THE CURRENT GEOTHERMAL EXPORATION AND DEVELOPMENT OF THE GEOTHERMAL FIELD OF MILOS ISLAND IN GREECE

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INTRODUCTION

Milos island is located in the Aegean Volcanic Arc and is characterized by abundant geothermal resources of high temperature. Early geothermal exploration undertaken by the Institute of Geological and Mining Research of Greece, summarized in Fytikas (1977), includes temperature measurements in shallow wells drilled for this purpose and Schlumberger resistivity measurements of subsurface rocks. The results, which are shown in Figure 1, indicate that the eastern part of the island and especially the plain of Zefyria is the region with the highest temperature gradients and lowest apparent resistivities, hence the parts of the island most promising for high enthalpy geothermal potential. Later drilling exploration undertaken by the Public Power Co (PPC) of Greece, summarized in Mendrinos (1988), identified geothermal fluids of temperature 300-323 ºC at depths 800-1400 m below sea level in theZefyria plain. The results of the geochemical exploration financed by the PPC are shown in Figure 2. By examining Figure 2, we conclude that the region of the island most promising for exploitation of shallow, low enthalpy (<100 ºC) geothermal resources, is the one where deep fluids are present in shallow aquifers, namely the east half of the island.

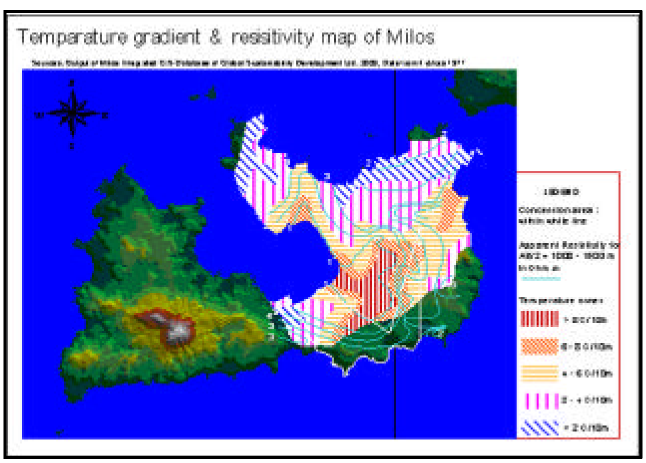

Figure 1.

Mendrinos (1988) performed evaluation of exploration data, well test analysis, resource assessment and computer simulation of the Milos geothermal system and indicated that the deep geothermal fluids correspond to boiled seawater of 80,000 ppm salinity. Mendrinos (1988) also calculated that by cooling the upper 2 km of the hot rocks

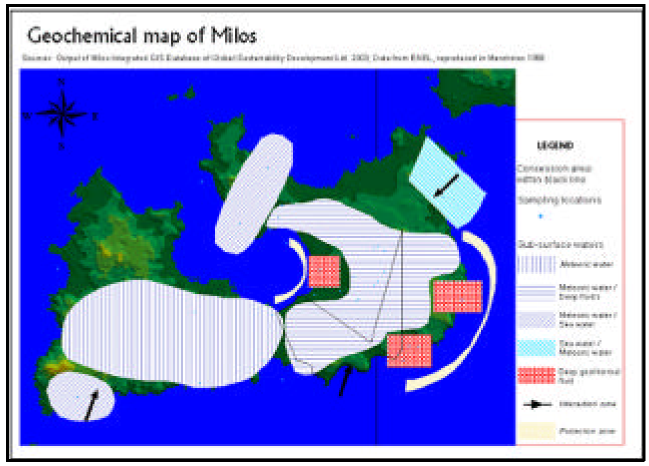

Figure 2.

below Zefyria, Vounalia and Adamas by 90 ºC would release 5 x 10^{18} J of heat (or 141 million TOE), which justifies the commissioning of 260 MWe geothermal power plant. In parallel, the evaluation showed that the minimum heat flow from deeper rocks cannot be less than 87.8 MWth. This value is slightly higher than the natural conductive heat flow towards the surface of the island, which has been estimated as 77 MWth (Mendrinos 1991) due to the convective heat flow component.

The figure of 87.8 MWth was based on small amount of natural convection through the geothermal system, due to the low permeability measured in the deep geothermal wells. Recent drilling in Vounalia, however, performed as part of the MIDES project, showed very high permeability and seawater infiltration to shallow rocks, as described above. This indicates that heat flow from deeper layers should be considerably higher.

