INTEGRATION OF POWER RETARDED OSMOSIS IN SOLAR MULTIEFFECT DESTILLATION

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ABSTRACT: A Solar-Energy Powered Desalination System is proposed and evaluated here. It is based on the use of Solar Multi-effect Distillation (S-MED) plants that integrate osmotic energy recovery systems, which makes it possible to improve the efficiency of the process, providing a cost-effective approach for desalination using solar energy.

Keywords: Osmotic Power; Concentrated Solar Power; Desalination.

1 Introduction

Water scarcity is among the main problems to be faced by many societies and the World in the XXI century. Water use has been growing at more than twice the rate of population increase in the last century, and, an increasing number of regions are chronically short of water. Water desalination is one of the most important solutions provided to satisfy the water demand and one of the most promising fields for the application of solar thermal energy due to the coincidence, in many places of the world, of water scarcity, seawater availability and good levels of solar radiation.

For higher desalting capacities, it is necessary to choose conventional distillation plants coupled to a solar thermal system, which is known as indirect solar desalination. Distillation methods used in indirect solar desalination plants are multi-stage flash Distillation methods used in indirect solar desalination plants are multi-stage flash (MSF) and multi-effect distillation (MED). MSF plants, due to factors such as cost and apparent high efficiency, pushed out MED systems in the sixties, and only small size MED plants were built. However, in this last decade, interest in multi-effect distillation has been significantly renewed and currently MED process is competing technically and economically with alternative technologies: Recent advances in research of low temperature processes have resulted in an increase of the desalting capacity and a reduction in the energy consumption of MED plants [3], providing long-term operation under remarkable steady conditions. Scale formation and corrosion with current process are minimal, leading to exceptionally high plant availabilities of 94% to 96%.

Solar thermal destillation is selected as the core technology due to its reliability, simple operation and maintenance, maturity and high purity of the produced water. In particular, from the thermal desalination processes, Multi-effect Destillation (MED) has the highest thermal efficiency and the lowest power consumption, so it is selected here, combined with a renewable source of thermal energy: Solar energy would be used as this thermal source, as these S-MED systems have already been shown to be feasible and efficient [1]. Moreover solar irradiation is high when water demand is high.

Following recent advances in Concentrated Solar Power (CSP) [2], and thermal storage systems [3], CSP with thermal storage is proposed as the source of thermal energy for SED. As has been mentioned, a central aspect of improving the energy efficiency of this process, which is unique to this project, is the recovery of salinity energy from the brines. For this, salinity gradient techniques [4,5] are included in the proposal, as they have shown good performance in realistic situations. In particular, Power Retarded Osmosis (PRO) is selected, as the authors of this proposal have already shown that it performs well at the high temperatures associated with the brines of S-MED systems [6].

2 Summary of the Proposal

The Solar Efficient Desalination (SED) system proposed here for renewable desalination is schematized in Figure 1: it is based on the use of Solar Multi-effect Destillation (S-MED) plants that integrate osmotic energy recovery systems, which makes it possible to improve the efficiency of the process, providing a cost-effective approach for desalination using solar energy.
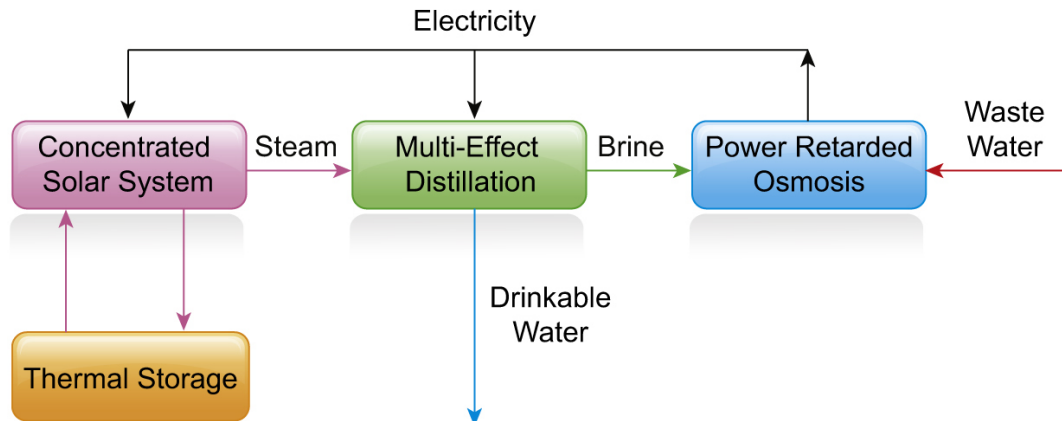
Figure 1: General scheme of the components of the proposed system

