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CLOSED LOOP VERSUS AN OPEN LOOP GEOTHERMAL DISTRICT SYSTEM: A TECHNO-ECONOMICAL ASSESSMENT

İ. B. Kilkis

Geoenergy Int. Consortium

ABSTRACT

Fundamental techno-economical parameters governing an open loop and a closed loop geothermal district energy system are briefly discussed. The maximum allowable closed loop distance between the geothermal plant and the district entry point is directly related to the thermal capacity of the system. A case study is presented, which indicates that a closed loop distance covering 31 kilometers between the well head and the district entry point is feasible for a 89.1 MW(t) district capacity for the City of Denizli in Türkiye. The same study reveals that the common base unit capital cost of 240 $/kW(t)-peak for a closed loop system favorably compares with 480 $/kW(t)-peak for an open loop system for the same district capacity for the existing geothermal well output.

INTRODUCTION

A competitive geothermal system primarily requires its cost effectiveness to be maximized. The solution depends on how efficiently the geothermal reservoir is spent and sustained for a given demand. These factors are formulated in terms of the Geofluid Effectiveness (GE), which is defined at maximum sustainable flow rate of the well(s):

$$GE = U/M \qquad (1)$$

Here:

U: Useful thermal energy claimed in unit time, at maximum sustainable flow rate of the well(s), and

M: Mass of geofluid spent in unit time, at maximum sustainable flow rate of the well(s):

The unit of GE is MW(t)-h/ton geofluid, and U includes the thermal energy input to electricity generation plant, if there is any in the geothermal energy system. Typical values range between 0.04 MW(t)-h/ton geofluid for open loop district systems and 0.22 MW(t)-h/ton for a combined-closed loop geothermal district energy system (Eltez, M., and Kilkis, İ. B, 1995). By increasing GE, the extraction rates of the geofluid, and thereby the heat from the reservoir, will decrease. Consequently, the Reservoir Decline Rate (RDR) will be reduced.

$$RDR = f(\text{heat extraction rate - natural recharge rate - re-injection rate}) \qquad (2)$$

In low enthalpy applications, the space heating equipment designed for conventional supply water temperatures need to be oversized. The oversizing factor, OF is given by the following equation:

$$OF = [(t^*-t_a)/(t_m-t_a)]^m \qquad (3)$$

Here, t^* is the rated mean water temperature in the heating equipment (usually 80°C), t_m is the design mean water temperature, and t_a is the design indoor air temperature. The power m depends on the equipment type. It is 1.33 for steel section radiators,1.1 for panel radiators, 1.5 for fan-coils, and approximately 1.25 for finned tube heaters. For radiant panels, m is 1.1, and 1.0 for floor and ceiling heating respectively. Recently, radiant panel heating and cooling systems are becoming popular, especially for low enthalpy geothermal systems, due to their various attributes like low t^* and m, and capability to cascade with other equipment.

Geofluid Effectiveness may be increased by increasing the temperature drop across the equipment and in the district. However, this reduces t_m for a given supply temperature, and the equipment needs to be oversized. At high enthalpy geothermal systems, this design philosophy may generally be justified up to about 1.3 OF (Kilkis, İ. B., and Eltez, M.,1996). However, at low enthalpy applications, t_m becomes sensitive to the supply temperature, and the required OF sharply increases with a decrease in the supply temperature. In low enthalpy cases, the following equation which defines the

Geothermal System Effectiveness for the district renders the additional criteria for evaluating and rating the geothermal district system with respect to actual amount of geothermal energy consumed in the district at a constant flow rate and the required district capacity:

$$GSE = C_O/C \tag{4}$$

Here:

C_O : District capacity without temperature peaking and equipment oversizing, and

C : District capacity with temperature peaking and equipment oversizing.