THE LOW ENTHALPY GEOTHERMAL UTILIZATION PROJECT FOR ELECTRICITY GENERATION AND SEAWATER DESALINATION

The main objective of our ongoing project is to construct and operate a low enthalpy geothermal energy driven water desalination unit producing 75 to 80 m^3/h drinking water and an ORC power generator unit of installed capacity of 470 kWe on Milos island. The only source of energy is geothermal heat and the unit is anticipated to be entirely self sufficient in thermal energy and to have the potential to become self sufficient in electricity as well. Local community will benefit from the production of clear desalinated water, which will be produced at a very low cost (. 1.5 EURO per m^3) and from the utilization of a sustainable and environmentally friendly energy source, which is low-enthalpy geothermal energy. The amount of water produced will cover completely the needs for drinking water of the island. The project will use geothermal water from the Vounalia concession of Milos SA (Figures 1, 2 and 3) and will have the flow chart shown in Figures 4 and 5.

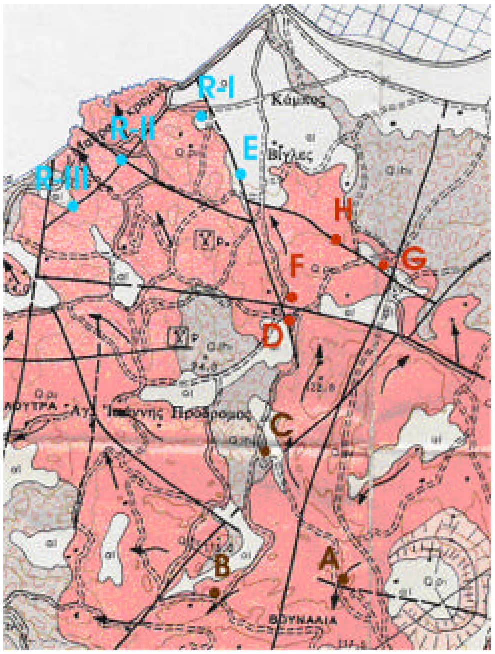

Figure 3.

"Gerling Sustainable Development Project GmbH – GSDP" is the project coordinator. Other project partners are "Milos Company for the exploitation of Renewable Energy Sources and Sustainable Development - Milos SA," the "Municipality of Milos", the "National Centre for Social Research – NCSR," the "Aristotelian University of Thessaloniki - AUTH" and the "Centre for Renewable Energy Sources - CRES." The overall project budget is 4,375,000 Euros, and the project as been partially financed by the European Commission (less than 10% financing through contract NNE5-1999-00041 MIDES project – "Energie" Programme).

GEOTHERMAL EXPLORATION RESULTS

MILOS S.A. a local subsidiary of GERLING SDP has allocated the drilling works to its subcontractor GEOEREVNA; a local contractor specialized in geothermal exploration and exploitation drilling. Well locations were decided in technical meetings between GSDP (Mr. G. Radoglou), AUTH (Prof. Dr. M. Fytikas) and CRES (Dr. C. Karytsas and Mr. D. Mendrinos).

Planning and supervision of drilling works and production testing was implemented by AUTH with the expert advice and assistance of CRES. The GIS database developed by GSDP proved a very effective tool for planning the drilling works. The GIS database includes all existing and documented information about the geology and geothermal potential of Milos. All data is digitalized and the frame is a topographic data package with an analysis of 4-meter height lines density combined with an evaluation of satellite images.

