoir life times, should not suitable modelling procedures and management policies be applied in due time. Semi-analytical computer models (Gringarten and Sauty, 1975) are used to simulate at local scale individual (and, by superposition, several) couplet thermohydraulic behaviour and so to assess a well spacing securing a minimum 20 years delay before breakthrough occurs. These models assume fairly idealized reservoir conditions, particularly lateral and vertical homogeneity and lack of natural hydrodynamism among others, which are not necessarily verified actually, even if the Dogger is an "easy" aquifer to deal with at well-test level for instance. Fast aquifer development and high, perhaps too high, well discharge (and recharge) have established new priorities addressing the modelling of heat and mass transfer, at regional scale.

EXPLOITATION OF LOW TO VERY LOW TEMPERATURE AQUIFERS

Development schemes of the type promoted in the Paris and, to a lesser extent, in the Aquitaine basins should not be regarded as universal models. They are in a sense specific to western Europe, as most direct users outside Europe extract geothermal heat at almost no mining costs with generally simply engineered small size outfits devoted to agro-industrial uses (drying, canning), balneology, fish farming, aquaculture and greenhouse heating.

Wider development could be sought in western Europe, should low temperature sources below 40° C or so be produced through suitable processes (heat pumps and heating systems) that would prove technically sound and economically attractive.

Heat pumps are a fascinating perspective in geothermal engineering, provided they demonstrate yearly average coefficients of performance (COP) of at least 3 and preferably 5 as advocated by Ungemach (1982) for a 45° C -150 m^3/h resource tapped by a single well. It has also been shown that supply of fresh water as a by-product can significantly upgrade the economics of such schemes. Heat pumps require an energy source, which is quite easy in most European countries, particularly in France where cheap and abundant nuclear electricity exists and in Sweden with hydropower. Elsewhere, natural gas and oil-fueled thermal engines can be used for driving heat pumps at competitive costs because of numerous feeder, pipe line and supply facilities. Hence, other than compression or thermal engine heat pumps, such as absorption and ejection type, heat pumps have limited applications in low temperature geothermal uses.

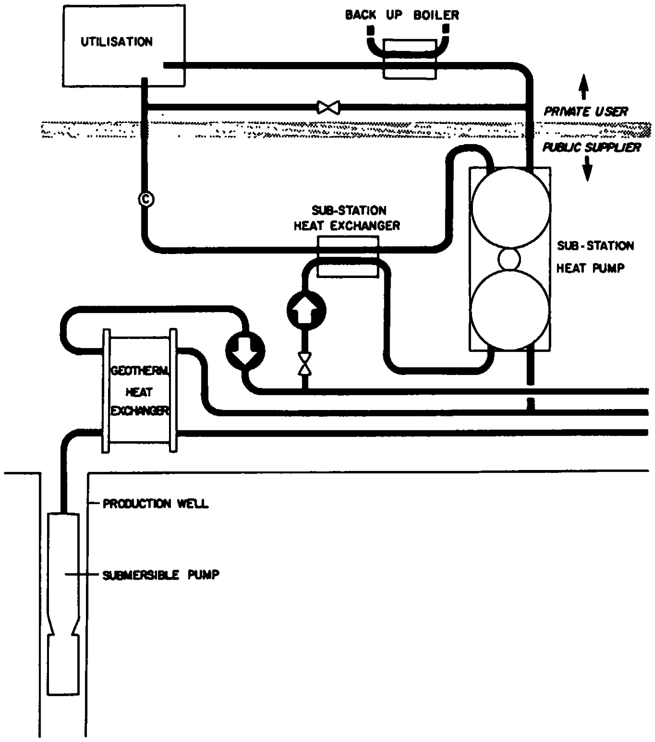

Figure 5. Combined heat exchanger-heat pump development, decentralized heat pump scheme

Another heating alternative calls for low temperature convectors, based on either natural or forced draft concepts, which operate at low inlet temperatures and flow rates on the water side. Extensive development work (Grossin, Roth and Soupault, 1982) has led to the following performances:

- water inlet (geothermal)temperature .... 40° C
- water flow rate ....30 l/hr
- water outlet temperature .... 29° C
- thermal power .... 400 W(t)

Economics also shape fine; the cost of a 400/800 W(t) rated unit amounts to ca US $150, which is acceptable by current European standards. Low temperature convectors do not necessarily require heat pumps to be added. However, studies have shown that a combination of heat pumps either of conventional or less conventional types, such as polytropic (staged) units, would markedly improve system COP's (Grossin, Roth and Soupault, 1982).