GSE is the ratio of geothermal power deliverable to indoor spaces in the district at the absence of equipment oversizing and temperature peaking, to the total power demand in the district which can be satisfied by temperature peaking and, or oversizing, as necessary. Essentially, a peaking plant is used not only for reducing the well drilling and operating costs, but also for back-up purposes. In ideal terms however, the peaking plant should not be used for temperature peaking, and little or no equipment oversizing should be present. Therefore, the ideal GSE is 1. In practice, it varies between 0.5 and 0.9 (Kilkis,İ. B., 1996). It is difficult to approach this ideal condition using conventional heating equipment with high m and t*. In this case, Equations 3 and 4 may be simultaneously solved for a specific project in order to determine the optimum split between temperature peaking and equipment oversizing, for given fuel prices, equipment and plant costs. Typical capital costs for low enthalpy geothermal building heating equipment (without temperature peaking) are about 110 \$/kW, 100 \$/kW, 75 \$/kW for steel section radiators, fan-coils, and radiant panels, respectively. For high enthalpy geothermal systems, these costs may drop to about 65 \$/kW, 60 \$/kW, and 40 \$/kW respectively.

For a common base comparison of the geothermal district system alternatives, some of the above equations may be combined to give a capital unit cost:

$$CBUC = \text{Capital Cost}/[C \cdot GSE] = \text{Capital Cost}/C_O \tag{5}$$

Here, CBUC is the Common Base Unit Capital Cost, \$/kW(t)-peak.

All these factors depend directly to the type of the district loop, namely closed and an open loop system. In other words, the above and other techno-economical factors are greatly influenced by the type of the district loop. In an open loop district system, fresh water is heated at the geothermal plant and delivered to the district by a single pipe. After the heat is delivered to the district, water is usually discharged to the original source like a river, downstream. In a closed loop district system the district water is circulated between the district and the geothermal plant in a closed loop, two pipe system. The major difference between the two systems is the amount of heat that can be delivered to the district: in an open loop system, fresh water has to be continuously heated in an additional amount proportional to the difference between the district return temperature and the fresh water intake temperature. The difference may be substantial, and a thorough, common base comparison must be carried out, before deciding whether an open loop or closed loop district system should be used in a specific project. There are many economical factors to be considered. These include but not limited to the installation and operating costs of the second (return) piping versus, additional heat recovered in a closed loop system; and the apparent savings associated with a single pipe (open loop) system, versus the installation and operating costs of a second plant in order to make-up the unrecoverable geothermal heat, and present value costs attributable to the use and associated problems of using an inhibitor. All these factors depend upon the size of the geothermal and district systems, and a simplistic expression may be obtained for L_{max} in terms of the thermal capacity, P (Kilkis, İ. B., 1996):

$$L_{max} = A + P^n \qquad P>0; \qquad \{L< L_{max}\} \tag{6}$$

Here:

L_{max} : Maximum allowable distance (one way) for a closed loop district system between the geothermal plant (well head) and the district entry point, km

A : Constant, usually 0.6

P : District capacity delivered by the geothermal system at peak conditions, MW(t). P includes thermal power provided to any electric plant which is located in the district

n : Power of the term P. It ranges between 0.8 and 0.95, depending upon the particulars of the specific district, local economical factors and the temperatures involved

L : Distance between the geothermal plant and the district entry point, kilometers.

As an example, a typical low enthalpy geothermal system in Paris has a capacity of around 5 MW(t). Choosing n:0.8 for low entalphy conditions, L_{max} will be:

$$L_{max} = 0.6 + (5)^{0.8} : 4 \text{ km}.$$

This value coincides with the general suggestions made for such capacities in France. On the other hand with a high enthalpy source having 50 MW(t) district capacity at peak conditions, the same equation will indicate an L_{max} value of 42 kilometers. Any closed loop system with a distance L shorter than 42 kilometers between the well head (geothermal plant) and the district energy should considered to be techno-economically feasible. The break even point between an open loop and closed loop system in this case will be 42 kilometers.

CASE STUDY

City of Denizli is located in the southwest inland of Anatolia with a population close to 400,000. At Kizildere, which is 19 miles [L=31 km] away from the city center, there has been a geoelectric plant since 1984 with 17 MW(e) design output. Current output is around 10 MW(e). The well head temperature is 414°F [212°C] and the production rate is about 830 ton/h. The existing flash tank delivers 80 ton/h steam. The remaining brine with high Boron content and other chemicals is currently recharged to a nearby river at about 293°F [145°C], without recovering any of the 375 MBtu/h [110 MW(t)] of available geothermal energy. This corresponds to a very low geofluid effectiveness, namely 0.020 MW(t)-h/ton. Obviously, the geothermal system effectiveness is zero (no district application). Drilling of re-injection wells at the vicinity of the existing plant will start in 1996. Two main alternatives were considered for utilizing the waste heat from the existing production wells: an open loop district circuit, and a closed loop/integrated district circuit.