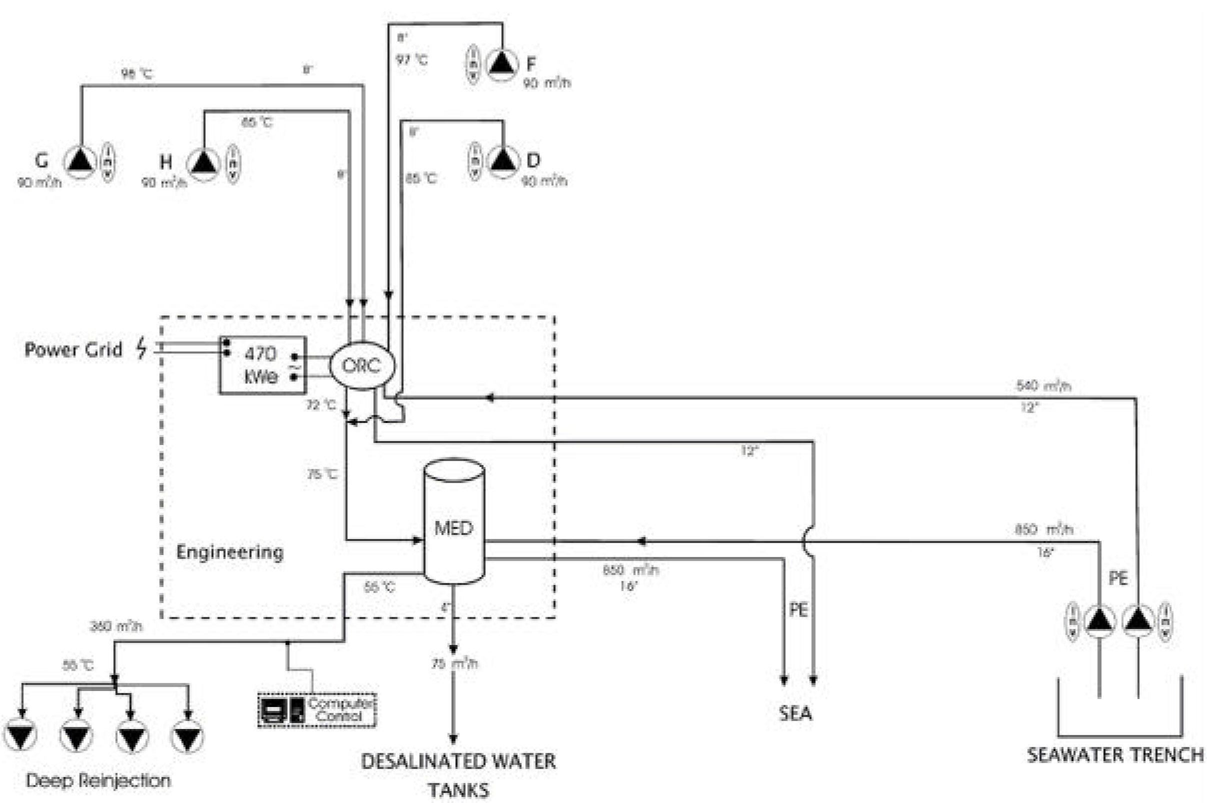

Figure 4.

