ECONOMICS OF SMALL SOLAR-ASSISTED MULTIPLE-EFFECT SEAWATER DISTILLATION PLANTS

Ali M. El-Nashar
Water and Electricity Authority, Abu Dhabi, UAE

Keywords : Cost Optimization, Sizing Consideration, System Configuration, Thermal Energy, Pumping Requirements

Contents

Summary

The objective of this paper is to compare the economics of using solar energy to operate small multiple effect seawater distillation systems in remote areas with the conventional method of using fossil fuels. The particular multiple effect system used is an advanced horizontal tube, falling film system called "multiple effect stack", MES, in which the pumping energy requirement is relatively low compared with the horizontal in-line system. Three system configurations were investigated: (1) conventional system using a steam generator to provide steam for the MES evaporator and a diesel generator to provide pumping power, (2) solar-assisted system which uses solar thermal collectors to provide hot water (instead of steam) for the evaporator and a diesel generator for pumping power, and (3) solar stand-alone system which uses solar thermal collectors for the evaporator heat requirement and a solar PV array to provide electrical energy for pumping.

At the present time, solar energy cannot compete favorably with fossil energy particularly under the present international market prices of crude oil. However, in many remote sunny areas of the world where the real cost of fossil energy can be very high, the use of solar energy can be an attractive alternative.

Two important cost parameters affect the relative economics of solar energy vis-à-vis conventional (fossil) energy: the collector cost in $ per square meter and the cost of diesel oil in $ per Giga Joule. Solar energy becomes more competitive as the local cost of procuring conventional fuel increases and as the collector cost decreases. The water cost from a solar thermal-diesel-MES system (configuration #2) can be seen to approach the water cost from a steam generator-diesel-MES system (configuration #1) when the collector cost drops to 200 $ m^{-2} and diesel oil cost at the remote site reaches 50 $ GJ^{-1}. Using a 100 per cent solar system (configuration #3) with solar thermal and solar PV collectors being utilized, the economics was seen to improve in favor of the solar system. Even when diesel fuel can be procured at 10 $ GJ^{-1} at the remote site, the cost of water from the solar system can be seen to approach that from a conventional plant when thermal collectors costing 200 $ m^{-2} are used. The cost of water from the solar system was shown to be always less than that from a conventional system which uses diesel oil procured at the high price of 50 $ GJ^{-1} but always higher than water produced from a conventional system using diesel oil at the low price of 10 $ GJ^{-1}.

1. Introduction

Many remote areas of the world such as many coastal desert areas in the Middle East or some Mediterranean and Caribbean tourist islands are suffering from an acute shortage of drinking water. Drinking water for these locations can be hauled in by tankers or barges, or produced by small desalination units using the available saline water. The transportation of water by tankers or barges involves a lot of expenses and is fraught with logistical problems which can make fresh water not only very expensive when available but its supply is susceptible to frequent interruption. The use of small conventional desalination units that utilize fossil fuel, such as diesel oil, as the energy supply can suffer from the same procurement problems that are encountered with transporting fresh water, namely transportation expenses and supply reliability.

Some of the remote areas are blessed with abundant solar radiation which can be used as an energy source for small desalination units to provide a reliable drinking water supply for the inhabitants of the remote areas. Recently, considerable attention has been given to the use of solar energy as an energy source for desalination because of the high cost of fossil fuel in remote areas, difficulties in obtaining it, interest in reducing air pollution and the lack of electrical power source in remote areas.

Desalination of seawater and brackish water is one of the ways for meeting future fresh water demand. Conventional desalination technology is fairly well established and some of the processes may be considered quite mature although there is still considerable scope for improvement and innovation. Conventional desalination processes are energy intensive and one of the major cost items in operating expenses of any conventional desalination plant is the energy cost. Thus, one of the major concerns about using desalination as a means of supplying fresh water to remote communities is the cost of energy.

Apart from energy cost implications, there are environmental concerns with regard to the effects of using conventional energy sources. In recent years, it has become clear that environmental pollution caused by the release of greenhouse gases resulting from burning fossil fuels is responsible for ozone depletion and atmospheric warming. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on growing reliance on renewable sources of energy.

In this paper, the economics of a solar-assisted and solar stand-alone multiple-effect stack (MES) distillation systems for seawater desalination are compared with that of a conventional system consisting of an MES unit operated in association with a steam generator and a diesel generator. The comparison is based on the economic and meteorological environments prevailing in Abu Dhabi, UAE.