Table 6. Comparative Economic Features of Contrasted Low and Very Low Temperature Development Schemes (Costs are Expressed in 1985 US $)

Headings	Heating Configuration		
	Case 1	Case 2	Case 3
Geothermal Capital Investment Costs			
subsurface	650,000	27,500	125,000
surface	1,550,000	82,500	3,925,000
Total	2,200,000	110,000	4,050,000
Running Costs			
***Conventional process**			
fuel	325,000	37,500	
power	32,000	5,000	1,105,000
water	98,000		
Total	455,000	42,500	
***Geothermal alternative**			
fuel (back-up)	127,000	1,000	210,000
power	11,500	300	285,000
water	32,500	14,000	—
maintenance	38,000	—	30,000
Total	209,000	15,300	525,000
Annual Savings			
costs (US $ 1985)	246,000	26,400	580,000
fuel (TOE)	1,400	130	2,100
Pay Back Time (years)	9	4.2	7

Greenhouse heating, although there are attractive market opportunities for agricultural outputs, cannot afford high initial capital investment to be competitive and flexible in handling. The three schemes thus far implemented in western Europe—Lamazère (Aquitaine): 1 well, 10 ha; Melleray (Paris basin): 2 wells, 15 ha; Monte Amiata (southern Tuscany): steam condensates from a back pressure power plant, 50 ha—required an acreage of at least 10 ha to be profitable, which is considerable by farming standards. Smaller size projects, ranging from 1 to 5 ha, could be developed at relatively low costs by taking advantage of shallow, often CO_2-rich water sources, milder climate and daily storage facilities. Such conditions are easily found in Italy and northern Greece (Macedonia). In Italy for instance, there are 14,000 ha of greenhouses among which almost 5,000 are heated, many of them being located in proven geothermal areas.

In semicontinental areas (minimum outdoor temperature: -7°C, useful degree-days: 2,400), economic calculations for retrofitted space heating from low temperature aquifers have been performed. In the Paris basin, various scenarios were contemplated (GEOTHERMA-OET, 1984) accounting for source temperatures (from water table to medium depth aquifers), water consumption taxes (when no injection is needed), heating systems (radiators vs floor slabs) and number of connected dwellings. Results are summarised in Table 5. It can be noted (Table 5a) that for water table aquifers, breakeven (expressed as 10 years PBT) is attained for 50 dwellings using floor slab-based heating systems. Breakeven is the rule whatever the water withdrawal policy and the heating process over 120 connected dwellings. The problem is more critical when dealing with warmer but deeper seated resources (Table 5b). Here breakeven requires a minimum threshold of 500 connected dwellings. It can be stated with fair reliability that (i) a deep resource (1,500 to 2,000 m) mined via a well couplet needs a minimum heat load of 2,500 dwellings to be depreciated, (ii) a medium depth aquifer (ca 1,000 m) requires 1,000 and 600 dwellings when tapped by a couplet or a single well, respectively, and (iii) in the case of a superficial aquifer, 100 dwellings would be sufficient. There is little doubt that the use of modern low temperature convectors would significantly improve these ratios.

These projections have been confirmed with several case histories. Three of them are summarized in Table 6. Case 1 addresses a 750-m deep reservoir, at 35° C, tapped at an average 150 m^3/h connected to a heat load equivalent to 1,000 dwellings. Heat pumps, used in the heating-cooling mode, are driven by gas thermal engines. Case 2 deals with a 50-m deep aquifer (15°C) heating 100 dwellings by electrically driven heat pumps and floor slabs. Case 3 reflects design features of a multi-purpose development scheme of a city located in central Italy (0° C; 1,360 degree-days) aimed at exploiting a prolific resource (40 to 45° C; 1,500 m^3/h) at 200 m depth. The scheme combines retrofitting and new, specially geothermal, activities: district heating, heating-cooling, thermal bathes, greenhouse heating, aquaculture. It is based in most cases on heat pumps (either of the compression or thermal engine type) used in decentralized mode with 250 to 500 kWt rated units split in substations as shown in Figure 5. In every respect projected economics, despite high piping costs, look very promising.

CONCLUSIONS

A status of European geothermal direct uses, with special emphasis placed on development taking place in the Paris metropolitan area, has been presented. The Paris basin, with some 50 district heating well couplets due to operate by late 1985, offers a representative data base for appraising production-related problem areas. Among these, injection into tight clastic sediments and, above all, submersible pump failures have been the most critical problems encountered to date. In particular, production pump running time without failure has dropped to 8 months. This is a likely consequence of excessive withdrawal rates and corrosion-generated scaling of pump sets by metal, principally iron sulfides. More realistic production targets combined with inhibitors and improved material definition should overcome these problems and warrant continuous pump operating from 12 to 18 months, compatible with competitive economic operation and maintenance criteria.

Presently installed capacities for sources above 40°C are nearing 2,000 MWt, mainly provided by retrofitted district heating schemes requiring significant mining investments. Production, at lower subsurface costs, of shallower deposits is a promising route for widening and diversifying the market of low grade heat uses. Based on available case histories and feasibility studies, a tentative projection of an additional 1,000 to 2,000 MWt installed capacity is a realistic objective.

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