Solar Steam Booster in the Ahuachapán Geothermal Field

Y. Alvarenga, S. Handal, and M. Recinos

LaGeo, S.A. de C.V. El Salvador, Central América

Keywords

Ahuachapán Geothermal Field, direct solar radiation, heat exchanger, heat transfer fluid, pyrheliometer, steam generator, solar collectors, solar field, solar steam booster, thermosolar-geothermal hybrid system

ABSTRACT

A thermosolar R&D project of 2 phases, sponsored by LaGeo, started in 2007. The first phase was presented in the GRC 2007, developing the solar to thermal conversion. The second phase, boosting geothermal power, is described in this paper.

By concentrating solar energy into a prototype array of parabolic mirrors, dry steam has been gained from separated geothermal water at well head conditions in the Ahuachapán geothermal field. A 160m^2 thermosolar-geothermal hybrid system has produced 0.1 Kg/s of steam, with 99.8% quality at 4.4 bar-g and 154°C well head conditions. A solar field 300m x 400m size, running from 9 a.m. to 5 p.m., could produce 5.8 kg/s of steam, equivalent to 2.5 MWe from a turbine 4.4 bar-g inlet steam pressure.

Introduction

The constant increment in the demand of energy and the high prices of fuels as well as the air pollution due to greenhouse gasses are enough reasons to move on the exploitation of renewable and non-conventional energy sources. These untapped energy sources such as geothermal, solar, wind, hydro, etc. are simply the energies of the future. Consequently, LaGeo has acquired the commitment of researching and developing projects focusing on non-conventional energy sources with emphasis in the exploitation of solar energy because of the high solar radiation available in El Salvador. By installing a commercial thermosolar-geothermal hybrid system it is possible to boost the output power of the current geothermal facilities.

This paper summarizes the process of gaining steam by operating a prototype, consisting of a couple of Solar Collectors (SC) and a steam generator, both developed in the Ahuachapán geothermal field since March 2007. It is demonstrated that dry steam, able to drive an available turbine, is produced by boiling separated geothermal liquid at a constant pressure into the steam generator fed by a heat transfer fluid (HTF) heated by the SC. This thermosolar-geothermal hybrid system can boost the current output power of any geothermal facility located on the sun-belt region of the Earth.

The Ahuachapán Geothermal Field

The Ahuachapán geothermal field is located in the western part of El Salvador, Central America, and 100 Km apart from San Salvador, the capital city, as shown in Figure 1. Due to its

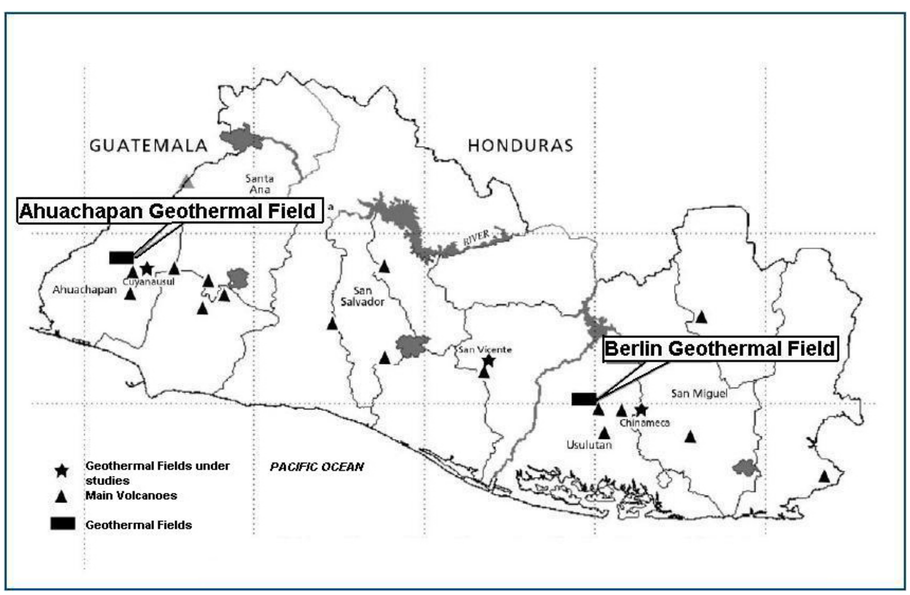

Figure 1. Location of the Ahuachapán geothermal field.

low latitude, 13.9º N, this area receives considerable solar irradiation year round, especially in the dry season, which goes from November to April. The average annual direct solar energy received in this area is approximately 60% of the amount received in Barstow, California[1] and 95% of the amount received in Almería, Spain[2], where large commercial solar power plants are being built.

