INTERNATIONAL SUMMER SCHOOL
on Direct Application of Geothermal Energy

Under the auspice of the
Division of Earth Sciences

GEOTHERMAL APPLICATIONS IN GREECE WITH EMPHASIS ON THE AEGEAN ISLANDS

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Abstract

Geothermal energy is a clean and r*eliable energy resource, capable of partially contributing to the energy needs of the world. Geothermal energy is available in most parts of Greece and, especially, in many Aegean Islands, although this potential has not so far exploited adequately. This paper reviews the current status of utilisation activities in Greece, with special emphasis placed on the current and potential applications in the Aegean region. The possibilities of geothermal development in the Aegean include, apart from the classical uses of geothermal heating and balneology, water desalination, fruit and vegetable dehydration and fish farming. Geothermal desalination appears to be an attractive way to tackle part of the pressing problem of water shortage in several Aegean islands.*

1. INTRODUCTION

Geothermal energy is known from antiquity and has been used for centuries for bathing, cooking or even heating. However, large-scale geothermal utilisation started almost 100 years ago. The geothermal uses are usually divided into two categories: in electrical uses, i.e. the production of electrical power, and in direct uses. The electrical uses are limited to fluid temperatures above 100ºC; the utilisation of fluids with temperatures lower than 150ºC is only possible with a 'binary" power plant. The high-temperature fluids for conventional electricity generation are confined in certain areas on earth associated with seismic and magmatic activity and young volcanism (e.g. California, Iceland, Larderello-Italy and in the active volcanic arc in the Aegean). On the other hand, low-temperature regions are more widespread and can be found in most countries. There is an abundance of applications of low- and moderate temperature geothermal energy as listed in the Lindal table (Lindal, 1970). In some cases, the geothermal water cannot be used directly, because of the problems of scaling and/or corrosion and a heat exchanger is used to convey the heat to a working fluid. Low-temperature geothermal waters (typically less than 40ºC) or geothermal effluents from cascade use can be also exploited using heat pumps. The utilisation of geothermal energy in principle employs known technology, borrowed mainly from the oil (e.g. drilling technology, scale and corrosion control), domestic and power sectors. However, in some cases high contents of dissolved solids and/or gases in the geothermal fluid may cause additional technical and environmental problems.

Geothermal energy is considered a sustainable energy resource, capable of providing a small, but significant, part of world energy needs, especially on a local basis. The geothermal resources are enormous and improving technology will allow geothermal energy to be more active in the near future. Provided that it is pro-perly implemented, geothermal energy is a sustainable resource and benign to the environment. In general, the use of geothermal energy reduces emission of greenhouse gases, since the emission of these gases from geothermal plants is an order of magnitude lower than that from burning fossil fuels. The efficient removal of hydrogen sulphide from high-temperature steam and the reinjection of spent geothermal waters reduce significantly any potential negative environmental impact of geothermal energy.

Greece is rich in geothermal energy. In particular, in the Aegean islands and coastal areas there are abundant easily accessible geothermal resources reaching almost 100ºC. Despite all these geothermal resources, the degree of geothermal energy utilisation in Greece is rather poor. A review of the geothermal potential of Greece can be found in Fytikas (1987) and Fytikas et al (2000). Fytikas (2002) discusses in particular the origin and the characteristics of the geothermal resources in the Aegean region. Islands with low and moderate temperature geothermal resources include Milos, Santorini, Kimolos, Kos, Nisyros, Evia, Chios, Lesvos and Samothraki.

The scope of this paper is two-fold: first, to present the developments in geothermal activities during the past three hears (a review of geothermal applications in 1999 in Greece can be found in Fytikas et al., 2000), and, second, to examine the potential uses of geothermal energy in the Aegean islands.

2. GEOTHERMAL APPLICATIONS IN GREECE

Greenhouse and soil heating are the major applications of geothermal energy in Greece, although the last three years a noteworthy diversification has been taken place. The developments in geothermal application with emphasis on the Aegean area and in comparison with those presented in Fytikas et al (2000) can be summarized as follows:

1) *Greenhouse and soil heating*. The developments include the construction of 4.6 ha of new geothermal greenhouses in Polichnitos (Lesvos Island), Nea Apollonia and Nigrita. In addition, the greenhouse unit in Nea Kessani started again operation last year after being dormant for several years. No major developments occurred in the area of soil heating aiming (currently 12 ha) exclusively in the out-of-season asparagus cultivation, although several small-scale projects are in the stage of implementation. The combined area of greenhouse and soil geothermal heating in Greece is about 35 ha.