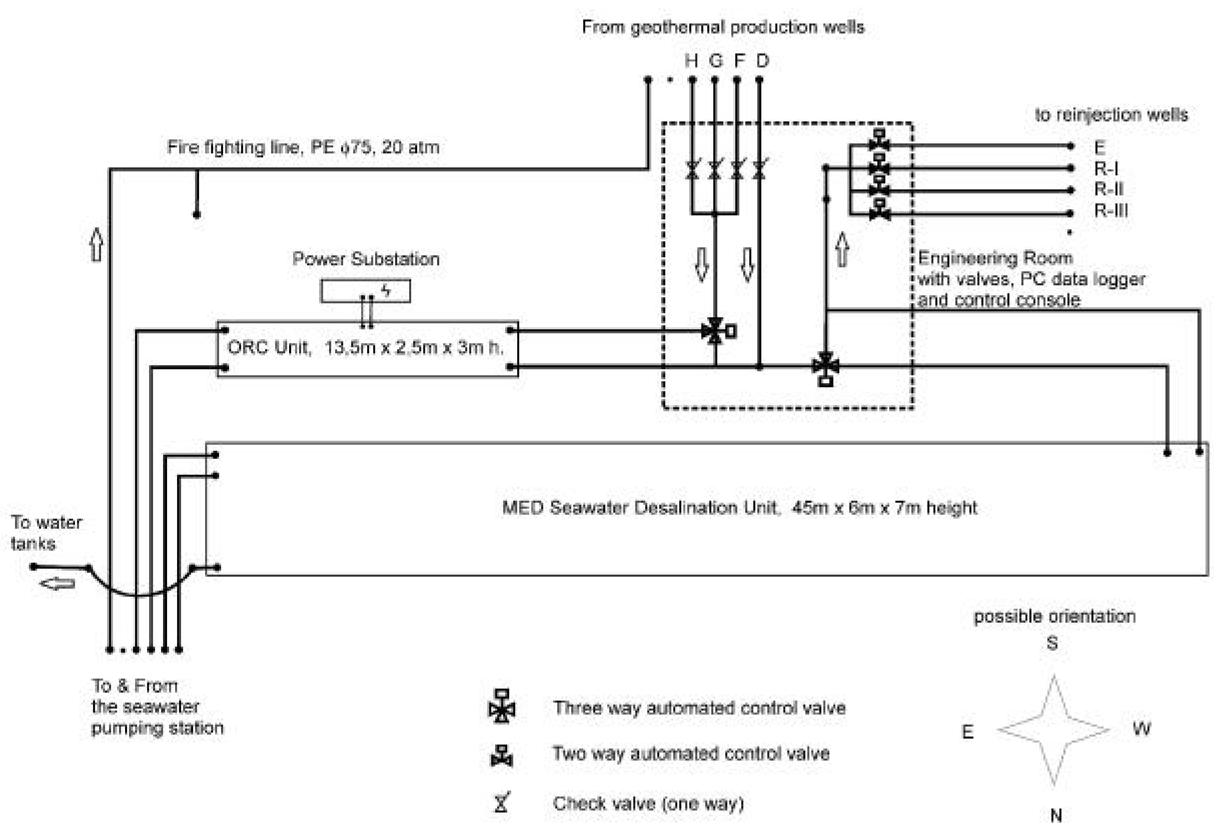

Figure 5.

The exploration area is in Vounalia, within the concession of Milos SA. Production wells, and the topography of the exploration area are shown in Figure 3. All production wells A to H have been completed. Tests performed included air lift, pumping at 3-5 flow rate steps, as well as continuous pumping at high flow rate for at least 48 h. Measurements included temperature profiles versus depth, static water level measurements, as well as water temperature, flow rate and water level during pumping tests.

In parallel, CRES implemented the optimal design study and integrated the engineering study which has led to detailed technical specifications of the entire application and of all necessary equipment.

The results of the production tests are summarised in Table 1, together with the energy potential of each well. Wells A and C are characterized by low flow rates, higher elevation, deep water level, low rock permeability, and temperature 84-100ºC. Wells D, E, F, G and H are characterized by high flow rates, lower elevation, shallower water level and very high rock permeability. In fact, the maximum flow rate they can yield is limited by the horsepower of the pump and the pressure losses of the piping rather than the permeability of the production layers. Production temperature varies from 55ºC (well E), to 99ºC (Well G).

All wells are relatively shallow, with well bottom at 70-185m, and stand with a water level approximately at sea level. With the sole exception of Well E, due to temperature close to the boiling point of water, which resulted in the presence of water vapor on top of the liquid surface due to evaporation, water level measurements were difficult and of questionable accuracy. This can be attributed to the condensation of water vapour directly on the water level sensor. Water samples were also taken and the results of their chemical analysis is shown in Table 2. The chloride content of the water varies between 11,200 and 25,000 ppm, indicating diluted to boiled seawater.

GEOTHERMAL EXPLORATION SCHEME

The geothermal power and desalination plant of the project will comprise the following components (based on CRES's engineering study please also refer to the plant flow chart in Figure 4):

- Geothermal production wells: Production will be derived from the wells located closer to the sea, due to their high energy yield and the corresponding hot water transmission costs. Wells F, D, G and H will produce 300 m^3/h of geothermal water 55-99ºC. Wells A and C will not be used due to their low energy output, their distance from the sea and their elevation, factors that raise considerably the capital costs and electricity needed for the production and transport of the geothermal water.
- Geothermal submersible pumps and inverters installed at the production wells.
- Piping network conveying the geothermal water to the main Plant. Buried steel or fiberglass piping will be used. Closed, pressurized at 10 bars maximum.

Table 1. Summary of Geothermal Well Data in Vounalia, Milos

Well	Well Bottom m	Casing Shoe m	Water Level m	Maximum Flow Rate m^3/h	Water Production Temperature ^oC	Thermal Power MWth ($T_{base} = 25^oC$)
A	150	149	74	20	98	1.70
B	71	67	-	0	-	0.00
C	184	183	86	25	84	1.71
D	158	152	65	100	85	6.97
E	125	122	19	125	55	4.35
F	89	82	54	100	97	8.36
G*	85	82.5	57	100	99	8.59
H*	106	86	35	75	85	5.25
R-I*	102	98	18	85	60	3.45
R-II*	63	61	24	125	50	3.63
R-III*, **	100**	98*	20**	125**		

* Final casing 10", otherwise 8"

** Proposed R-III reinjection well

Table 2. Chemistry of the Produced Geothermal Waters from the Vounalia Geothermal Boreholes

