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A first approach study on the desalination of sea water using heat transformers powered by solar ponds

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HIGHLIGHTS

- Source temperature with steady values during the year, obtainable through solar ponds.
- Use of an absorption system, operating as "heat transformers".
- Desalination process, with temperatures over 100 °C through the use of solar ponds.
- This study addressed the problem of the theoretical feasibility of the system.
- Surface of solar ponds ensuring the production of desalinated water.

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ABSTRACT

In many emerging countries over the past few years some phenomena, such as a better welfare state, industrial growth and a development in agriculture, led to a significant increasing of the demand concerning fresh water. In order to face this ever-growing demand, one of the possible solutions to counterbalance the lack of water resources, is the desalination of sea water. For this specific goal solar energy, as a resource, is the process which has more reliance since it allows a low-cost production of desalted water (without using any valuable energy resources such as fossil fuels) and in a complete respect of the environment.

This first study has the purpose to analyze from an energetic perspective whether it is possible or not to reach process temperatures over 100 °C, through the use of solar ponds and heat transformers, in order to produce desalinated water. The final aim of this work is to quantify the surface of solar ponds needed to a production (expressed in cubic meters) of desalinated water.

An absorption heat transformer is a thermal machine that while extracting heat from a source (at an available temperature) is able to ennoble a portion of the heat collected/obtained, making it available at higher temperatures. This process occurs at the expenses of the remaining portion of heat whose temperature degrades by lowering its values. The portion of heat will be then transferred to a thermal well. Hence an absorption heat transformer can use the solar energy stored in solar ponds as an energy source at an average temperature.

Process temperatures which are higher than 100 °C for a whole year can take place only under certain chained conditions such as: source temperature with steady values during the entire season obtainable through solar ponds; condensation process occurring at sufficiently low temperatures through the use of sea water; exertion of heat transformers. The heat which is usually available at these temperatures could be used for common thermal processes during the desalination of seawater.

In this work we want to demonstrate that it is possible, energetically speaking, to produce desalinated water by exploiting the solar energy stored in solar ponds and the technology of absorption heat transformers. We can notice how for every m^3 of desalinated water produced in one day we need ponds with an area ranging between 1000 and 4000 m^2, this depends on the amount of heat flux drawn.

The analysis we carried out represents a first attempt to face this kind of problem. In future studies we will examine both technical and economic feasibility.

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1. Introduction

Over the past few years a remarkable increase of the demand of fresh water arose in many emerging countries placed in the warm regions of the world. This is primarily due to a better welfare state, an industrial growth and a development in agriculture. Such growth occurs where there is a frequent and endemic lack of water resources [1].

We have a similar situation in countries overlooking the South Mediterranean Sea where, due to climate changes, some areas are subject to a desiccation process which inevitably determine the necessity of having fresh water [2]. Thus the desalination of sea water seems one of the possible solutions to counterbalance the lack of water resources. On the other hand, the need of a sustainable production of water through renewable resources suggests the use of solar energy in desalination processes as well [3,4].

Several studies faced the problem of having a production of desalinated water without using non-renewable energy sources with the purpose to decrease the costs [5] and respect more the environment. Tsiourtis [6], while taking into consideration the energy requirements of the desalination processes, suggested the exertion of renewable sources to ease the impact on the environment. Hájek and Jegla [7] examined the energy needs by taking into consideration untraditional production technologies. Darwish et al. [8] studied the feasibility of those systems using aeolian energy and/or solar source (for what concerns the solar source the study was carried out by using concentration thermal systems or through the production of photovoltaic energy). Olwing et al. [9] analyzed the economic feasibility of traditional desalination systems supplied with heat from solar concentrators. El-Ghonemy [10] suggested the exertion of solar energy, applying it to untraditional technologies for the production of desalinated water, by extracting humidity from the air. Zaragoza et al. [11] examined the possibility to produce desalinated water by supplying thermal energy, taken from solar source, to membrane systems. These and other studies [12–16] show how the solar energy source is a valid choice for the production of desalinated water which is environmentally compatible and this is possible thanks to the exertion of traditional desalination technologies that are mature and reliable.

