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PAPER 028 - A SOLAR POND FOR FEEDING A THERMOELECTRIC GENERATOR OR AN ORGANIC RANKINE CYCLE SYSTEM

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Abstract

The world energy demand is continuously growing, which means an increase in consumption for all modern fuels or stronger effort on the development and improvement of renewable technologies.
Moreover, Developing Countries claims more energy and they have often wide unutilized or unusable lands. The solar energy represents a useful opportunity for these Countries.

The Solar Pond is both a solar collector and a thermal storage for long period and is suitable to use in wide sunny areas.
Solar pond technology is able to supply heat for several applications requiring low-grade thermal energy or for electrical power production.
In order to produce electrical energy from solar ponds it is necessary to use systems fed by low enthalpy sources, such Thermoelectric Generator (TEG) and Organic Rankine Cycle (ORC).
In this paper, a model of a Solar Pond for power generation is analyzed in conjunction with an Organic Rankine Cycle. The model has been validated using climate data of an area near to Palermo city (Italy) and exactly the Test Reference Year developed by the Authors.

The Solar Pond

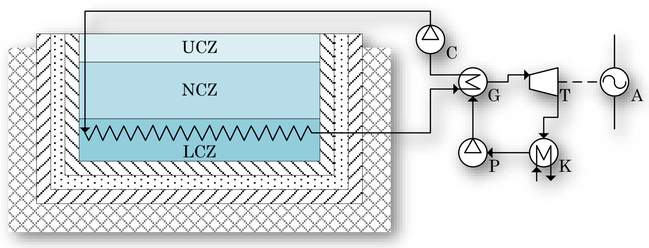
A solar pond is both a solar collector and a thermal storage. It works with a salt solution that is able to stratify creating a density gradient. Solar pond study began in 1902 in Hungary, with the observation of a natural salt lake in Transylvania. In this lake at a not so high depth, about 1.32 m, were measured 70 °C in summer and 26 °C in winter.

There are several types of solar pond: the Salt Gradient Solar Pond (SGSP) is among these. A SGSP is a small deep basin, typically from one to five meters, varying in width, insulated and fill with water and a large amount of salt, commonly NaCl and exposed directly to the sun radiation. It is possible to distinguish three overlaying layers where the salt concentration strongly varies and this characterizes the thermal behaviour.

Starting from the surface, the first layer, the Upper Convective Zone (UCZ), has a thickness of tens of centimetres and is slightly salty or not at all. The bottom layer, the Lower Convective Zone (LCZ), has the highest salt concentration, typically is saturated, and has the highest density. His thickness is greater than that of the UCZ. Both in the UCZ and in the LCZ the solar radiation is able to generate a convective motion in the fluid, even if with different characteristics.

Between these two zones, there is the Non Convective Zone, NCZ, a layer with a salt gradient concentration. The NCZ may be considered as a series of layer where the salt concentration increasing with the deep into each one. The solar radiation passes through the water and, reaching the LCZ, it is partially absorbed and converted to heat. The heating is able to decrease density, but due to the highest salinity, density remains higher enough to be able to rise. Therefore, the mass of solution remains at the bottom and heat is stored in it.
In the NCZ, the salinity gradient prevents any convective motion. The transparency of the NCZ layers allows to the solar radiation to pass through and to reach the LCZ where is stored as heat but heat transfer to the top of the pond as a convective way is not possible. So, the NCZ acts, regarding the heat transfer, as an electric diode and may be considered as a “thermal diode”.

Main problems are the evaporation of the water at the surface of the UCZ and the stability of the salinity gradient that may be corrupted with the heat extraction.



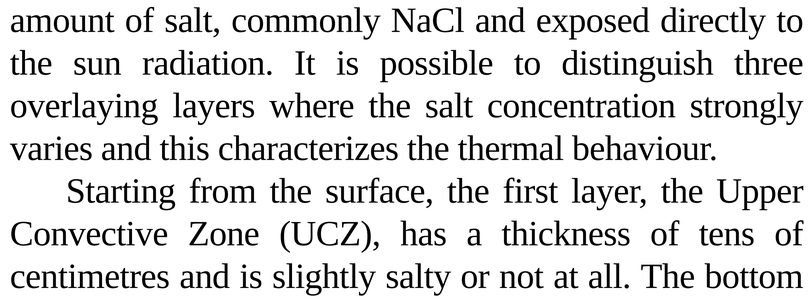
The proposed SGSP-ORC System

The heat stored in the solar pond can be extracted directly from the LCZ with an auxiliary heat exchanger. This prevents the disruption of the salinity gradient and a mixing of the whole fluid. A Solar Pond connected with an ORC is able to produce about 5 W/m².