The reservoir temperature in the main exploitation area is 225°C. For most of the wells, mixed fluids at well head conditions are 4-7 barg, 154-160°C and 15-20% of mass steam fraction. Mass flow production averages 45 and 10 kg/s of water and steam, respectively. Ahuachapán geothermal field is a double flash system. First fluid separation is in the range 4-7 barg medium pressure (MP) and steam factor consumption is 2.3 $Kg.s^{-1}$/MWe. Liquid separated flashes into a boiler system at 0.6 barg low pressure (LP) and 8.8% separation efficiency. Consumption factor for LP steam is 4.2 $Kg.s^{-1}$/MWe. Current gross and net generations are 83 MWe and 77 MWe. Approximately 593 kg/s of water leaving the flashers are pumped at 8.6 barg and reinjected into a neighbor field (Chipilapa) located 5 km away of the reservoir to avoid cooling effects and sustain a reservoir pressure above 18 bar. Besides, 50 kg/s of waste water (condensed steam from cooling tower) is pumped and reinjected into Chipilapa area[3].

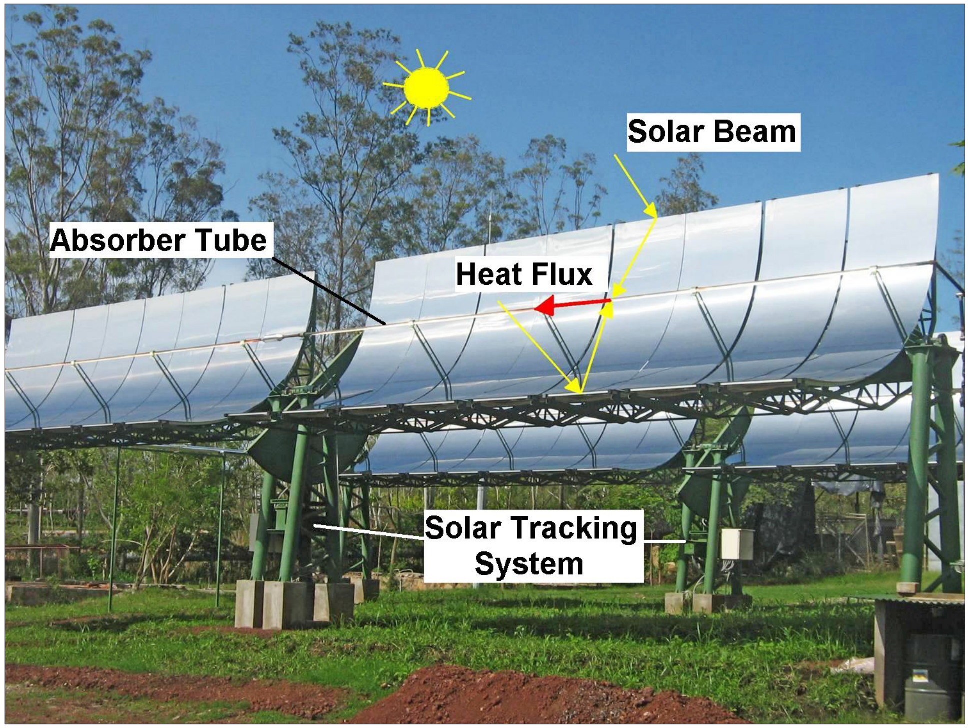

Figure 3. Picture and optical working principle of the SC.

The Pilot Thermosolar Project

The pilot thermosolar project is located at the platform of the AH-6 geothermal well. The cyclonic separator of this well (see Figure 2) operates at medium pressure of 4.6 barg (67 psig) and 154 ºC, producing 2.8 Kg/s of separated water and 9.1 Kg/s of steam. The steam is conducted to the medium pressure steam turbines. The separated water travels to the flasher tanks, where the pressure falls down until a lower pressure of 0.6 barg, producing 0.24 Kg/s of steam. This steam is sent to the low pressure steam turbines, while the residual water at 115 ºC is pumped to re-injection wells.

