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Economic and Environmental Analysis of Solar Powered Desalination

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Abstract

In this paper the economics of a small-scale humidification dehumidification desalination (HDD) unit driven by a concentrating v-trough solar thermal collector is explained. A comparative analysis using the net present value method was carried out for when the system is operated using solar energy and electricity from fossil fuels. The system could provide different amount of fresh water depending on mode of operation. It was shown that by end of year six the investment for the solar system reaches breakeven when compared to the electric system. The analysis also considers the amount of carbon savings that could be achieved and final cost of water produced per cubic meter. The factors that influence the systems economic viability are the outputs and costs of the desalination unit and solar collector systems, the cost of alternative energy source, cost of operation and maintenance, and the geographic location of the system, i.e. solar intensity, environmental temperature and humidity.

Keywords: Solar thermal collector; desalination; cost analysis; carbon savings.

I. Introduction

THE cost of building a desalination unit and the quality/ quantity of fresh water produced are very crucial to designing a desalination system. The costs of energy and carbon emissions from a desalination plant are generally very high regardless of the type of technology used [1]. Fig. 1 shows percentage cost of major desalination systems; namely Multi Stage Flash (MSF) Distillation, Multi Effect Distillation (MED), Reverse Osmosis (RO) and that driven by Renewable Energy Sources (RES).

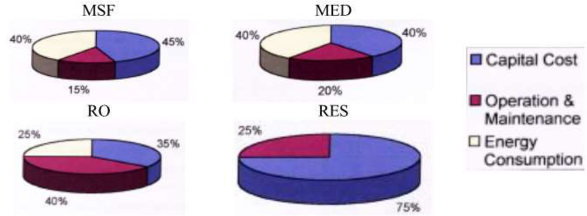

Fig. 1. Major cost of desalination plants

Not-with-standing the anticipated cost reduction offered by new emerging desalination technologies, the conventional desalination process remains expensive and unfeasible in many countries around the world. The limited means of financial resources of many countries are insufficient to meet the required process capital and operation expenses. Reference [2] compared the current water production cost of the MSF, RO, MED processes. Fig. 2 shows comparison of the major desalination technologies. For the MSF process, with a 27,000m³ per day plant, the unit cost \$0.8/m³.

This is almost equivalent to that of the RO process at an average of 0.93 per m³. However, the value presented is not the real final value; it's mostly scientific and not based on a commercial plant. The actual value is highly dependent on the feed water source and the treatment cost of the feed water. So also with the MED, despite the fact that a lower unit cost is documented at \$0.45 per m³, this method has only been utilised commercially by the desalination industry to a very limited scale. Both the values from MSF and MED do not include thermal energy cost of the systems. Assuming utilising solar energy to provide the thermal which can be considered free of charge, the cost of solar desalination will be \$1.03 per m³. This indicates solar energy as very competitive when compared to fossil fuel driven desalination system.

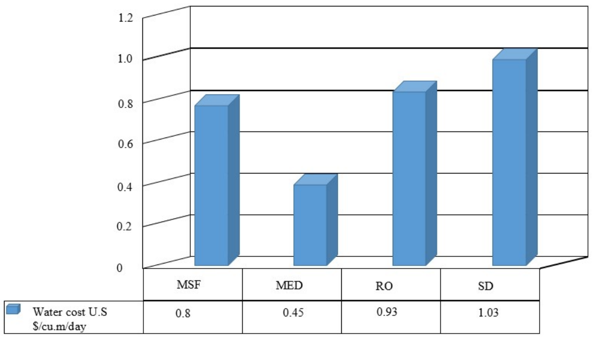

Fig. 2. Unit water cost comparison of major desalination technologies

In this study, a small scale humidification dehumidification desalination systems driven by a concentrating v-trough solar thermal collector was considered, with the focus on economic and environmental analysis of the system. Full technical details of the system can be obtained in reference [3].