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3 Review of technologies

The main technologies involved in the proposed system are now briefly presented:

3.1 Multi-effect Destillation

A typical forward-feed vertically stacked MED plant is schematized in Fig 1. MED plants consist mainly of connected elements called effects that generate simultaneous evaporation/condensation processes in a decreasing sequence of pressures and temperatures [5,6,7]. The first effect has the higher pressure, an external heat source (steam) makes seawater boil: The steam thus generated is used as the heat source of the next effect, and so on. Each effect has a preheater placed next to it with the aim of increasing the temperature of the feed seawater before it is introduced within the first effect. Vapour condensed inside each horizontal tube bundle from the second to the last effects represents most of the distillate production of a MED plant. The vapour produced in this last effect is condensed in a final condenser, which is cooled by seawater. Brine and destillate are then extracted by pumps.
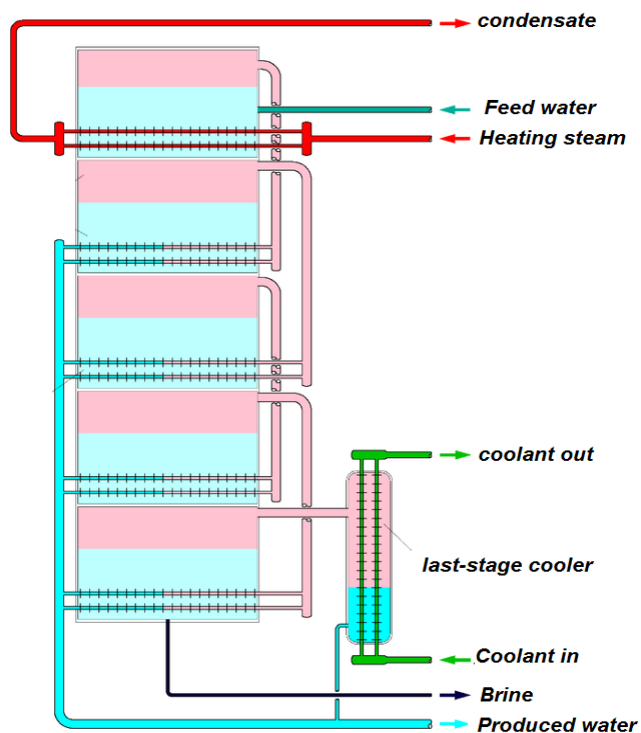
Fig.1: Schematic Process Diagram of a typical MED plant

3.2 Pressure Retarded Osmosis

Pressure retarded osmosis (PRO) is based on recovering the salinity gradient caused by differences in the salt concentration between seawater and fresh water [4]. In a typical PRO process (presented in Figure 3), water molecules spontaneously transport through a semi-permeable membrane from a low salinity stream (such as river water, brackish or waste water), at ambient pressure into a pressurized high salinity stream (seawater or brine), with the aid of the osmotic pressure gradient across the membrane. The produced osmotic power is a product of the transmembrane pressure and water permeation rate. This power is then converted into electricity by feeding the pressurized stream to a hydro-turbine or used in standard energy recovery systems [7-9].
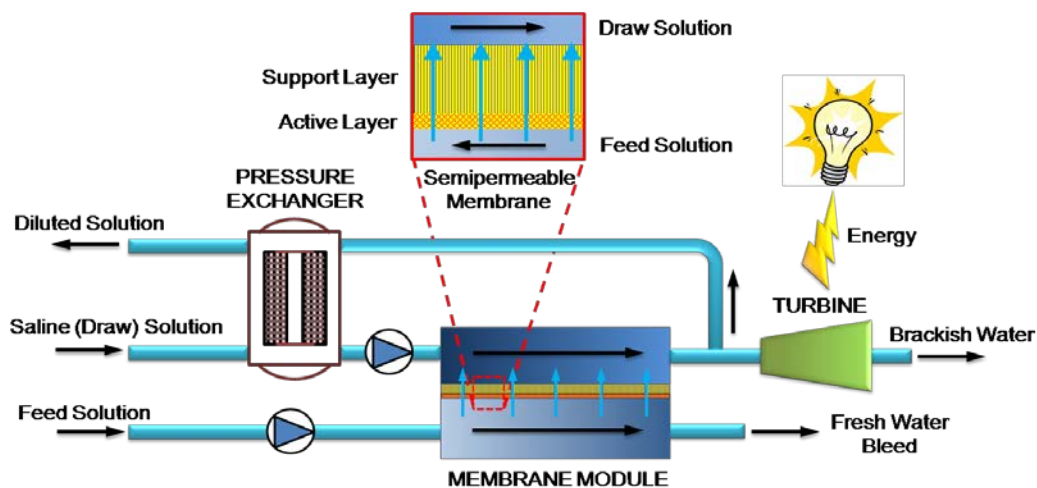

