

Wind energy systems adapted to the seawater greenhouse desalination unit designed for arid coastal countries

H. Mahmoudi ^{1*}, S.A. Abdul-Wahab ², M.F.A. Goosen ³,
A. Ouaged ¹, S.S. Sablani ⁴ and N. Spahis ¹

¹ Faculty of Sciences and Engineering Sciences,
Hassiba Ben Bouali University, Chlef, Algeria

² College of Engineering, Sultan Qaboos University,
P.O. Box 33, Al Khod 123, Sultanate of Oman

³ New York Institute of Technology (NYIT) - Amman,
P.O. Box 840 878 Amman, 11184 Jordan

⁴ Department of Food Sciences and Nutrition, Sultan Qaboos University,
P.O. Box 34, Al Khod 123 Muscat, Sultanate of Oman

(reçu le 10 Janvier 2007 – accepté le 25 Mars 2007)

Abstract – *The wind energy can be used to power the seawater greenhouse. The aim of this study is to present the feasibility of wind energy in the seawater greenhouse desalination unit. The seawater greenhouse combines fresh water production with growth of crops in a greenhouse system. The technique is adapted for farms in arid coastal regions that are suffering from salt infected soils and shortages of potable groundwater. The dimension of the greenhouse has the greatest effect on the water production and energy consumption. A wide shallow greenhouse (200 m wide by 50 m deep) has been found to give 297 litres per day of fresh water in only eight hours (between 09.00 and 17.00). The greenhouse produces 98 % of total fresh water. This interval corresponds to the higher winds period.*

Résumé – *Le but de ce travail est d'étudier l'utilisation de l'énergie éolienne pour faire marcher une unité de dessalement d'eau de mer incorporée à l'intérieur d'une serre agricole. La serre produit l'eau d'irrigation tout en créant un climat propice pour la culture des récoltes. Cette technique adaptée pour les fermes situées dans les régions arides et côtières, qui souffrent des problèmes de salinité du sol et du manque d'eau d'irrigation. La production d'eau et la consommation d'énergie varient en fonction des dimensions de la serre. La serre de 200 m de longueur et de 50 m de largeur produit 297 litres d'eau d'irrigation en un intervalle de huit heures (entre 09.00 et 17.00 correspondant à la période où les vents sont productibles). Cette quantité représente 98 % de la quantité journalière produite.*

Keywords: Desalination – Wind energy systems – Solar energy – Seawater greenhouse.

1. INTRODUCTION

The technological advances achieved over the last 30 years in the field of desalination have enabled considerable reductions in investment costs and energy consumption. Consequently, desalination projects can be regarded as an alternative means of satisfying water demand [1]. In fact, desalination sea water and underground saline water have become one of the main sources of water in the arid regions of the Middle East, which has nearly two-thirds of the world desalination plant capacity. In certain areas in the world, the scarcity of water has resulted in a significant use of desalinated sea water for agricultural purposes.

Today, most desalination plants use fossil fuels and thus contribute to the increased levels of greenhouse gases. There have been numerous voices that are more inclined in favour of an approach to the problem that is more ecological and safer proposing the use of renewable energy sources, basically wind and solar for small scale sea water desalination [2-4].

* Usto98@yahoo.fr _ sabahl@squ.edu.om _ mgoosen@nyit.edu.om _ shyam@squ.edu.om

In many countries that suffer a chronic shortage of water, such as those of the Middle East and North Africa (MENA), over 80 % of their fresh water consumed is used for agriculture. As fresh water resources are finite, there is an inexorable pressure to reduce agricultural use of water. Desalination has become the main source of fresh water in many parts of the world, especially in the MENA countries. Thermal and reverse osmosis are the most widely used desalination technologies. Recently, technologies based on air humidification – dehumidification in a greenhouse have been proposed and investigated. The greenhouse desalination is one example. It provides a solution to the problem by creating a growing environment that substantially reduces the amount of water required for irrigation, together with new sources of fresh water.

The greenhouse, which is equipped with humidification-dehumidification devices, creates the proper climate to grow valuable crops and produces fresh water from saline water as well. The need to employ the greenhouse in coastal and isolated regions has driven the search for energy from renewable sources, such as wind and solar power. The utilization of wind energy systems is becoming increasingly attractive and therefore it is being widely used [5].