II. SYSTEM ECONOMIC ANALYSIS

The net present value method used for cost analysis is a comparison between the investments made at present using the present value of money considering interest rate over a period of time. The net present value analysis was made according to (1) [4].

$$NPV = I_O + \frac{\sum_{j=1}^{t} F_t}{(1+i^t)} \quad (1)$$

Where, I_O is the capital cost, F_t, the running cost, i, the interest rate and t, the time in years.

The v-trough solar thermal collector was considered as the renewable energy source for the desalination system. A cost breakdown of the capital cost of the solar collector unit is given in Table I. The quantity of solar collector required to produce 20L/h of fresh was calculated as 7.5m² for 38% collector efficiency [5]. The miscellaneous costs include costs such as piping and installation. This is considered at around 10% of the cost of the entire system.

Table I. Capital cost of solar system

Item	Quantity	Unit Cost	Total Cost [£]
Solar collector	7.5 m²	£350 per m²	2625
Pump	1	£100	100
Miscellaneous	-	-	275
Total			3000

The capital cost of the desalination for the desalination unit is given in Table II. The miscellaneous cost here is considered to be 15%. This includes insulation costs in addition to piping and installation.

Table II. Capital cost for prototype desalination system

Item	Quantity	Unit Cost	Total Cost [£]
Desalination unit	1	£700	700
Pumps	3	£100	300
Water tank with coil HX	1 (140L)	£300	300
Miscellaneous	-	-	200
Total			1500

The running cost of the system is the cost of operating and maintaining the system over life of the system. The maintenance cost of the system is 2% of the total cost of the system. And then the energy cost base on the energy consumption of the system. For the solar driven system, the energy is said to be provided free from sun. However, there is still additional energy cost for the 0.5kW electricity used by the auxiliary components of the system. The cost of electricity is taken as £0.07 per kWh. The calculated running cost of the system is shown in Table III.

Table III. Running costs of desalination unit for both solar and electric

Costs Items	Solar System	Electric System
Total capital cost (£)	4500	1500
O&M cost (£/yr)	90	30
Energy consumption (kWh/yr)	1460	10220
Energy cost (£/yr)	100	715
Total running cost (£/yr)	190	745

The results obtained from the net present value analysis are shown in Fig. 3. It can be seen that by the end of the sixth year the investment for the solar system reaches breakeven when compared to the electric system. After this time the solar driven system will cost less than the electric driven system. This is mainly due to much less running cost of the solar system.

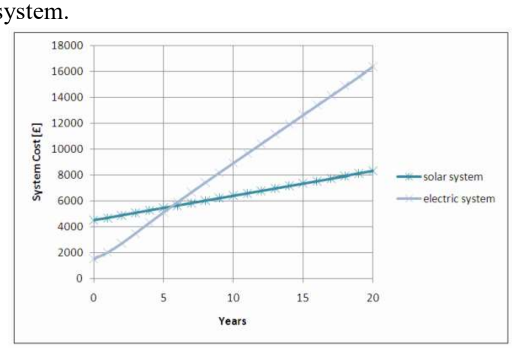

Fig. 3. Net present value analysis

It can be seen that in the sixth year of operation the investment comparison between the two systems is the same. Thereafter the cost for the electric system increase sharply while that of the solar system is more steady and gradual. Hence the life cycle saving for using the solar system is around £8000 at the end of the 20 year period.

III. CARBON SAVINGS ANALYSIS

To investigate the environmental benefit of utilizing solar energy instead of conventional source of energy, the different emission of kg CO_2 per unit energy resulting from the solar system operation are estimated and compared to those of a conventional electric system. The carbon emission is considered because it is reported as the emission which is responsible for the most important environmental problems. The analysis was carried out based on the United Kingdom's guidelines for company reporting on greenhouse gas emissions [6]. Equation (2) is used in converting electricity to CO_2:

Carbon emission = electricity used per year (kWh) x 0.54 (CO_2 conversion factor) (2)

The amount of carbon saving is amount of carbon from the solar system subtracted from that of the electric system. The amount of carbon emissions from both systems is calculated and given in Table IV. If the solar system is considered, it will amount to saving up to 4730 kg CO_2 per year.