Fig.3: Schematic Process Diagram of a PRO system.

4 Integration of Pressure Retarded Osmosis into MED desalination

The integration of PRO with MED is presented in Figure 2. The process would operate as follows: the osmotic energy of the outlet brine in MED system brine water from wastewater through a membrane (specially developed for PRO processes), generating hydraulic pressure; this pressure is then transformed into electricity in a turbine (it could also be used to assist pumping inside the MED process, by exchanging pressure using standard hydraulic energy recovery devices, but this possibility is outside the scope of this work).

From the available Salinity Gradient approaches, PRO has been selected because the high temperature of the brine improves the performance of PRO processes. In fact, brines are frequently cooled down in MED plants using seawater and a heat exchanger. As an alternative, the wastewater that would be used as feed water in the PRO process can be used in the heat exchanger, so that the PRO process operates at the best operating point for each specific membrane.
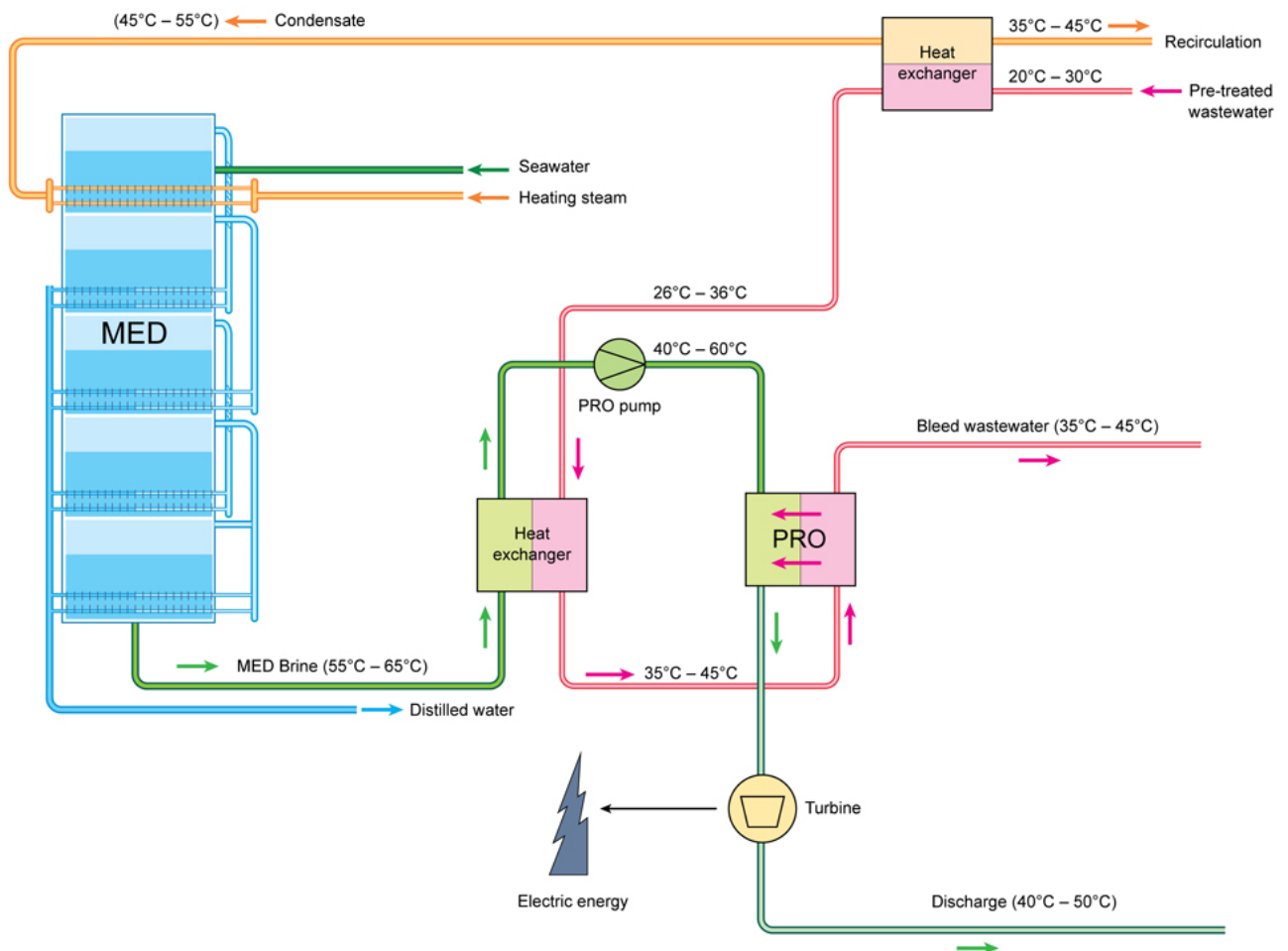