The pumping and heating methods of the geothermal greenhouse and soil heating installations in Greece are illustrated in Figures 1 and 2. Almost 80% of the heating systems are of direct heat use by employing finned metallic tubes, plastic polyethylene 'bags' having diameter of ~0.2 m, placed on the ground and used only in one cultivating period, and corrugated polypropylene (PP) pipes of o.d. 28 mm (buried, on ground or aerial). The PP pipes last between 3 and 7 cultivating periods. Fan heaters are used when the water temperature exceeds 60ºC; in all cases this heating method is combined with direct heating with PP pipes in a cascading use. The use of plate heat exchangers is limited to about 11% of the total greenhouse area. Most geothermal waters for greenhouse heating are transported over distances less than 500 m, although a distance of 2500 m is reported in Geras, Lesvos. Almost 80% of transportation pipes are of PVC and are uninsulated. The vast majority (>70%) of the geothermal waters used in greenhouse and soil heating has a temperature less than 50ºC. The main reason for this is the easiest handling and the better quality of the low temperature waters. Finally, reinjection of the geothermal waters is practiced only in 20% of the installations, but this percentage is increasing over the last few years.

2) *Space heating*. There are not any new developments in this sector. The use of geothermal energy for space heating is practiced only in a spa complex in Traianoupoli, Thrace and in several houses.

3) *Aquaculture.* Last winter the first use of geothermal water in aquaculture was practiced in Porto Lagos for anti-frost protection/heating of artificial ponds. The water came from two new production wells in the South-East of Nea Kessani geothermal field with a water temperature of 38ºC. The installed thermal capacity of the installation is 2 MWt. The use of geothermal energy in this fish farm averted the severe damage of the fish stock occurred in other farms of the region during the heavy frosts of last winter.

4) *Bathing and balneology*. There is no any systematic study of the use of geothermal energy in spas and bathing. A conservative estimate (assuming the water leaving the bathing centers has a tem-

perature of 30ºC) of the total thermal capacity of the Greek spa resorts is 35 MWt, with a load factor of 0.15 (Fytikas et al, 2000).

5) *Agricultural drying.* A tomato dehydration unit has been established in N. Erasmio, 25 km south of Xanthi, and produced “sun-dried” tomatoes (Andritsos et al, 2002). The unit uses low cost geothermal water to heat atmospheric air to 55°C in finned tube air heater coils. During its first year of operation 4 tn of high quality dried tomatoes were produced.

6) *Water desalination*. A geothermal desalination plant has been completed last year and tested in Kimolos Island. More details can be found in the following chapter.

7) *Other direct uses*. Another geothermal application practiced in Greece the last 5 years involves the cultivation of spirulina (green-blue algae) in temperature-controlled ponds in Therma-Nigrita utilizing both the geothermal heat and the dissolved CO_2 in the geothermal water. The plant has a capacity of producing about 2000 kg of dried spiroulina.

8) *Geothermal Heat Pumps*. Apart from the three small heat pump systems reported in Fytikas et al (2000) a new project has been recently completed dealing with the heating and cooling of the Mining and Electrical Engineering Building of the National Technical University in Athens.

Table 1 presents the thermal capacity of direct use systems in operation in Greece. The total installed thermal capacity in 2002 reached 69 MWt, up about 20% of the capacity reported for 1999 (Fytikas et al, 2000).

3. POTENTIAL GEOTHERMAL APPLICATIONS IN THE AEGEAN ISLANDS

The prospects of using geothermal energy in a variety of applications in the wider region of Aegean Sea appears to be large due to the enormous geothermal potential of the region. Some drawbacks in this development is the large discrepancy in energy demand between summer (due to tourism) and winter, the relative isolation of some islands that makes almost impossible the electricity transmission and increases the transportation cost of greenhouse products, the aggressiveness of some geothermal fluids (very saline waters in Kimolos, Samothraki, Sousaki, Methana and Aedipsos and dissolved H_2S in Sousaki and Methana) and, finally, the mild weather conditions of most islands rich with geothermal energy.