2. System Configurations

Three system configurations are considered for the current economic study:

- A conventional distillation system consisting of an MES evaporator supplied by steam from a low-pressure steam generator with the pumping power supplied by a diesel generator as shown schematically in Figure 1 (configuration #1).
- A solar-assisted system consisting of an MES evaporator supplied by thermal energy in the form of hot water from either high-efficiency flat plate collectors or evacuated tube collectors with pumping power supplied by a diesel generator as shown in Figure 1 (configuration #2).
- A solar stand-alone system consisting of an MES evaporator supplied by thermal energy from flat plate or evacuated tube collectors, as in configuration 2, with pumping power supplied by a solar PV system as shown in Figure 1 (configuration #3).

The system labeled as "configuration #1" needs two types of fossil fuel, namely crude oil for the steam generator and diesel oil for the diesel generator. The thermal energy required by this system is supplied by steam at a pressure ranging from 1-1.5 bar. Several pumps are required to force the different streams to flow through the system and to inject different chemicals into these streams to ensure safe and reliable operation. The major pumps required by the evaporator are the seawater intake pump, feed water pump, distillate (product water) pump, brine blowdown pump, drain pump, antiscalant dosing pump (for feedwater stream), NaClO dosing pumps (for seawater intake and distillate streams), $NaHCO_3$ dosing pump (for distillate stream) and $CaCl_2$ dosing pump (for distillate stream). All these pumps are operated by 3-phase 415 VAC motors except the chemical dosing pumps which are operated by 3-phase 220 VAC motors. Steam ejectors are used to create and maintain the vacuum inside the evaporator.

The system labeled as "configuration #2" needs only one type of fossil fuel, namely, diesel oil for the diesel generator. The thermal energy required by the MES evaporator can be supplied in the form of hot water generated by either flat plate or evacuated tube collectors. Double glazed, well designed flat plate collectors can produce hot water at 80°C with reasonable efficiency while evacuated tube collectors can easily produce water at more than 95°C with good efficiency albeit higher collector cost. The pumping power for this system is more for the conventional system because at least three additional pumps should be incorporated: mechanical vacuum pump, heat collecting pump and heating water pump. The mechanical vacuum pump is to replace the steam ejector in the conventional system since no steam is available in the current system. The heat collecting pump is used to circulate the collector fluid (water) through the collector field to enhance solar heat collection. The heating water pump is used to draw hot water from the heat accumulator and supply it to the first effect of the MES evaporator to initiate seawater boiling in that effect. The capacity of the diesel generator for this system is therefore larger than that of the conventional system.