The use of irrigation water represents more than 80 % of the total fresh water consumed in the MENA countries [6]. Solar desalination methods are well suited for the arid and sunny regions of the world as in the Arabian Peninsula. A variety of solar desalination devices have been developed. A comprehensive review of ways that renewable energy sources can be used for seawater desalination has been presented by Kalogirou [5]. One of the more successful examples is the multiple effects still [7]. Latent heat of condensation is recovered in two or more stages (generally referred to as multi-effects) so as to increase the production of distillate water and improve the system efficiency as well.

It has become apparent that a key feature in improving overall thermal efficiency is the need to gain a better understanding of the thermodynamics behind the multiple use of the latent heat of condensation within a multi-effect humidification-dehumidification solar still. In addition, while a system may be technically very efficient, it may not be economic (i.e., the cost of water production may be too high). Therefore, both efficiency and economics must to be considered when choosing a solar desalination system. There is also a growing realization in arid and non-arid countries that the desalination techniques are the long-term solution to a shortage of potable water.

An example of a humidification - dehumidification system is a pilot plant which has been built at Kuwait University [8]. The system consists of a salt gradient solar pond, which was used to load the air with humidity. Fresh water was collected by cooling the air in a dehumidifying column. Further, a closed-air cycle humidification - dehumidification process has been used by Al-Hallaj for water desalination [9]. Sablani *et al.* [7], Paton and Davis [10], and Goosen *et al.* [11, 12] used the humidification-dehumidification method in a greenhouse-type structure for desalination and for crop growth (Fig. 1). In these studies, the seawater greenhouse produced fresh water and crop cultivation in one unit. The design is suitable for arid regions that have the seawater nearby.

2. PROCESS DESCRIPTION

The sea water greenhouse uses sunlight, seawater and the atmosphere to produce fresh water and cool air, creating more comfortable conditions for the cultivation of crops. The process recreates the natural hydrological cycle within a controlled environment. Seawater is pumped from a well near the sea. The naturally occurring sand filtration allows removal of solid particles, and other impurities. Filtered water is directed to the cold tank where it goes to the condenser and then to the first evaporator. The brine from the first evaporator turns over to the cold tank (Fig. 1 and Fig. 2).

The evaporator is the entire front wall of the building. It consists of a cardboard honeycomb lattice and faces the prevailing wind. Seawater trickles down over this lattice, cooling and humidifying the air passing through into the planting area. After that dust, salt spray, pollen and insects are trapped and filtered out.

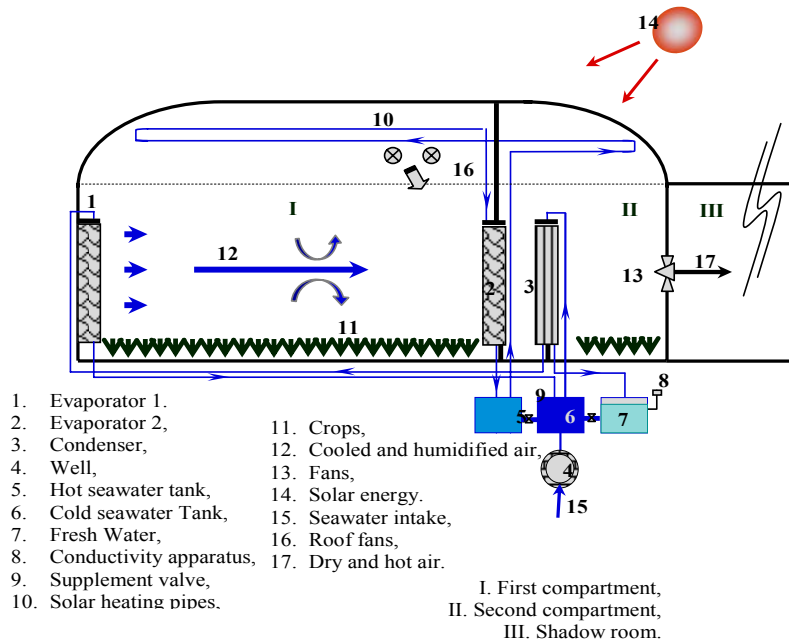


Fig. 1: Process schematic [10, 13]