We need to explore new methods for the exploitation of solar source, and find a way to make it a choice which is technically possible and energetically sustainable.

Solar energy, in spite of its unsteady and random nature, is a resource which consents the production of desalinated water. The amount of cool water can be stored and used later than the time in which it was produced [17]. As a matter of fact the lack of water resources is present in those areas full of solar radiation and where the exploitation of solar resources seems to be an interesting solution [18].

In some of what we call "small types of solar thermal desalination systems," solar energy is used straightaway, but the production of desalinated water is not particularly abundant [19].

In desalination plants (with or without heat recovery), where productions are bigger and where process temperatures must be over 100 °C, solar energy is only used to preheat the sea water [20]. Some innovative plants, thanks to the use of concentrating solar systems, can reach operating temperatures of about 300 °C [21]. But such systems still present problems concerning installation costs of collector surfaces. Hence, using solar energy raises problems due to both the discontinuity of the source and the availability of process temperatures [8].

The temperatures of the heat stored in solar ponds tend to increase. Such temperatures will be compatible with desalination processes thanks to the exertion of absorption heat transformers which use water and lithium bromide [22]. They can be defined as thermal machines that, through the exploitation of special chemical–physical proprieties characterizing pairs of solute/solvent, are able to ennoble the available heat [23]. This phenomenon, in order to respect the laws of thermodynamics, determines a thermal reduction of most of the available heat. Such an occurrence is acceptable because we are dealing with a gratuitous and renewable resource.

A process temperature producing values higher than 100 °C can occur under certain conditions, such as: an adequate uniformity of the source temperature during an entire season thanks to the use of solar ponds; the possibility of a condensation process performing at low temperatures through the use of sea water. Besides these two conditions, it must be kept in mind all those plant-engineering simplifications which such temperatures require.

In this article we take into consideration process temperatures that reach values higher than 100 °C while using solar energy (concentrated solar systems excluded). It is possible to extend the production of desalinated water, whether the solar radiation is simultaneously present or not, if we use solar ponds as heat collectors. It is important though to find a solution when dealing with lower temperatures, because that is where the heat is stored [24]. The outline examined expects the exertion of an absorption system working as "absorption heat transformers" [25] whose energy source (at a certain average temperature) is the solar energy stored in solar ponds.

The first part of such study focuses on the purely theoretical feasibility of the system (we consider all the processes basically idealized and then reversible). Later on the attention shifts to an analysis of the maximum feasibility reachable regarding the production of desalinated water.

2. Absorption heat transformers

An absorption refrigerating machine subject to a "heat transformer" structure allows the exploitation of heat sources with low exergy values [26]. In other words, an absorption heat transformer is to an absorption refrigeration machine, as a heat pump is to a compression refrigeration machine.

By exploiting the difference between the source and the local temperature, this machine permits, (thanks to the chemical–physical properties of a solution of an absorbent substance – the solute – in a refrigerant substance – the solvent) to transfer a portion of the heat absorbed by the source to a higher temperature. This transition occurs without the necessity of further energy resources, except for the energy needed for the fluid flow inside the machine. If compared to other systems which are fit for the ennoblement of low exergetic heat, the heat transformer distinguishes itself for the significant lack of a further refined energy supply [27]. Hence the heat transformer does not require significant expenses for the energy supply. On the other hand depreciation expenses for the machine installation is something that must be faced.

The working mode of a heat transformer [28] and its constituent parts are shown in Fig. 1.

In Fig. 1, R_1 and R_2 are regenerative heat exchangers, P_S is the pump solution and P_R is the pump of the refrigerator. See at glossary for the definitions of specific terms.

The heat that we want (not the entire amount but just a portion of it) ennobled from a thermal view point is provided to evaporator E (Q_E) and generator G (Q_G) [29]. In this case the thermal source is the solar pond. The evaporator contains pure water that once heated evaporates. Thanks to the pressure difference between container E and container A (this difference is due to the Raoult's law which allows the functioning of the machine), the steam moves/migrates towards the container A (absorber) where the

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