Figure 2: Detail of the proposed SED system

4.1 Evaluation of Energy Recovery

The numerical results obtained using models and data from the literature [5,9] are summarized in Table 1. This main results for the energy recovery system, extrapolated from the laboratory results published in [6] by the authors of this proposal, correspond to the case study presented in Figure 2. To derive the data in Table 1, the MED plant presented in [7] is used as case study, in which the available wastewater flow is assumed to be at least 125m3/h (with a maximum concentration of 1 g/l of dissolved salts). For the extrapolation of the results, the PRO membrane parameters given in Table 2 are used, as they represent the characteristics of membranes expected to be commercially available in the year 2015. To make the results general, four different combinations of configurations of heat exchangers and brine temperatures were tested (corresponding to case studies 1 to 4).

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Table 1: Expected energy recovered using the proposed system for different seawater and feed water conditions.

Case Study	MED Brine concentration	PRO Brine temperature	PRO Feed water temperature	Operating pressure	Discharge concentration	Power recovered
#1	65 g/l	40ºC	35ºC	26.0 bar	46.2 g/l	28.8 kW
#2	65 g/l	50ºC	40ºC	26.8 bar	42.3 g/l	33.5 kW
#3	65 g/l	60ºC	40ºC	27.7 bar	41.8 g/l	38.6 kW
#4	65 g/l	60ºC	50ºC	27.7 bar	42.3 g/l	41.4 kW

4.2 Estimation of savings

The estimation of the water costs was carried out starting from the costs in state-of-the-art S-MED plants, which are assumed to be 0.240\$ per cubic meter of desalinated water (for a 2000m3/day plant operating 24 hours, thanks to thermal energy storage). The proposed SED system would recover a significant part of the osmotic energy of the brines as electrical energy, which makes it possible to reduce the operating costs. A summary of the estimation of costs are presented in Table 2 for the four case studies presented in Table 1.

Table 2: Expected water costs using the proposed SED system for different operating conditions

Case Study	SED Expected Costs (\$/m^3)	Predicted Savings with SED (%)
#1	0.208	5.5%
#2	0.199	9.5%
#3	0.190	13.6%
#4	0.184	16.4%

5 Conclusions

Based on the results obtained by numerical simulations, it can be concluded that:

- The quantity (714m3/day) and quality (WHO standards) of the freshwater produced would be adequate for the expected application.

- The proposed energy recovery system improves the energy efficiency by recovering a significant amount of the osmotic energy (up to 41 kW), when operating directly with the MED brine (case studies #3 and #4), using the structure presented in Figure 2. Drinkable water quantity and quality would not be affected.

- The discharge concentration of the proposed system has a concentration not very different from that of seawater, significantly reducing its environmental impact.

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