Fig. 2: A photograph of the seawater greenhouse of Al Hail at Muscat in the Sultanate of Oman

Fans draw the air through the greenhouse and into the shade room. Air passes through a second seawater evaporator and is further humidified to saturation point. Only a small fraction of sunlight is useful for photosynthesis. Sunlight is selectively filtered by the roof elements in order to remove radiation that does not contribute to photosynthesis. This helps to keep the greenhouse cool whilst allowing the crops to grow in high light conditions.

In a normal greenhouse the remaining sunlight translates into hot growing conditions and large watering requirements. The current greenhouse is equipped with a preheating system which consists of long pipes placed the length of the greenhouse. The seawater in the pipes is heated directly by the radiation of sunlight and feed the second evaporator before returning to the hot tank.

Air leaving the evaporator is nearly saturated. It passes over the condenser coils carrying cool seawater, which may come from the cold tank. The fresh water condensing from the humid air is of overall zero salinity. This water is piped to the storage for irrigation.

The seawater greenhouse needs electric energy to produce water. The power is mainly used by the:

- Feed pump, which feeds the greenhouse by seawater (Fig. 3),
- Pump of the cold tank which feeds the first evaporator (Fig. 4),
- Pump of the hot tank, which feeds the second evaporator,
- Two wall fans (Fig. 5),
- Two roof fans (Fig. 6).



Fig. 3: Feed pump



Fig. 4: Pump of the cold tank



Fig. 5: Wall fans



Fig. 6: Roof fans

3. METEOROLOGICAL/SITE-SPECIFIC INFORMATION

The seawater greenhouse uses the renewable energy for climate control and for production of the fresh water. Hence, it is necessary first to carry out the analysis of the local climate. The greenhouse integrates meteorological sensors which can be used to give the required data file. This file contains observations at every half hour of the day and it covers a whole year quarter. The file contains data related to wind speed, SWG (seawater greenhouse) fresh water production,

the ambient temperature, humidity of the air in different points, wind direction, and the power consumption.

Temperature and humidity are high throughout the year from the period May to September [12]. The peaks of high humidity usually occur from sunset to sunrise with a corresponding reduction in humidity in the day (Fig. 7). The variation of humidity is faithfully following a cycle, which repeats itself every day. The yearly average wind speed is 2.7 m/s, although gusts of up to 50 m/s are recorded from 30°N [12].

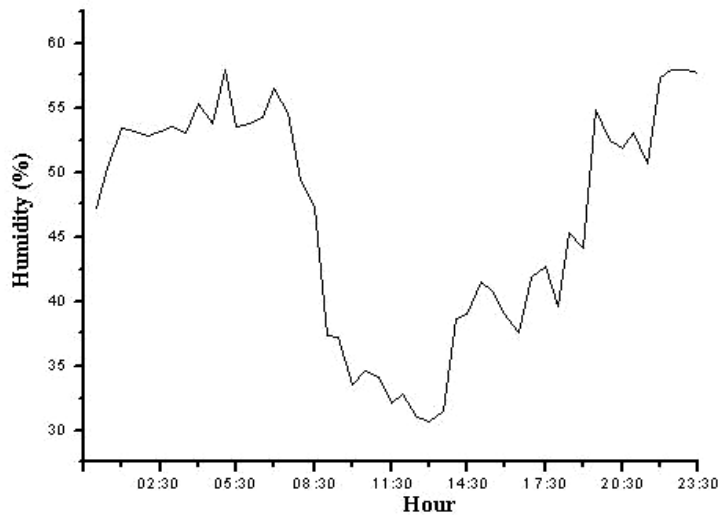


Fig. 7: Diurnal humidity distribution at Al Hail, Muscat, 18 January 2005

4. POWER OF THE WIND ENERGY

All renewable energy (except tidal and geothermal power), and even the energy in fossil fuels, ultimately comes from the sun. The sun radiates $1,74 \cdot 10^{17}$ watt of energy to the earth per hour. A wind turbine obtains its power input by converting the force of the wind into torque (turning force) acting on the rotor blades. The amount of energy that the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed. The energy content of the wind varies with the cube (the third power) of the average wind speed (Fig. 8). The power of the wind passing perpendicularly through a circular area is shown in equation (1):

$$P = 1/2 \rho v^3 \pi r^2 \quad (1)$$

where:

P: the power of the wind measured in W. ρ : the density of dry air measured in kg/m^3 , at average atmospheric pressure at sea level at 15 °C. v: the velocity of the wind measured in m/s. $\pi = 3.1415926535$.