A- Open loop district circuit:

One of the proposals for the Denizli project was an open loop system, which relies on a continuous supply of treated and inhibited water from the nearby Menderes river, at a flow rate of 1275 m^3/h at peak winter conditions, heating it at the plant by the brine, transporting it to the city in a single pipe system, and circulating it in the district piping for heating, absorption cooling, domestic warm water supply, and other low temperature heating applications (Mertoglu, O. et al, 1994). District water will then be discharged to the same river, downstream. Figure 1 shows the anticipated steps of typical geothermal energy recovery in an open loop district system. The peak district thermal delivery is 187 Btu/h [55 MW(t)]. Mainly due to continuous fresh cold water intake, in an open loop system, about 136 MBtu/h [40 MW(t)] power is wasted, at winter peak design conditions. The corresponding geofluid effectiveness in the district from will be 0.077 MW(t)-h/ton.
This approximately corresponds to about 30% loss in the well potential. At summer design conditions, this waste will be about 18 MW(t). The use of an environmentally safer inhibitor generally imposes a temperature limit, which is typically 80°C, and it requires to oversize the space heating and cooling equipment by about 20%, compared to 90°C supply temperature in the district. This reduces the geothermal system effectiveness roughly by the same percentage. If oversizing is not desirable, temperature in the main supply line may be kept below the limit, and then peaked in the district. However, this will not assure the stability of the inhibitor in the entire circuitry.

B- Closed loop/inegrated district circuit

In principle, about 35 MW(t)-peak in winter, and 15 MW(t)-peak in summer can be further recovered by a closed loop-integrated district system, when the associated parasitic losses are encountered. Figure 2 indicates that in fact, an integrated-closed loop system can deliver 304 MBtu/h [89.1 MW(t)] without thermal peaking and an additional 5 MW(e) to the district with a second stage turbine generator set. Accordingly, the geofluid effectiveness in the district will increase to 0.11 MW(t)-h/ton (Eltez, M., and Kilkis, I. B.,1995). With the contributions of ground source heat pumps, the total supply may increase to 355 MBtu/h [104.1 MW(t)]. This corresponds to a geofluid effectiveness of 0.13 MW(t)-h/ton. This is almost double of the geofluid effectiveness of an open loop system. The general outline of the closed loop/integrated system is shown in Figure 3. In this arrangement, the plant and the district energy system will have their own sets of closed loops. At the plant, a secondary flash tank and a turbine-generator at a design capacity of 5 MW(e) will be installed after modifying and upgrading the existing turbine-generator set. A binary system may also be considered. Heat is delivered to the city by a two pipe system.
The return piping is optimized for minimum installation and operation costs by using less thermal insulation and piping of lower cost material, which economically enable to choose larger pipe diameters for minimizing the pumping requirement. A shallow trench will be used for the pipe laying. The system may be operated as an open loop under certain circumstances, like pipe failure in one of the lines. This reminds that an open loop system is a sub-set of a closed loop system.
District circuit is cascaded into four temperature steps:
Cascade 1: In winter, the optimum flow rate in the district closed loop will be1600 ton/h at peak demand, with 203°F [95°C] and 95°F [35°C] supply and return temperatures, respectively. Existing heating units will be operating without retrofitting or temperature peaking (OF:1). Projected power demand at this cascade is 94 MBtu/h [27.6 MW(t)]. Domestic hot water is prepared in plants at sub-district level. Design capacity is 20 MBtu/h [5.8 MW(t)], using 280 ton/h of the district water.
Hot domestic/service water tanks will also establish an