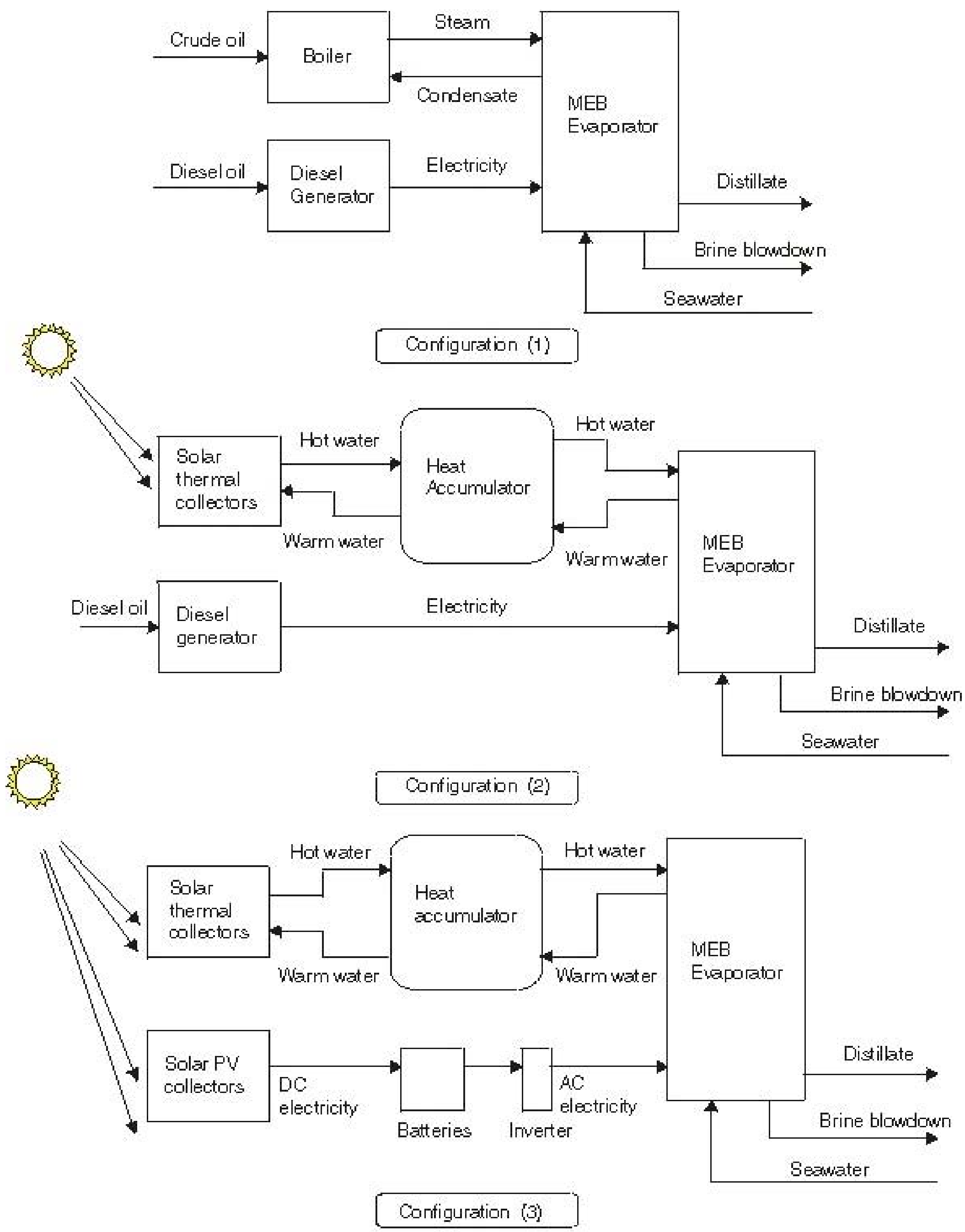

Figure 1. System configurations.

The system labeled "configuration #3" utilizes solar energy to satisfy both thermal and electrical energy demands of the system. The electrical power requirements of this system are essentially the same as that of "configuration #2". However, the power requirement is supplied by an array of solar PV cells instead of a diesel generator. An inverter is used to change the DC output into AC electricity.

3. Design and Sizing Considerations

3.1. Thermal Energy Requirement

The thermal energy requirement of the MES evaporator, Q_{ev}, depends essentially on its rated capacity as well as its performance ratio. The performance ratio for MES evaporators depends essentially on the number of effects according to the following relations (ENAA and WED 1986; Hanbury et al. 1995)

$$PR = -0.809 + 0.932N - 0.0091N^2 \quad (1)$$

Q_{ev} can be obtained from (2)

$$Q_{ev} = M_d \frac{L}{PR} \quad (2)$$

where M_d is the rated (design) capacity and L is the latent heat of vaporization.

-
-
-

Bibliography and Suggestions for further study

Al-Karaghouli A.A., Alnaser W.E. (2004), *Experimental comparative study of the performance of single and double basin solar-stills*. Appl Energy **77**(**3**), pp. 317-25.

Al-Karaghouli A.A., Alnaser W.E. (2004), *Performances of single and double basin solar-stills.* Solar Energy **78**(**3**), pp. 347-54.

Al-Shammiri M., Safar M(1999). Multi-effect distillation plants: state of the art. Desalination , 126:45-59.

Chafik, E., 2003. A new type of seawater desalination plants using solar energy. Desalination

Corrado Sommariva ,(2010),COURSES IN DESALINATION, Thermal Desalination

Delyannis E. (2003), *Historic background of desalination and renewable energies.* Solar Energy **75**(**5**), Elsevier pp. 357-66.

El-Nashar A M (1990) Computer Simulation of the Performance of a Solar Desalination Plant. *Solar Energy* 44(4).

ENAA and WED (1986) Research and Development Cooperation on Solar Energy Desalination Plant. Final Report.

Florides G., Kalogirou S. (2004), *Ground heat exchangers – a review*. Proceedings of third international conference on heat power cycles, Larnaca, Cyprus, on CD-ROM.

Fosselard G and Wangnick K (1989) *Comprehensive Study on Capital and Operational Expenditures for Different Types of Seawater Desalting Plants (RO, MVC, ME, ME-TVC, MSF) Rated between 200 m^3 d^{-1} 3,000 m^3 d^{-1}*. Proceedings, Fourth World Congress on Desalination and Water Reuse, Volume IV, Kuwait.

García-Rodríguez L. (2003), "Renewable energy applications in desalination: state of the art", Solar Energy 75, 381-393.