The power curve of wind turbine is a plot that indicates how large the electrical power output will be for the turbine at different wind speeds. Wind energy calculations are made by matching the power-wind speed characteristics of commercial wind machines (CWMs) with the long term hourly wind speed data. The characteristics/technical data of some NORDEX-CWMs (Fig. 9) are illustrated in Table 1.

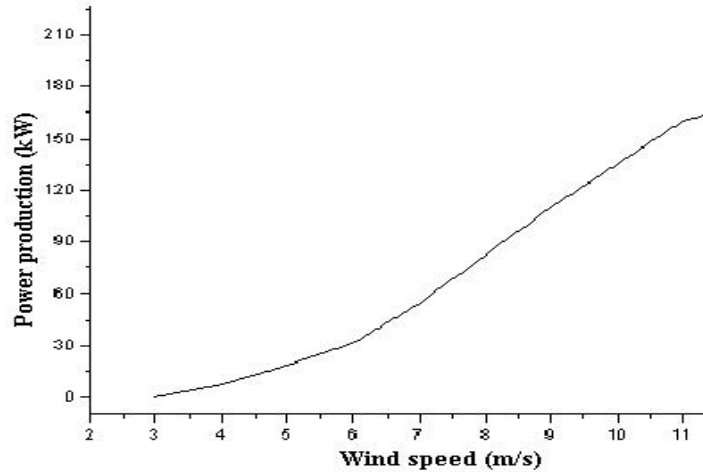


Fig. 8: Power curve for the N27/150 model

The power curve of wind turbine is a plot that indicates how large the electrical power output will be for the turbine at different wind speeds. Wind energy calculations are made by matching the power-wind speed characteristics of commercial wind machines (CWMs) with the long term hourly wind speed data. The characteristics/technical data of some NORDEX-CWMs (Fig. 9) are illustrated in Table 1.

Table 1: Power-wind characteristics of commercial wind machines (<http://www.nordex.com/>)

Wind machine model	Nominal power (kW)	Nominal output (m/s)	Cut-in wind speed (m/s)	Cut-out wind speed (m/s)
N27/150	150	16	3-4	25
N29/250	250	15.5	3-4	25
N43/600	600	13	3-4	25
N54/1000	1000	14	3-4	25
N60/1300	1300	15	3-4	25

5. WIND DATA

Solar and wind energy represent a highly desirable, clean, and abundant source of energy [14]. Experimental data should always be repeated to verify that results are reproducible. In general, results should not vary by more than a small amount. The principal challenge when performing experiments is to obtain accurate and reproducible results. The plot, which shown in Figure 10, tracks daily wind speed variations from 18 December to 7 February 2006. It illustrates perfectly the reproducibility of the journal distribution of wind speed. The same philosophy has been applied to confirm the good reproducibility of the daily data.

Figures 11 and 12 represent significantly the reappearance of the same daily plot of respectively the fresh water production and the power consumption during the entire experimental interval. This makes possible to use arbitrarily any day measurement data for analysis.