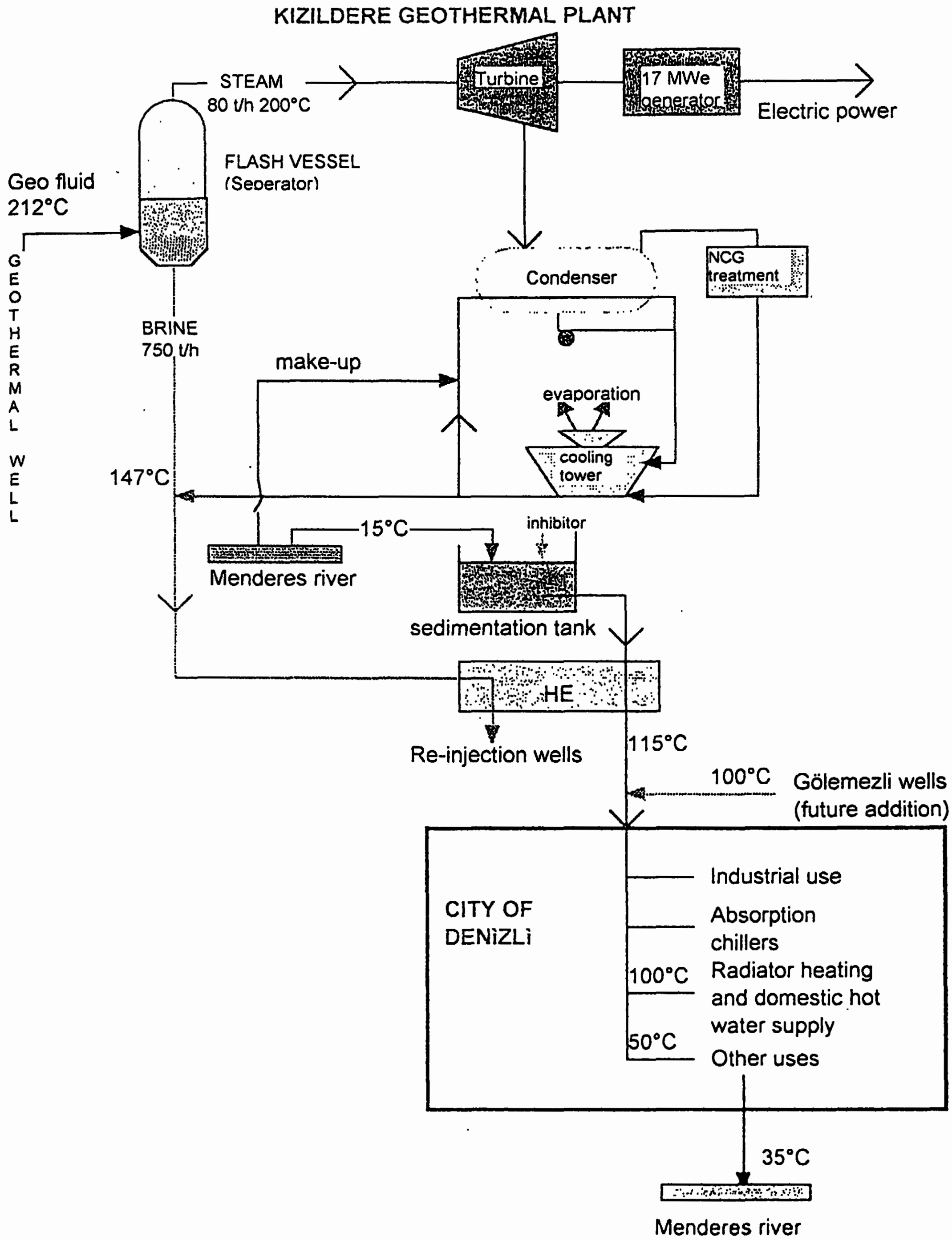

Figure 1. Open Loop Alternative for the City of Denizli.

energy storage medium. In summer, the peak flow rate will be 1000 t/h, and the supply temperature will increase to 240°F [115°C] for an efficient operation of the absorption chillers, which will provide cooling water at sub-district levels. Cold storage tanks will level the peak loads. Reject heat from the absorption chillers will support the hot domestic/service water plant, where the demand is 58 MBtu/h [17 MW(t)] due to peak touristic season. Comfort cooling will be delivered by radiant panel and hybrid HVAC systems.