Table IV. Carbon emissions

	Solar System	Electric System
Energy consumption (kWh/yr)	1460	10220
Carbon emission (kgCO_2/yr)	788.4	5518.8

IV. WATER COST ANALYSIS

The cost of water produced is calculate by taking the net present value of the system as the life cycle cost (LCC) and dividing it by the total amount of water produced over its life period. The cost of water produced is calculated as shown in Table V. The water production cost was found to be 7 £/m^3. There is a 50% reduction in cost compared to when electricity from the grid as the main heat source. This is competitive to a 0.1m /day RO system reported in [7] with water production cost of 14 \$/m^3.

Table V. Water cost

Costs Items	Solar System	Electric System
LCC (£)	8000	16000
Water production (m^3)	1168	1168
Water cost (£/m^3)	7	14

The cost of the solar driven system is much cheaper compared to when driven by electricity from the grid with six years payback period. This can further be significantly reduced by up to 50% if the system is mass produced. The quantity of the fresh water can be also be increased and its cost decreased if the system is optimised or operated / made to operate for longer period of time using storage. This needs a cheaper collector with heat storage in large amounts. Such collector storage can be a solar pond. For a larger scale system [8], the minimum cost of water production was estimated between £0.55-0.57 per m^3 for 20 years life cycle with running cost at 2% of total capital cost per annum, and interest rate at 10%. This is assuming the system operates 24 hours a day.

V. CONCLUSION

Up to 20kg/h of fresh water was obtained base on the test carried out. Cost analysis of the desalination system was carried out base on the preliminary results. The cost of the fresh water production is £7 per cubic meter which is 10 times higher than the tariff of conventional water. The energy requirement of the system constitutes about 58% of the system cost. When solar energy is used, there is about 34% reduction in energy cost of the system. The cost can be improved by improving the amount of water production and reducing the capital cost and energy consumption of the system.

Field testing can be carried out to ensure that the developed system operates satisfactorily under real life conditions and is suitable for commercial exploitation. A larger scale system can be designed for field trial based both theoretical and experimental research activity carried out in the laboratory. Having predicted maximum 8m of v-trough collector required to drive the HDD unit with an optimum water production of 20L/h [8], it can be used to specify for larger scale systems ranging from domestic to town size application

References

[1] A. K. Lalzad. "Development of Novel Small-Scale Desalination," Ph.D. dissertation, London South Bank University, London, UK, 2005.

[2] J. Bednarski, M. Minamide, O.J. Morin. "Test program to evaluate and enhance seawater distillation process for the metropolitan water district of southern California," Proc. IDA World Congress on Desalination and Water Sciences, Madrid, Spain, pp. 227–241, 1997.

[3] Z. Hongfei, T. Tao, H. Kaiyan and A. Mayere. "A New Trough Solar Concentrator and its Performance Analysis," Solar Energy, vol. 85, no. 1, pp. 198-207, 2011.

[4] J. L. Wolpert. "Solar Powered Ejector Air Conditioning System for Mexican Climate," Ph.D. dissertation, University of Nottingham, Nottingham, UK, 2003.

[5] A. Mayere, S. Riffat, "Performance Evaluation of V-Trough Solar Concentrator for Water Desalination Applications," Applied Thermal Engineering, vol. 50, no. 1, pp. 234-244, 2013

[6] Greenhouse gas reporting - Conversion factors 2008 [Online], Available: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2008. Accessed: May 2013.

[7] A. Eslamimanesh, M.S. Hatamipour. "Economical study of a small-scale direct contact Humidification-Dehumidification desalination plant," Desalination, vol. 250, no. 1, pp. 203-207, 2010.

[8] A. Mayere, "Solar Powered Desalination," Ph.D.dissertation, Dept. Eng., University of Nottingham., Nottingham, UK, 2011.