Fig. 9: A photograph of a wind park

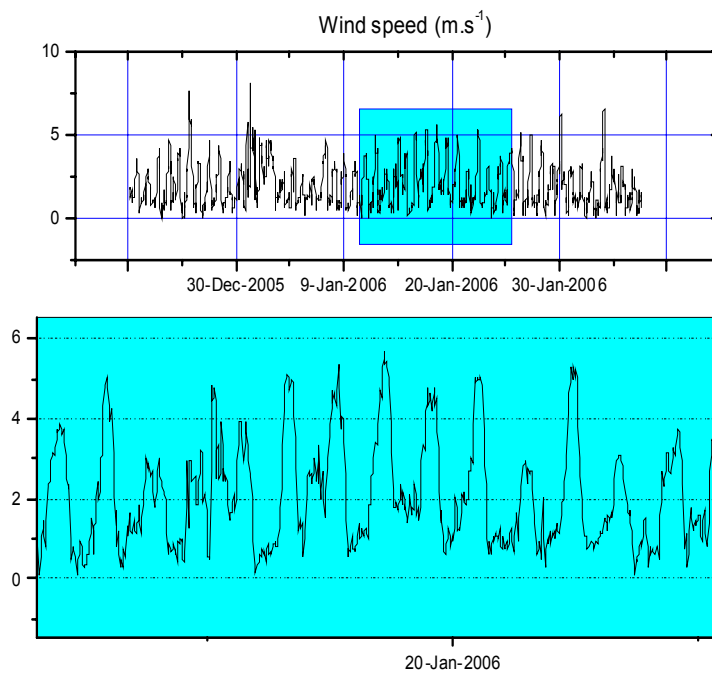


Fig. 10: Wind speed distribution (18 December to February 2006)

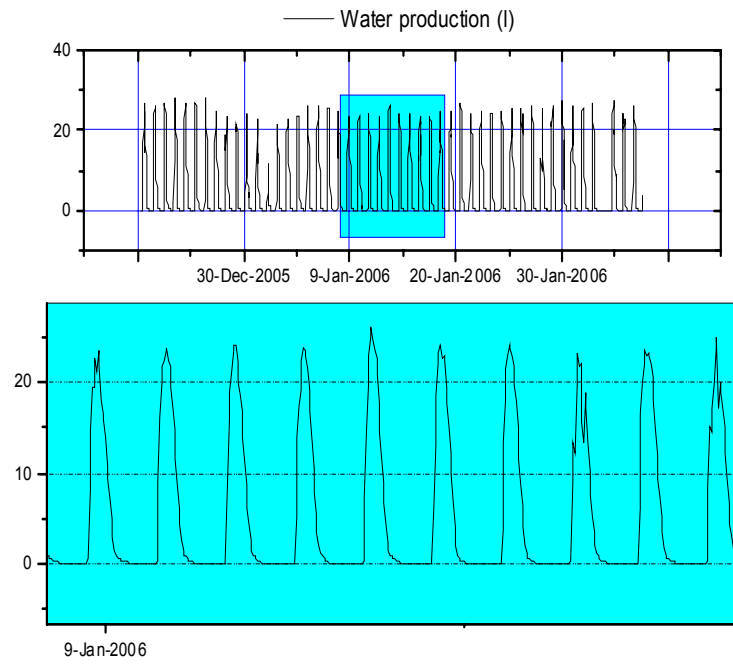


Fig. 11: Fresh water production distribution (18 December to 7 February 2006)

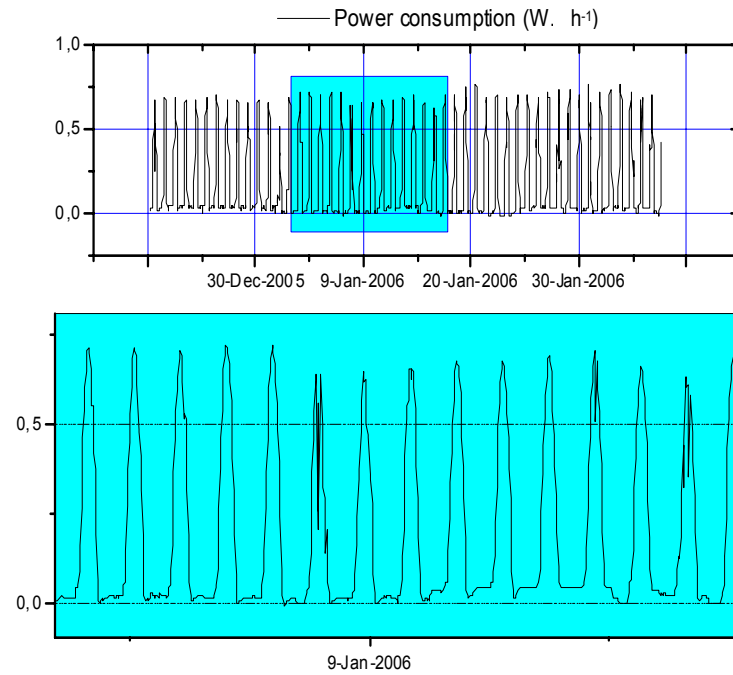


Fig. 12: Power consumption distribution (18 December to 7 February 2006)