__Cascade 2:__ In winter, return water from radiators will supply heat to radiant panel/hybrid HVAC systems. These systems will be installed in new buildings, and some of the existing buildings will be retrofitted. There are two

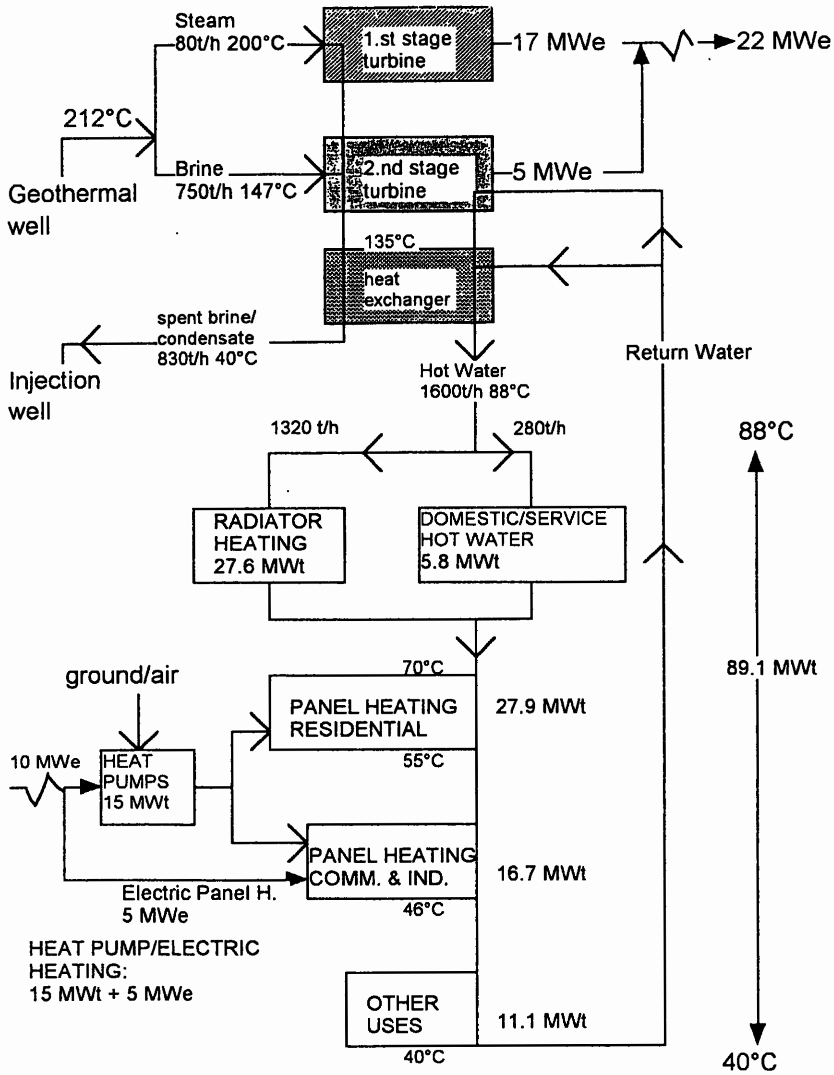

Figure 2. Demand Highlights for the Integrated/Cascaded/Closed Loop Alternative.

sub-cascades. In the 158°F [70°C] to 130°F [55°C] temperature range, the primary target will be residential applications, where the VAC demand is small. Projected geothermal energy consumption is about 95 MBtu/h [27.9 MW(t)], including input from heat pumps.
At remote locations or in spaces where hydronic or forced air heating is not feasible, radiant electric panels will be employed. The second sub-cascade is mainly targeted to commercial and industrial locations between 130°F [55°C] to 115°F [46°C] temperature limits, where panel/hybrid HVAC systems will be dominant. Projected power demand is 57 MBtu/h [16.7 MW(t)]. Ground source heat pumps will consume 5 MW(e) geoelectricity, and will supply 51 MBtu/h [15 MW(t)] heat. In summer, in addition to ground source heat pumps, cold water from the absorption chillers will be delivered to buildings with comfort cooling demand through hybrid and conventional cooling circuits at various sub-district levels.

<u>Cascade 3:</u> Return water from cascade 2 at 115°F [46°C] serves low-temperature applications in the industry, including agriculture and horticulture.

<u>Cascade 4:</u> In this cascade, heat rejected from ground source heat pumps during summer, and any remaining heat in the district return, are seasonally stored in the ground loop through a heat exchanger. The total projected heat supply in cascades 3 and 4 is 38 MBtu/h [11.1 MW(t)]. The district water returns to the plant at 95°F [35°C].