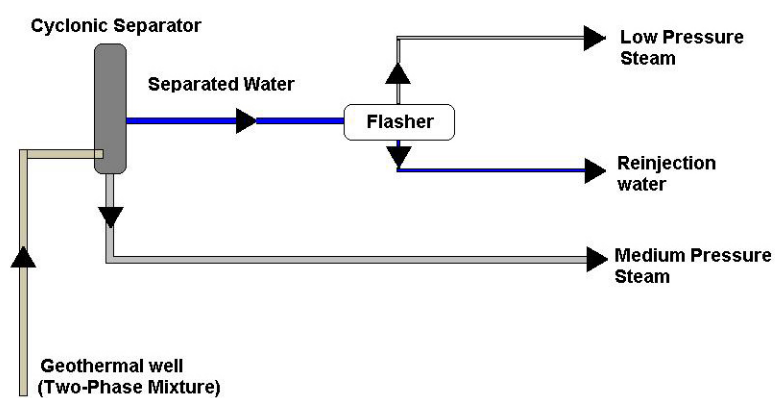

Figure 2. The AH-6 well connections.

The Pilot thermosolar project consists of two SC, which concentrate the solar irradiation into an absorber pipe due to both its parabolic shape and solar tracking system. As shown in Figure 3, the irradiation is concentrated in the linear focus of the parabola provided that it is well positioned towards the solar disc. The solar tracking system positions the SC to the appropriate angle from 8 a.m. to 4 p.m. period of time with higher solar irradiation. Design and construction of all the system, including solar tracker system, was done locally, even though there are several companies that offer these services, like FLABEG, Solel, Schott, Solar Millennium, etc.

The solar field is compounded by the 2 SC, which are 4m wide and 20m long each one, with 160m^2 of solar receiving area. The purpose of the solar field is to heat a HTF that circulates through the absorber pipe. This HTF is thermal oil called Therminol 55, which can reach up to 290°C as a maximum working temperature without any degradation[4].

Figure 4 sketches circulation of HTF through the SC and storage in the so-called "Hot Tank". As the HTF circulates in the absorber pipe, it gains heat and increases temperature. The HTF, which is total 1200 Kg, is re-circulated into the system at 1.5 kg/s mass flow until it reaches 225°C, the minimum working temperature of the steam generator (SG).

A daily typical chart performance of the SC is shown in Figure 5. The upper graph shows the direct solar irradiation measured by a pyrheliometer installed in the site. In some periods the irradiation is almost zero because of the presence of clouds. The middle graph shows the temperature of the HTF. The initial temperature of the HTF storaged in the hot tank was 100°C. The temperature increment is linear

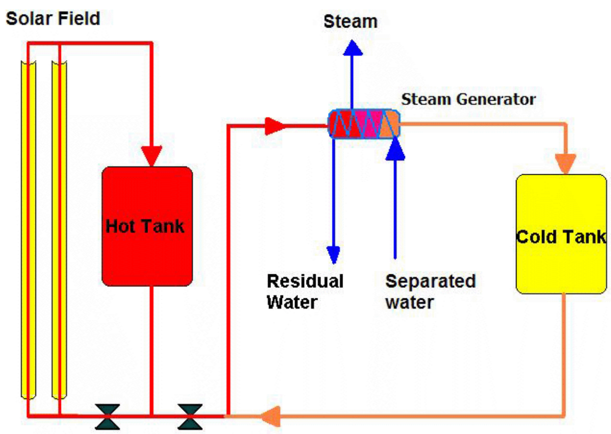

Figure 4. The HTF hydraulic circuit.

during periods of maximum irradiation. The rate of temperature increment declines when direct irradiation is disturbed by presence of clouds. In the latest period of the day, when the temperature is the highest, the trends temperature becomes flat because of higher thermal losses to the environment occurred there. Finally, the lower graphs show the output thermal power given by the SC and the efficiency of the conversion *solar radiation to heat*. It is noticed that both curves are parallel each other and the efficiency lowers as the HTF temperature increases.