Recently there is some interest in coupling of SGSP with Thermoelectric Generator (TEG), a well-known technology that permits generating directly electricity from heat transfer, based on the Seebeck effect. The TEG utilizes a particular heat exchanger composed by sets of thermocouples of two different metals. The hot and cold fluids, flowing in through the heat exchanger, by placing the junctions at two different temperatures, generate an electromotive force.

The System Model and the Case Study

The proposed system in this paper is composed by a SGSP and an ORC able to produce electrical work.
The mathematical model for the SGSP is based on the theoretical modelling of Sayer et al., with some improvement from Husain et al., Abbassi Monjezi and Campbell. The modelling for the ORC is based on a previous article of the Authors.



ORC Cycle with working fluid R123 (left) and R245fa (right)

The SGSP is a basin filled with salted water and has a surface of 1000 m², a total depth of 3.25 m. The main parameters are reported in a table in the Article.
The ORC plant is fed by a heat exchanger placed in the LCZ. The heat removed by a process fluid, water, goes into the generator where the ORC working fluid is able to evaporate. The working fluids considered in this paper are R123 and R245fa, which are two suitable and available common fluids.

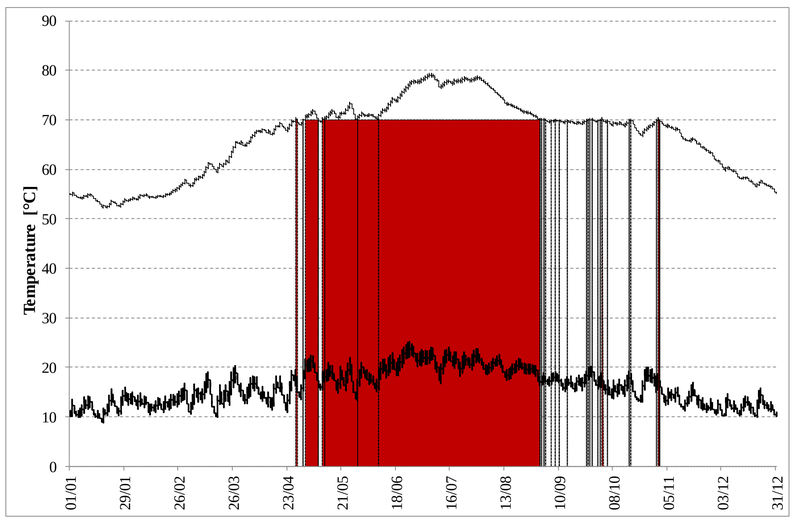
It has been here assumed that the system is installed on an area not shaded sited in the city of Palermo (South of Italy). The kind of climatic data set utilized for the simulation is the Test Referee Years (TRY), which provides hourly values of climatic parameters of the selected sites. The utilized climatic database is the Test Reference Year for the city of Palermo, in Italy, developed by the Authors.

The mathematical model of the system have been implemented in the Python environment by the Authors, in order to simulate the behavior of the ORC system fed by SGSP, considered the process quasi-static. The simulation has been carried out for two years for evaluating the effective production of energy, so to avoid the transient period, therefore the second year only has been investigated. The annual average efficiency of solar pond has been assessed as the ratio between the annual heat extracted by the LCZ layer and the annual solar radiation flux within the salted water at surface of the pond. The assessed value is equal to 5.05%.

Substance		R123	R245fa
Pump consumption	[kWh]	79	131
Turbine power output	[kWh]	5561	5508
Efficiency η	[%]	6.7	6.6

Results of simulations for the SGSP-ORC System

The study on the SGSP - ORC system with the two fluids (R123 and R245fa), shows that the efficiencies are aligned with the main results in Literature. There is a substantial equality of the efficiency value among the fluids. Deep considerations must be carried on regards the environmental aspects, and with the plants programming. In fact the end of production of R123 is scheduled by 2030, due the ODP correlated, and moreover the R245fa has an elevated GWP value.



Trend of Temperature in UCZ and LCZ.
In red the periods of working of ORC.

NIST National Institute of Standards and Technology
REFPROP Reference Fluid Thermodynamic and Transport Properties Database
python™

For further information, see the full Article in the Proceedings and, in case, send an e-mail to the Corresponding Author massimo.morale@unipa.it, even with the QR-code by side.