Thermal peaking and back-up heat will be provided by circulating fluidized beds with a total capacity of 68 MBtu/h [20 MW(t)], custom-designed for low-quality

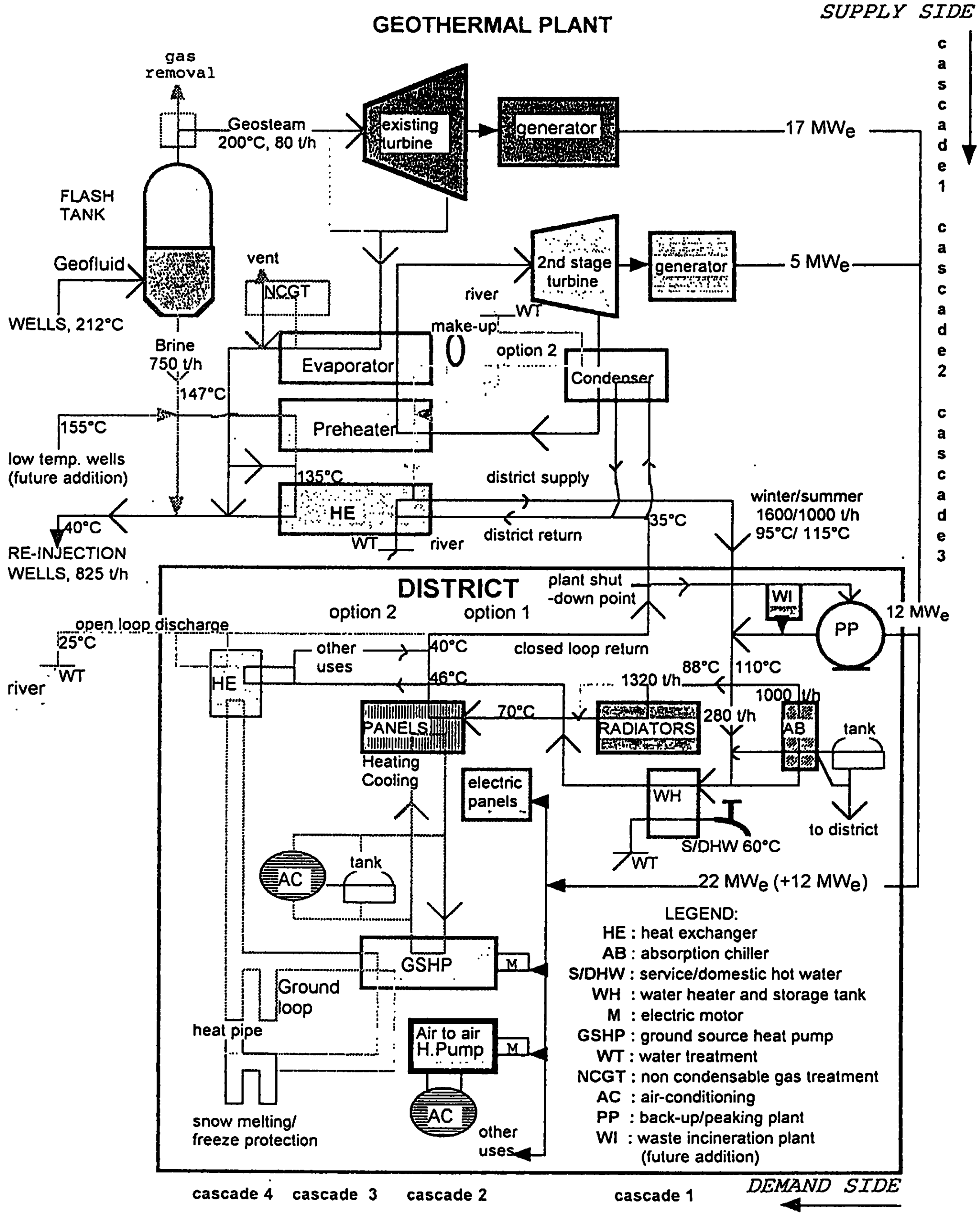

Figure 3. Basic Principles of the Integrated/Cascaded/Closed Loop System.

lignite, which are available in the region. This plant will operate at constant load by continuously varying the output split between district energy and electricity generation. Including the back-up capacity and with an optimum demand side management, the total district heating capacity is expected to be 28,000 residential flats-equivalent.

The annual allocation status of the geothermal energy (peaking is excluded) is shown in Table 1.

RESULTS

A common base installation cost comparison for the same district energy capacity was performed by using estimated costs for items directly attributable to the type of circuitry. Table 2 shows that a closed loop system is indeed feasible and cheaper.