The new uses or the expansion of current geothermal applications in the island areas of Greece can be summarised as follows:

1) *Greenhouse and soil heating*. There are 7.5 ha of geothermal greenhouses in Lesvos (Polychnitos and Geras), Milos and Nisyros Islands with an installed capacity of ~8 MWt. Table 2 presents the greenhouse installations in the Aegean islands and in some coastal areas. Other information presented in the table includes: greenhouse area, covering material (glass or plastic), heating method and percentage of heating needs covered by geothermal energy. Some problems encountered during operation and comments on the installation are also included. The potential of expanding greenhouse geothermal heating is rather greater in the colder islands of Northern Aegean (Lesvos, Chios and Samothraki) as well as in Evia Island. In Lesvos Island, apart from the Polichnitos geothermal field, other locations for possible greenhouse and soil heating are Argennos, Stipsi-Kalloni and Lisvori, where a geothermal greenhouse was in operation several years ago.

2. *Space heating including DHE.* District heating is rather difficult to be implemented in because of the way the houses are built in Greece and of cultural reasons. It has been suggested the use of geothermal energy for heating the district of Sousaki, but the high content of the fluids in dissolved solids and gases (and especially H_2S, Andritsos et al, 1994) makes the project rather costly. Individual houses and residential buildings can be heated by geothermal energy, especially in Northern Aegean. In an interesting example, the heating needs of a house in Milos are provided by the recirculation (by natural convection) of ‘clean’ water through a “downhole heat exchanger” (DHE). The system consists of a metallic U-tube submerged in a swallow (20 m) geothermal well with 60ºC water, which is directly connected to house radiators. The DHE eliminates the need of the geothermal fluid disposal, which may be costly in small systems. The method uses a system of pipes placed inside a well and a working

fluid (usually 'clean' water) is pumped through the pipes or allowed to circulate by natural convection to extract heat from the well water. The warm fluid then passes through the house heating system. A schematic of a simple DHE system is presented in Figure 3. In general it can be applied in cases where shallow wells (10-50 m) contain hot water. These areas are not many (e.g. Klamath Falls - USA, New Zealand), but some Greek islands satisfy this criterion (Milos, Kimolos, Santorini and even Lesvos).

3) *Aquaculture.* The potential of using geothermal energy for fish farming appears to be significant especially in the islands and the coastal areas of Northern Aegean Sea and especially in Lesvos, where several fish farms are in operation.

4) *Bathing and balneology.* Thermal spas and bathing centres operate at 56 locations in Greece, almost half of which are located in coastal or island areas. Twelve spas are in operation in the Aegean islands. In the 90's new bathing complexes were constructed or (e.g. in Kyllini, Polichnitos, Kythnos), while others were expanded or renovated (e.g. Aedipsos, Sidirokastro). Certain swimming pools are also heated by geothermal fluid (Aedipsos-Evia island, Aridea). There is large potential in expanding the number of spa facilities in the Aegean region and in using geothermal water to heat swimming pools.

5) *Agricultural drying.* Drying or dehydration of fruits and vegetable under the sun is a traditional method for food preservation in Greek islands. Low- and moderate temperature geothermal energy can be efficiently used in fruit and vegetable dehydration and can be partially substitute the traditional 'sun-drying' process. Recently, it has been demonstrated in Thrace that geothermal energy can be successfully used in drying tomatoes (Andritsos et al, 2002). Geothermal drying can reduce some of the quality problems of the dried products associated sun-drying, like dust and insect contamination and enzymic activities. Geothermal water, with temperature as low as 55ºC, can be used to heat atmospheric air in finned tube air heater coils. In case that the geothermal water is corrosive, as is usually the case with the saline geothermal waters encountered in the Aegean region, a second water-water heat exchanger may be required. Cherry-tomato is almost the only agricultural products that can be dehydrated in Cyclades islands (Santorini, Milos). On the other hand, in the islands of Northern Aegean with richer crop production several crops can be dried: peppers, onions, apricots, figs and prunes.

6) *Water desalination*. Desalination technology has been available for decades. Two are the most important technologies: thermal desalination and membrane desalination (mainly reverse osmosis). The former is employed for large seawater desalination, especially in countries and industries with low fuel cost. Two refineries in Greece, in Aspropyrgos and Thessaloniki, apply this technology for brine water desalination. In general, the thermal technologies for seawater desalination systems are the multistage flash distillation (MSF) process and the multiple effect distillation (MED). Membrane technology has been used widely during the recent years for small or large systems. In the Aegean Sea there are numerous islands facing severe problems of water supply. Water needs are partially covered by wells, small dams, collection of rain and ship transportation. There are reverse osmosis membrane desalination plants in several islands (e.g. Syros and Myconos), but several hotel businesses have also installed desalination units. The major drawback of both desalination technologies is the large energy requirements in the form of oil or electricity. The large amounts of energy required for the desalination process is opening the way to the use of other energy resources, among them geothermal energy, in the Greek Islands.