WELL	A	C	D	E	F	R-I
Temperature (^oC)	97	89	85	55	97	60
pH (at 25^oC)	6.86	6.36	6.69	7.75	7.20	7.50
Conductivity (25^oC, mS/cm)	55.1	43.9	25.2	32.8	57.1	69.0
Total hardness (mg $CaCO_3$)	4,800	3,900	1,700	2,510	5,230	5,940
Non-carbonate hardness (mg $CaCO_3$)	4,650	3,850	1,520	2,440	5,160	5,785
Total dissolved solids (g L^{-1})	42.3	33.2	19.0	25.2	43.6	54.1
Density (kg/L, at 15^oC)	1.0288	1.0217	1.0114	1.0160	1.0300	1.0330
(mg/L)	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	
Na^4	12,200	9,400	5,280	7,600	12,600	15,100
K^4	2,620	1,800	1,150	1,370	2,700	3,780
Ca^{2+}	1,515	1,350	725	850	1,520	2,120
Mg^{2+}	192	120	85	94	348	1,560
Fe^{2+}	0.4	30	0.7	0.6	1.1	0.4
Mn^{2+}	19	12	6	6.9	12.9	26.5
Sr^{2+}	23	18	10	14	23	32
Li^4	30	24	14	15	23	33
Zn^{2+}	0.5	5.2	1.2	0.4	3.3	0.3
Cu^{2+}	0.1	0.5	1.2	-	-	-
Pb^{2+}	0.01	0.02	0.07	0.04	0.04	0.04
Cd^{2+}	-	-	-	0.002	0.001	0.002
Ni^{2+}	0	0.015	-	-	-	-
Cr	0	-	-	-	-	-
NH_4^+	6.4	3.1	8.8	4.3	6.2	11

Cl^-	25,125	19,900	11,200	13,700	23,900	30,300
F^-	1.3	0.5	0.9	0.6	0.8	0.5
HCO_3^-	56	59	82	85	90	86
HS^-	-	-	-	-	-	-
SO_4^{2-}	310	275	170	1,350	2,180	850
NO_3^-	0.8	1.3	3.1	1	1.2	0.8
NO_2^-	0.04	0.4	0.01	0.5	0.7	0.01
PO_4^{3-}	-	-	-	-	-	0
SiO_2	158	202	162	104	138	142
As	0.12	0.03	-	0.02	0.03	0.05
B	28.0	25.1	11.4	14.0	25.6	30.3

- Power and data transmission lines from the main plant to the wells.
- ORC unit, transforming approximately 7% of geothermal energy to electricity designed to generate approximately 470 kWe.
- MED-TVC seawater desalination unit providing 75-80 m³/h desalinated water.
- Main heat exchanger, transferring the energy from the hot geothermal water exiting the ORC unit to the MED-TVC desalination unit.
- Reinjection wells (RE I and II) located at the margin of the geothermal field, close to the coast, downstream and at lower elevation of the main Plant, in order to minimize water transmission costs and avoid disturbing the hot part of the geothermal aquifer, well E will also operate as a reinjection well, due to its low well-head temperature (only 55 °C).
- Geothermal water transmission lines from the main heat exchanger to the reinjection wells: buried steel or fiberglass piping, closed pressurized system at 10 bars maximum, no extra pumping.
- Seawater transmission lines conveying 1000 m³/h cooling seawater to the MED-TVC unit plus 200-575 m³/h cooling water for the ORC unit: Buried polyethylene piping, seawater intake and disposal from a trench close to the sea line, pumping station close to the intake point.
- Desalinated water transmission line from the plant to the water tanks near the town of Adamas: Buried polyethylene piping.
- Power substation for power provision or delivery to the local power net: 500 kWe.
- Main computer monitoring and control system for real time data logging and automation control.

Until now, drilling of production and reinjection wells has been completed. Construction works for the piping networks, the ORC power plant, the desalination plant and the electro-mechanical equipment, are expected to commence shortly.

CONCLUSIONS

The ongoing Milos low enthalpy geothermal energy utilization project, demonstrates that through the innovative and sustainable utilization of low enthalpy geothermal energy for electricity generation and seawater desalination in Milos, it can substantially contribute to the local water needs. It is sustainable, as it will use only a minimal fraction of the available geothermal potential. It can cover local water demand, as production wells drilled in Vounalia can provide the necessary energy quantity for the seawater desalination plant.

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