At the area of the study, wind speed measurements are generally higher in summer months (May to August.) as compared to other months (Fig. 13). This indicates that a WECS (Wind Energy Conversion Systems) would produce appreciably more energy during summer months as that compared to the other months. This conforms perfectly to the needs for agriculture production using the greenhouses, which consume much more water in summer than in winter.

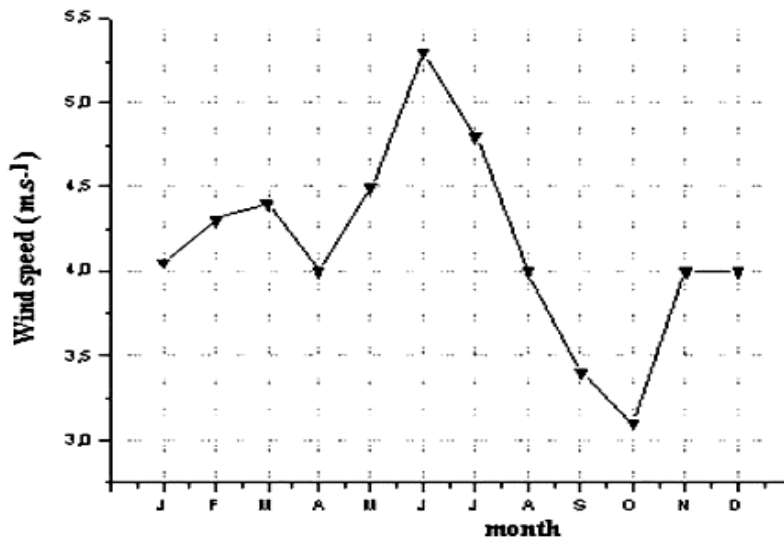


Fig. 13: Monthly average wind speed at Muscat (Seeb airport, period of 1999-2004)

Figure 14 shows the diurnal variation of wind speed at the area of the study. The diurnal variation provides information on the availability of the wind during the entire day. The diurnal variation shows relatively higher winds between 10:00 and 18:00 hours while lower values during the rest of the day. It is clear that there are large diurnal variations with peak during the midday.

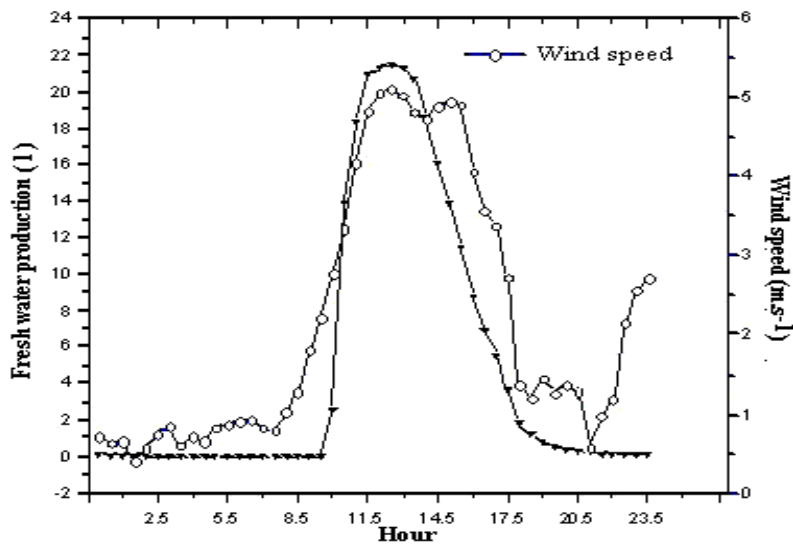


Fig. 14: Comparison between diurnal wind speed and the SWG water production Al Hail Muscat) (01/18/2005)

The cut-in speed of most of the commercial wind machines (CWMs) is about 4 m/s. This implies that stand-alone WECS (Wind Energy Conversion Systems) if installed for the SWG (Seawater greenhouse) will produce energy at least eight hours per day. In the same eight hour period (between 09:00 and 17:00 h), the greenhouse produces 98 % of the total daily fresh water. This interval corresponds to the duration of the interval of higher wind speeds (Fig. 15).