Two desalination projects have recently commenced in the islands of Kimolos and Milos. The Kimolos project has been completed last year and a detailed description can be found in Karytsas et al (2002). The Milos project is implemented through a THERMIE programme and it is in the stage of well drilling. Both plants use a MED process and utilise (or will utilise) low enthalpy water (60-100ºC) from shallow bores (50-200 m). In a MED geothermal plant, a stream of geothermally heated seawater flows through a low-pressure vessel containing several chambers or stages, each operating at a slightly lower pressure than the previous one. As the seawater enters each stage, a portion of it “flashes” into steam and is then condensed to produce a pure distillate product, which is pumped into the fresh-water tank. The concentrated brine remaining at the end of the process is rejected to the sea. A schematic of the process is shown in Figure 1.

7) *Geothermal Heat Pumps*. Recently a geothermal heat pump (GHP) system was installed in a municipal building in Rhodes city (140 kW rated power), used for both heating and cooling. In addition, a heat pump (coupled with ground heat storage uniformly distributed below the building basement) is in operation for heating and cooling an office building of 6000 m^2 by utilising the warm water (36ºC) of a nearby well. The heat pump rating is 220 kW. The GHP are similar to ordinary air-conditioners and heat pumps, but it utilises the ground instead of the outside air to provide air-conditioning, heating and hot water. There are several types of GHP systems. The most common type is the earth-coupled GHP (Figure 5), which uses sealed vertical or horizontal pipes as heat exchanger through which water is circulated to transfer heat from the ground to the house. In the second type, the groundwater type (Figure 6), the heat pump extracts heat from the water produced in a shallow well. The mild climatic conditions prevailing in most island and coastal areas in Greece seem to make rather uneconomical at a first glance the investment in such units, although the combination of the system with air-conditioning using seawater may turn out to be attractive.

8) *Electric Power generation.* It is well known that a double-flash 2 MWe power plant was installed in 1985 in Milos and operated intermittently till 1989, when it was shut down due to technical problems and environmental protests due to H_2S emission to the atmosphere. It is noted that by using common technology, the hydrogen sulphide could be efficiently abated from the geothermal gases. Because of the unfortunate fate of the Milos electrical plant, a renewal of interest for power generation in Milos and Nisiros in flash cycle units is not probable. On the other hand, the installation of small binary Organic Rankine Cycle (ORC) units cannot be excluded. During the past three years the Public Power Corporation has started exploratory work towards the installation of a binary ORC unit in the island of Lesvos. The construction of a small binary unit is also scheduled for construction to supply electricity for the Milos desalination plant. In a binary system the geothermal water is passed through a heat exchanger, as shown in Figure 7, where its heat is transferred into a second (binary) liquid, such as isopentane, freon, ammonia or pentane, that boils at a lower temperature than water. When heated, the binary liquid flashes to vapour, which, like steam, expands across and spins the turbine blades. The vapour is then recondensed to a liquid and is reused repeatedly. In this closed loop cycle, there are no emissions to the air. The potential for electrical generation using ORC units in several Aegean islands (Milos, Nisyros, Lesvos and possibly Chios) is large and a preliminary estimate is ~20 MWe. The substitution of fossil fuel derived electric power by a “green” power from ORC units, which may be located away from the coast, will undoubtedly have a positive impact on the environment (reduction of CO_2, NO_x and CO emission), will reduce the noise associated with conventional power plants and avert possible oil spill during oil shipment.