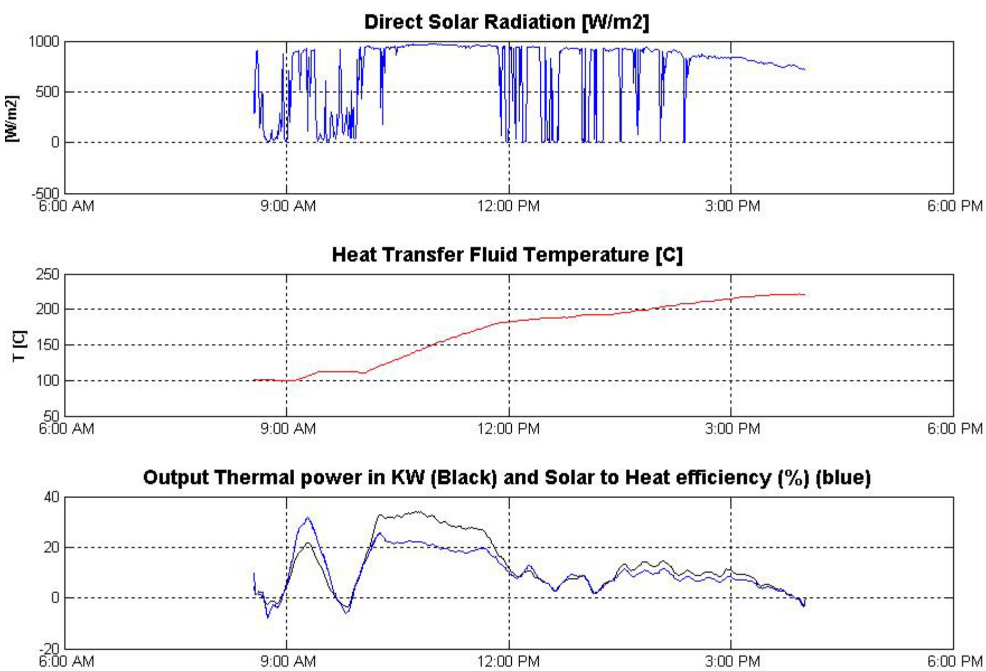

Figure 5. Performance of the pilot solar project during a common day.

Thermosolar System and Geothermal Field Interaction

As can be seen in Figure 6 there are two possibilities to combine the thermosolar and geothermal energies to boost the current geothermal power plant.

The first option considers installing the SG in the separated water line between the cyclonic separator and the flasher system. A fraction of the geothermal liquid boils in the SG and the generated steam can be sent to the medium pressure steam line. The residual water that does not boil is sent to the current flasher tanks.

The second option installs the SG in the output line of water at 115 ºC leaving the flasher tanks. A fraction of the water entering into the SG boils to produce low pressure steam, which can be sent to the current low pressure steam line. The residual water continues to the reinjection line.

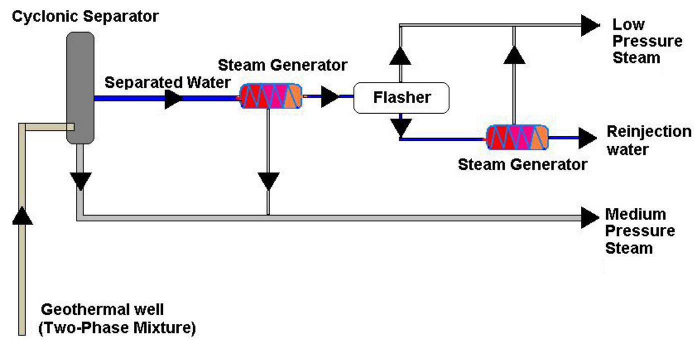

Figure 6. Options considered for interfacing the solar and the geothermal plant.

To date the first option, which produces steam at medium pressure has been successful tested. When the HTF, stored in the hot tank, reaches the minimum working temperature, both separated geothermal water and HTF are pumped to the SG. Figure 3 suggests the heat transfer between both fluids inside the SG. A mass flow of 1 Kg/s of separated liquid enters to the SG and 1.8 Kg/s goes to the flasher system. Approximately 10% of the geothermal water boils into steam at 4.4 barg and 154 ºC. The residual water, leaving the SG at the same inlet conditions travels to the current re-injection system. The outing cold HTF is stored into another tank called cold tank.

Figure 7 shows a scheme of the SG, where the HTF and geothermal liquid flows exchange heat. A flow of 1.5 Kg/s of HTF is pumped at 25 psig to the hot tubes. The HTF inlet and outlet temperatures are 225 °C and 175 °C, respectively, while the pressure drop in the oil circuit is 10 psig. On the other side, geothermal saturated water floods the hot tubes inside the shell and gains heat from the HTF. Steam is produced at 4.4 barg (64 psig) and 154 ºC; which are the same conditions for the inlet and outlet geothermal brine.