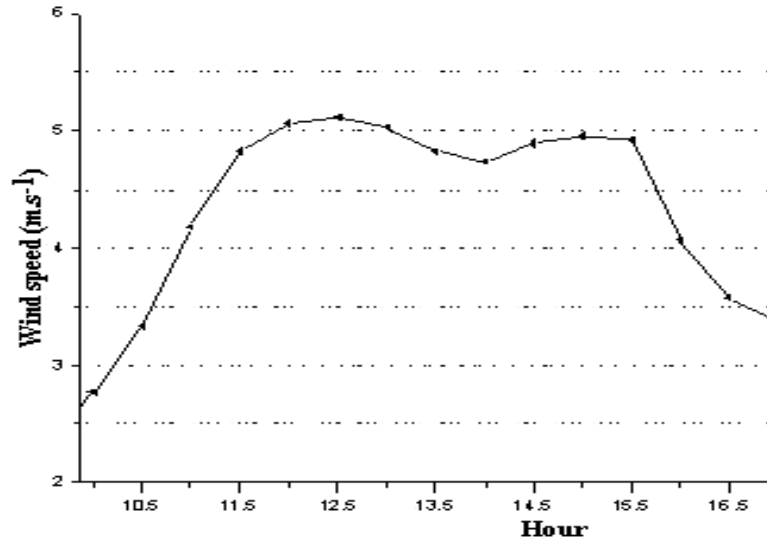


Fig. 15: Daily domain of working of the WECS (Al Hail at Muscat, 18 January 2005)

Regarding frequency distribution of wind speed (Fig. 11), the collected wind data shows that wind speeds are less than 4 m/s for 70 % of the day.

Figure 16 indicates the diurnal plots of the solar radiation and fresh water production of the SWG. It can be seen clearly that the solar radiation goes hand-in-hand with the amount of fresh water product.

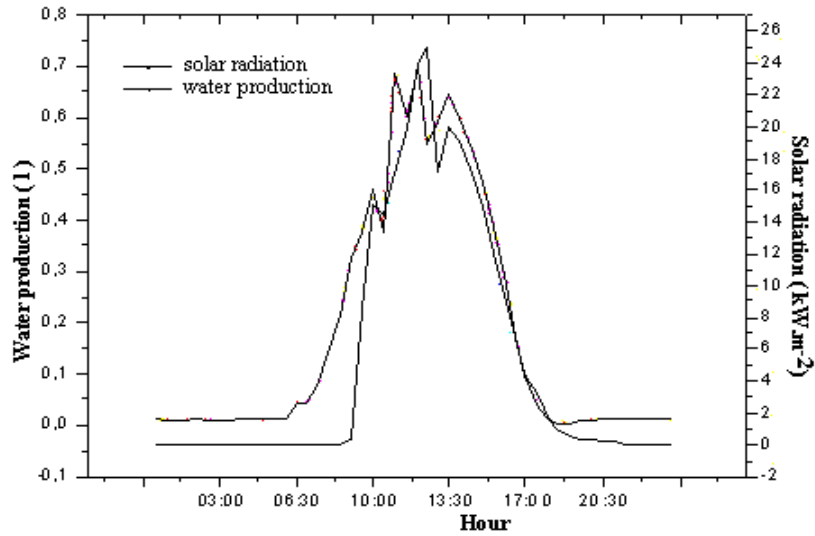


Fig. 16: Diurnal variation of solar radiation and water production at Al Hail site (Muscat)

6. CONCLUSION

Many research efforts have been carried out to address the challenges in using the wind energy. Wind energy is fuelled by the wind and therefore it is a clean fuel source. It doesn't pollute the air like power plants that rely on combustion of fossil fuels (e.g., coal or natural gas). Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gasses. Wind energy is one of the lowest-priced renewable energy technologies available today. Wind turbines can be built on farms or ranches, thus benefiting the economy in rural areas where most of the best wind sites are found. Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land.