4. CONCLUDING REMARKS

In conclusion, the geothermal potential of Greece and especially of the Aegean Islands is big and the prospects are good, although due to technical and economic constraints the degree of exploitation is so far very limited. Most of these highly touristic islands face a significant water shortage, especially during summer time,with possible negative impact on tourism. Geothermal desalination appears to be an attractive way to tackle part of the pressing problem of water shortage in several Aegean islands (mainly in Milos, Nisyros, Santorini, but also in Lesvos and Chios). Greenhouse and soil heating can be expanded in Lesvos, the island with the most geothermal greenhouses, and new geothermal greenhouses can be established in Nenita (Chios) and in Therma (Samothraki). Another interesting geothermal application seems to be the geothermal dehydration of some traditionally sun-dried vegetables and fruits, such as cherry-tomatoes, apricots, figs and prunes. “Green” electric power from modular binary ORC units can be produced not only for the needs of the desalination plants, but also for the needs of the islands in a environmentally benign way with the reduction of noise and the elimination of greenhouse gases and of the risk of oil spills. In all touristic places there is also the possibility of using geothermal heat pumps (or in favourable areas downhole heat exchangers) for heating in the winter, coupled with the possibility of using seawater for air-conditioning in the summer. Finally, the extension of bathing period in almost all spa resorts is possible by using geothermal fluids directly or indirectly for space heating and heating of open or closed swimming pools.

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Table 1. Summary of the geothermal direct uses in Greece in 2002.

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr = 10^{12} J/yr)	Capacity Factor
Space Heating	1.15	13.3	0.37
Greenhouse Heating	27.8	265	0.32
Fish and Animal Farming	2.0	9.2	0.15
Agricultural Drying	0.15	1.0	0.20
Bathing and Swimming	35*	164*	0.15*
Water Desalination	1.8		
Other Uses [1]	0.4	4.1	0.32
Geothermal Heat Pumps	1.0	7.2	0.25
TOTAL	69.3	464	0.23

* conservative estimate, [1] spirulina production

Table 2. Geothermal greenhouses (and soil heating units) in the Aegean islands and coastal areas in 2002.

Location	Covered area, ha (type)	Inlet/outlet temper. (°C)	Flow rate (L/s)	Cultivation	Heating method	% cover of heating needs	Problems-comments
N. Erasmio, Xanthi	7.7 (P)	60/30	17	Asparagus	Soil heating with PP	100	- no corrosion/scaling - small heat pump and house & pool heating
Polichnitos, Lesvos	6.0 (P)	80/35	17	Vegetables	Fan coils+ PP	100	- corrosion problems
Geras, Lesvos	0.4 (P)	38/25	6	Vegetables	PP	100	- water transportation 2500 m
Milos	0.55 (P)	46/24	3	Vegetables	PP	100	- limited water
N. Kessani, Xanthi	0.2 (P), 0.4 (G)	72/40	15	Vegetables	Fan coils + PP	100	- $CaCO_3$ scale problems, needs scale inhibitors
Lisvori, Lesvos	0.45 (P)	70/-	-	-	Fan coils + PP	-	-out of operation, corrosion problems
Nisyros	0.05 (P)	50/-	-	-	Plastic bags	-	-out of operation

(G) Glass covered, (P) plastic covered, plastic bags, PP: direct heating using plastic bags and polypropylene corrugated pipes, respectively.

Figure 1. Percentage distribution of the pumping methods of geothermal fluids (total flow rate 250 kg/s).

Figure 2. Percentage distribution of the heating systems of geothermal greenhouses (including soil heating, total covered area 35 ha).

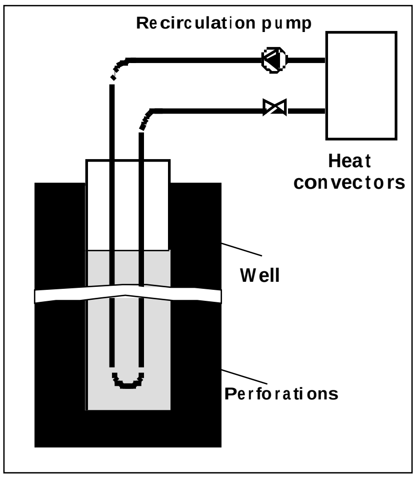

Figure 3. Schematic of a simple DHE system.