Table 1, overleaf, shows some results of the heat exchange process between the two fluids. 97% of the heat lost by the HTF is gained by the water, which means that heat losses to the environment are only 3%. Chlorides and total dissolved solids chemical analysis indicate 99.8% quality for the generated steam.

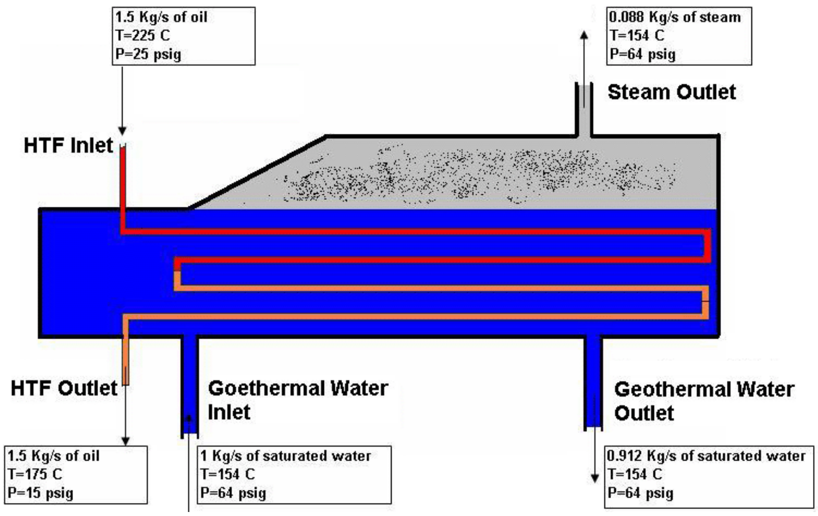

Figure 7. Sketch of the Shell and Tubes SG used in the pilot project.

Computing the *Steam Generator Thermal Efficiency (SGTE)* defined as:

$$SGTE = \frac{T_{HTF_{in}} - T_{HTF_{out}}}{T_{HTF_{in}} - T_{water_{in}}}$$

Gives:

$$SGTE = \frac{225 - 175}{225 - 154}$$

Thus, this particular SG transfers only 70.4 % of the available heat at the above mentioned working conditions.

Simulation of a Thermosolar-Geothermal Hybrid System

Simulation results of a large scale thermosolar plant boosting the current Ahuachapán Geothermal Field (AGF) are discussed as follows. Considering solar to heat efficiency as the conversion from direct solar radiation into heat transferred to the HTF, the pilot project has peak efficiency between 10% and 30 %. To build a large-scale plant for commercial purposes is necessary to import the world-wide technology used in solar thermal power plants managing solar to heat efficiencies in the range of 50% to 60%. For an output electric power of 2-3 MWe during 8 hours on sunny days, the solar field should be compounded by 21 troughs, 300 m long and 5.7 m wide. The land required should reach a 300 m by 400 m square, which can be available downstream of the bore field closer to the power plant.

The annual capacity factor could be around 30% because of the length of the solar day. Under this scenario a hybrid solar-geothermal power plant could operate neither as a base line nor as a stand-alone power plant, but it will provide peak power to offer during the high-demand periods. While the thermosolar block shuts off, the geothermal power plant will normally operate; otherwise the current geothermal plant will continue giving its normal output power plus extra power during sunny hours.