This current study has analyzed the feasibility of an innovative autonomous wind/ solar powered seawater greenhouse desalination unit. The examination of the data collected during the operation of the SWG confirmed that it is technically feasible to take advantage of renewable energy in order to ensure the autonomy of the SWG.

It was found that the use of wind/solar system can produce fresh water without the back up support of fossil fuel energy sources. This was justified by the fact that in only eight hour (between 09.00 and 17.00); the greenhouse produced 98% of total fresh water required. This interval corresponded to the duration of the solar sunning and wind efficiency interval.

Acknowledgements - We would like to acknowledge the valuable assistance of Mr Charles Patton of Seawater Greenhouse Ltd, UK, in the design, construction and optimization of the system.

REFERENCES

- [1] N.X. Tsiourtis, 'Desalination and the Environment', Desalination. Vol. 141, pp. 223 – 236, 2001.
- [2] G. Petersen, S. Fries, J. Mohn and A. Meuller, 'Wind and Solar Powered Reverse Osmosis Desalination Units, Description of Two Demonstration Projects', Desalination, Vol. 31, pp. 501 – 509, 1979.
- [3] V. Belessiotis and E. Delyannis, 'Water Shortage and Renewable Energies (RE) Desalination Possible Technological Applications', Desalination, Vol. 139, pp. 133 - 138, 2001.
- [4] E. Delyannis, 'Historic Background of Desalination and Renewable Energies', Solar Energy, Vol. 75, N°5, pp. 357 - 366, 2003.
- [5] A. Soteris Kalogirou, 'Seawater Desalination Using Renewable Energy Sources', Progress in Energy and Combustion Science, Vol. 31, pp. 242 - 281, 2005.
- [6] Abdulhaiy M. Radhwan and Hassan E.S. Fath, 'Thermal Performance of Greenhouses with a Built-in Solar Distillation System: Experimental Study', Desalination, Vol. 181, pp. 193 - 205, 2005.
- [7] S. Sablani, M.F.A Goosen, C. Paton, W.H. Shayya and H. Al-Hinai, 'Simulation of Fresh Water Production Using a Humidification-Dehumidification Seawater Greenhouse', Desalination, Vol. 59, pp. 283 - 288, 2003.
- [8] E. Delyannis and V. Belessiotis, 'Solar Desalination for Remote Arid Zones', In: M.F.A. Goosen and W.H. Shayya (Eds.), Water Management, Purification and Conservation in Arid Climates, Vol. II: Water Purification, Technomic Publishing, Lancaster, PA, pp. 277 – 296, 2003.
- [9] S. Al-Hallaj, M.M. Farid and A.R. Tamimi, 'Solar Desalination with a Humidification-Dehumidification Cycle: Performance of the Unit', Desalination, Vol. 120, pp. 273 - 280, 1998.
- [10] A.C. Davis and C. Paton, 'The Seawater Greenhouse for Arid Lands', In: Proc. Mediterranean Conf. on Renewable Energy Sources for Water Production, Santorini, 10-12 June, 1996.
- [11] M.F.A. Goosen, S.S. Sablani, W.H. Shayya, C. Paton and H. Al-Hinai, 'Thermodynamic and Economic Considerations in Solar Desalination', Desalination, Vol. 129, pp. 63 - 89, 2000.

- [12] M.F.A. Goosen, S.S. Sablani, C. Paton, J. Perret, A. Al-Nuaimi, I. Haffar, H. Al-Hinai and W.H. Shayya, 'Solar Energy Desalination for Arid Coastal Regions: Development of a Humidification-Dehumidification Seawater Greenhouse', *Solar Energy*, Vol. 75, pp. 413 - 419, 2003.
- [13] M.A. El Hadidy and S.M. Shaahid, *Journal of the Association of Arab universities for Basic and Applied Sciences*, Vol. 1, pp. 1 - 14, 2005.