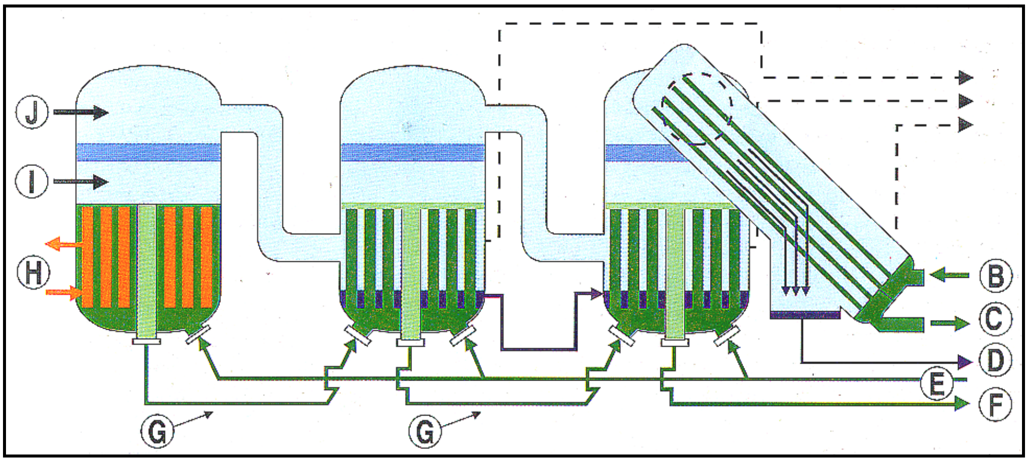

Figure 4. Schematic of a multiple effect distillation process. A: Vacuum chamber. B and C: inlet and outlet of cooling seawater. D: distillate product. E: feed seawater. F: brine outlet. G: heat recovery from the brine. H: condensate steam. J: dry steam.

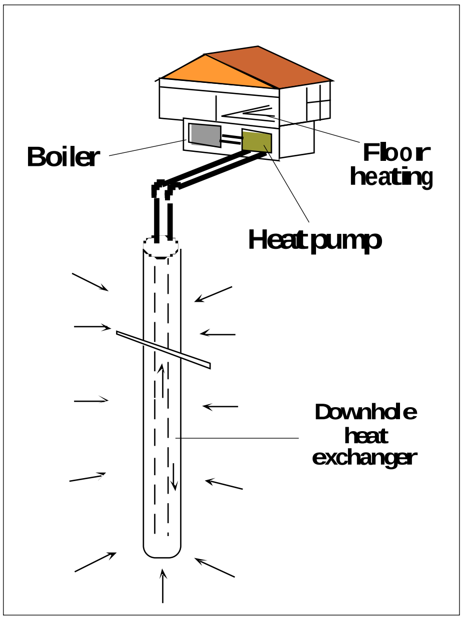

Figure **5.** Schematic of a GHP system using a downhole heat exchanger (coaxial double plastic pipe).

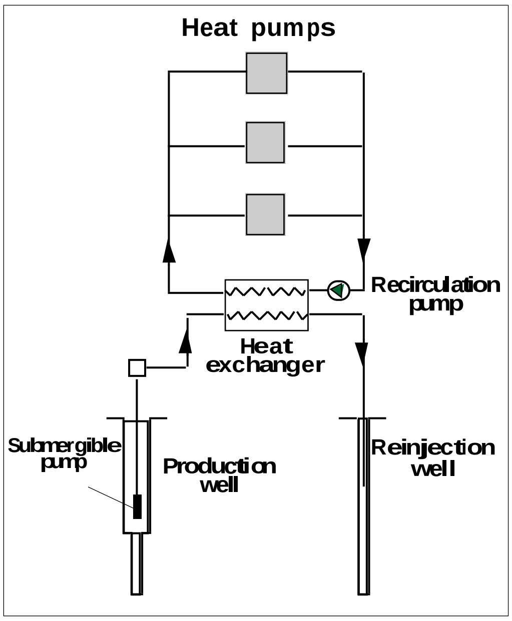

Figure 6. Schematic of a GHP system using underground water.

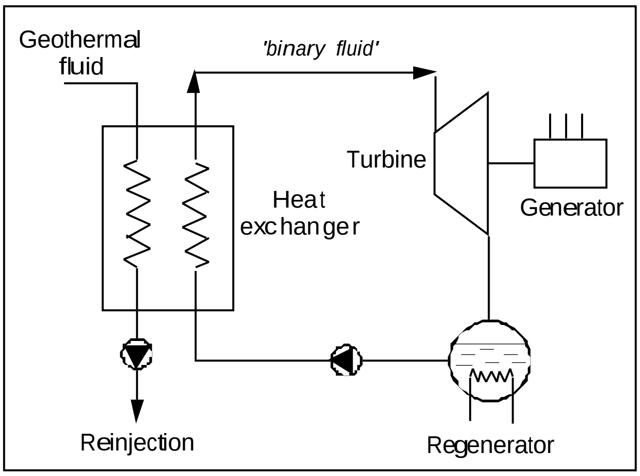

Figure 6. Schematic of the organic cycle power production process.