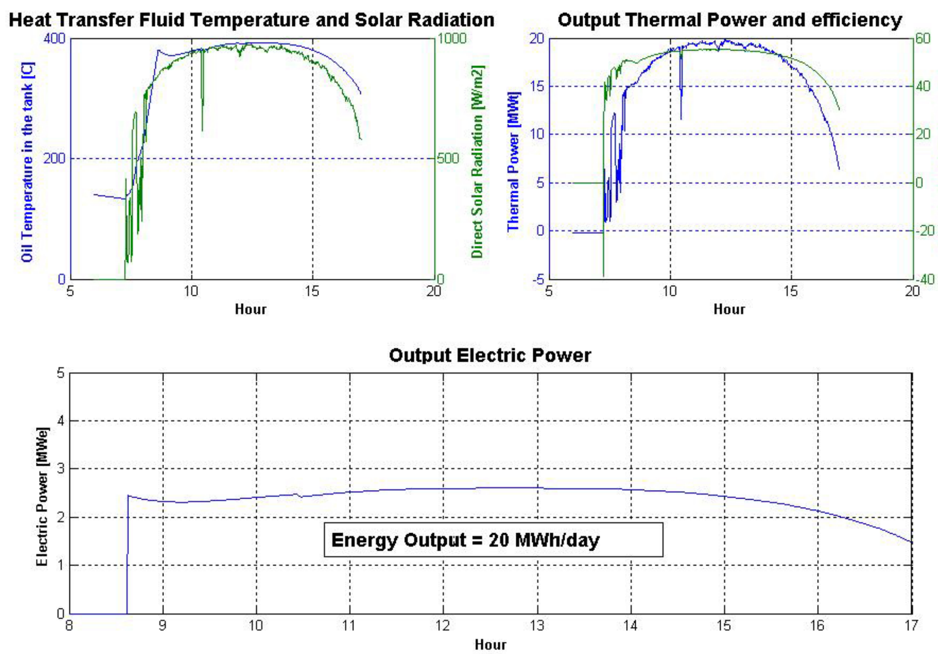

Figure 8. Performance of the Thermosolar-Geothermal Hybrid System.

Table 1. Power Exchanged in the SG.

Thermal Power Given by the Oil		
Initial Enthalpy(T=225 C)	534.0	KJ/kg
Final Enthalpy (T=175 C)	408.1	KJ/kg
Enthalpy Change	-126.0	KJ/kg
Oil Mass Flow	1.5	Kg/s
Thermal Power	188.9	KWt
Thermal Power Gained by the Water		
Outing Steam Flow (Mixture)	0.088	Kg/s
Outing Steam Quality	99.8%	
Outing Dry Steam	0.0878	Kg/s
Initial Enthalpy (Saturated Water)	657.7	KJ/kg
Final Enthalpy (Outing Dry Steam)	2751.0	KJ/kg
Enthalpy Change	2093.3	KJ/kg
Thermal Power	183.8	KWt
(Output power/Input power) ratio	97%	

Figure 8 shows the performance of the simulation. The HTF temperature remains at almost 400 ºC during the 8 hours of operation. The output thermal power ranges from 15 to 20 MWt and the solar to heat efficiency is approximately 50 %. Given that AGF medium pressure turbines consumes 2.3 $Kg.s^{-1}/MWe$, the output power behaves as shown in the lower graph of Figure 8, equivalent to 20 MWh/day.

Conclusions

Based on the testing results of this pilot project, local solar radiation measurements, reliable information from solar devices manufacturers and solar power plants developer companies, it is possible to draw the following conclusions:

The Solar Steam Booster located in the AGF built with local technology is technically feasible, even though the measured efficiency is a third of the efficiencies reported by thermosolar plants currently operating at commercial scale.

The HTF temperature measured in the SC outlet is considerably higher than the geothermal fluids temperatures available on the AGF wellheads.

Solar field efficiency significantly decreases when HTF temperature is higher than 225 ºC. This boundary temperature is enough to boost power to the current geothermal power plant.

The solar power booster will positively shift the geothermal power base line up to 8 hours/day.

The implementation of a commercial large-scale thermosolar-geothermal hybrid system in the AGF should cost lower than a pure thermosolar power plant because the power block and the gathering fluid system are already available. The investment should be focused on importing high-tech solar field and heat exchanger equipments further than local technology because of their efficiency differences.

Acknowledgments

We would like to recognize to LaGeo´s Managers and Board of Directors the advanced decision to allow developing this research. Special thanks to the AGF's crew, technical and administrative staff for their logistic support and ideas to carry out several tests.

References

US Department of Energy, Energy Efficiency and Renewable Energy, Solar Parabolic Trough, p.14. Available from internet: http://www1.eere.energy.gov/ba/pba/pdfs/solar_trough.pdf

Geyer, Michael, Potential of Solar Trough Installations in Europe, Solar Millennium Group, p. 14. Available from internet: http://www.ec.europa.eu/energy/res/events/doc/geyer_andasol.pdf

Handal, Salvador., Y. Alvarenga., M. Recinos, 2007. Geothermal Steam Production by Solar Energy. Geothermal Resources Council *Transactions*. V. 31, p. 503-510

Solutia. 2005. Therminol 55, Efficient Reliable, Synthetic Heat Transfer Fluid. http://www.therminol.com