García-Rodríguez, L., 2002, Seawater desalination driven by renewable energies: a review. Desalination 143: 103-113

Gregorzewski, A. and Genthner, K., High efficiency seawater distillation with heat recovery by absorption heat pumps. Proceedings of the IDA World Congress on Desalination and Water Reuse, pp. 97-113, Abu Dhabi, November 18-24, 1995.

Hanbury W T and Hodgkies T (1995) *Desalination Technology 95*, Glasgow, UK: Porthan Ltd.

Kalogirou S. (2003), *The potential of solar industrial process heat applications.* Appl Energy, **76**(**4**), pp. 337-61.Lysen E. (2003), *An outlook for the 21st century*. Renew Energy World, **6**(**1**), pp. 43-53.

Kalogirou S. (2004), *Solar energy collectors and applications.* Prog Energy Combust Sci, **30**(**3**), pp. 231-95

Karameldin, A. Lotfy and S. Mekhemar (2003), *The Red Sea area wind-driven mechanical vapor compression desalination system,* Desalination **153**, Elsevier pp. 47-53.

Kudish A.I., Evseev E.G., Walter G., Priebe T. (2003),*Simulation study on a solar desalination system utilizing an evaporator/condenser chamber*. Energy Convers Manage **44**(**10**), Elsevier, pp. 1653-70.

M.A. Darwish , Iain McGregor, (2005), *Five days' Intensive Course on - Thermal Desalination Processes Fundamentals and Practice*, MEDRC & Water Research Center Sultan Qaboos University, Oman

Millow B. and Zarza E., Advanced MED solar desalination plants. Configurations, costs, future – Seven years of experience at the Plataforma Solar de Almería (Spain), Desalination 108, pp. 51-58, 1996.

Mobil Solar Energy Corporation (1985) Applications of Photovoltaics. Report.

Müller-Holst, H., 2007. Solar Thermal Desalination using the Multiple Effec Humidification (MEH) method, Book Chapter, Solar Desalination for the 21st Century, 215–225.

Parekh S., Farid M.M., Selman R.R., Al-Hallaj S. (2003), *Solar desalination with humidification-dehumidification technique – a comprehensive technical review*. Desalination **160**, Elsevier pp. 167-86.

Peters M S and Timmerhaus K D (1981) *Plant Design and Economics for Chemical Engineers*, Third Edition. McGraw-Hill International.

Sayig A.A.M. (2004), *The reality of renewable energy*. Renewable Energy, pp. 10-15.

Solarpac Energy Systems Inc. (1985) Photovoltaics, Electricity from the Sun, Report, 1985 by Solarpac ESI, Mississauga, Ontario L5T 1M9, Canada.

Soteris A. Kalogirou (2005), *Seawater desalination using renewable energy sources*, Progress in Energy and Combustion Science **31**, Elsevier, pp. 242-281.

Thomson M., Infield D. (2003), *A photovoltaic-powered seawater reverse-osmosis system without batteries*. Desalination **153**(1-3), pp. 1-8

Tiwari G.N., Singh H.N., Tripathi R. (2003), *Present status of solar distillation.* Solar Energy 75(5), Elsevier, pp. 367-73.

Tzen E., Morris R. (2003), *Renewable energy sources for desalination.* Solar Energy **75**(**5**), Elsevier, pp. 375-9.

United Nations, Water for People, Water for Life – UN World Water Development Report, UNESCO Publishing, Paris, 2003.

Wiseman, R., Desalination business “stabilised on a high level” – IDA report, Desalination & Water Reuse 14(2), pp. 14-17, 2004.

Biographical Sketch

Ali M. El-Nashar received the B.Sc. (Mech. Eng.) from Alexandria University (Egypt) in 1961 and Ph.D. (Nuclear Engineering) from London University (UK) in 1968. He has been a faculty member at several universities in Egypt, UK and USA and was appointed professor of mechanical engineering at Florida Institute of Technology (USA) and Mansoura University (Egypt). He was a research fellow at Clemson University (USA) during the period 1971 to 1976. He has worked as consultant for different industrial and UN organizations among which Dow Chemical Co. (USA), Ch2M-Hill Co. (USA), Science Application Co. (USA), UNEP, Technology International Co. (USA). He is member of the ASME, ISES and IDA and editor of the International Desalination and Energy journals. He has worked at the Research Center of the Abu Dhabi Water and Electricity Authority (UAE) as manager of the desalination and cogeneration section which pioneered development work on solar desalination for ADWEA for 20 years. He has been associated with the International Centre for Water and Energy Systems, Abu Dhabi, UAE.