Indeed, Equation 6 shows that a closed loop distance (L) of 31 km in the Denizli project is in the

Table 1. Geothermal Energy Breakdown at Design Conditions (excludes thermal peaking plant)

DEMAND	SYSTEM		SECTOR	WINTER Thermal MW_t	WINTER Electric MW_e	SUMMER Thermal MW_t	SUMMER Electric MW_e
SPACE CONDITIONING	HYDRONIC	PANEL (floor and/or ceiling) t_{supply} =70°C and 55°C	residential	27.9			
			commercial	9.0			see GSHP
			industrial	7.7			
		CONVENTIONAL (radiator, baseboard, convector) t_{supply} = 88°C	residential	15.0			
			commercial	8.0			
			industrial	4.6			
	AIR/HYBRID	ASHP	residential		2.0		2.0
		GSHP	commercial	6.0**	5.0	10.0*	3.0
			industrial	4.0**		7.0*	
		HVAC	commercial		3.0		3.0
			industrial				
	electric panel		all		5.0		
	absorption cooling		all			35.0	10.0
S/DHW	hot water heater		all	5.8		17.0	
	electric		all		4.0		4.0
OTHER	aqua /horticultural heating			2.0	1.0		
	snow melting/ice protection		commercial	2.1	2.0	2.0*	
	greenhousing		agricultural	3.0			
	low temp. process heat		industrial	4.0			
			TOTALS	89.1 + **10 MW_t from ground storage	22.0	71.0	22.0

*to ground storage

feasible domain even with the worst case scenario (n:0.8, and no heat pumps):

$$L_{max} = 0.6 + (89.1)^{0.8} = 37 \text{ km}. \quad (GE = 0.11)$$

At the presence of heat pumps in the district which operate on additional 5MW(e) geoelectricity delivered to the district see Figure 2), L_{max} becomes:

$$L_{max} = 0.6 + (104.1)^{0.8} = 42 \text{ km}. \quad (GE = 0.13)$$

In both cases L is less than L_{max}, and 31 km is techno-economically feasible.

Table 2. Present value attributable cost estimation for open loop and closed loop circuitry for Denizli District Energy Project.

	OPEN LOOP	CLOSED LOOP
PERFORMANCE ITEM		
Geofluid Effectiveness, GE (approximate)	0.077	0.11
Oversize Factor, OF	1.2	1.0
Geothermal System Effectiveness, GSE (approximate)	0.75	0.92
CBUC, $/kW (t)-peak	480	240
COMMON BASE ADDITIONAL COST ITEM	COST (Million US $)	
Return circuitry	----	8.5*
35 MW(t) additional plant (for the same district energy capacity)	10.0**	----
Temperature peaking or oversizing the HVAC equipment (due to inhibitor temperature limit in the supply line)	2.7	----
Continuous fresh water intake/ discharge circuitry*	1.4	0.6 (for filling/make-up only)
Fresh water settlement, filtration, inhibitor treating plant	1.4	----
Sediment reclaim and waste plant	0.5	----
Environment control, monitoring and lab. facilities (according to Int. standards)	0.4	----
TOTAL ADDITIONAL COST	16.4	9.1

* · Includes present value of extra parasitic power costs.

** Includes present value of 30% well potential loss, and inhibitor cost.

DISCUSSION OF RESULTS

Above results indicate that the feasibility of a closed loop system increases with the geofluid effectiveness and the geothermal system effectiveness at a given well thermal output. Higher the geofluid effectiveness, longer is the allowable maximum closed loop distance.
This direct relationship also yields one of the strongest incentives for incorporating more efficient, environmentally safer and high technology district systems, including heat pumps, alternative heating and cooling systems, and equipment. Table 2 shows the capital cost difference attributable to closed loop and open loop alternatives. Including the anticipated capital costs for the district system, for a common base comparison, CBUC for an open loop system will be about 480 $/kW(t)-peak, and CBUC for a closed loop system will be about 240 $/kW(t)-peak power in the district. It is clear that the unit peak power capital cost of a closed loop system will be much less than an open loop system for this example. These figures indicate that a common base unit cost analysis is very important in selecting the type of the loop, and the decision also depends upon the size of the district system, enthalpy of the source and the technical merits incorporated to the district for increasing GE, and GSE, and reducing OF.

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