# Homemade Solar Desalination System for Omani families

Miqdam T Chaichan, Hussein A Kazem, Khaleel I Abaas, Ali A Al- Waeli

**Abstract**— Oman suffers from the lack of the water supply and demand balance, causing a sharp decrease of groundwater stored in the Sultanate, which if continued, it will have an adverse impact on irrigation, agriculture, drinking water projects in this country. In this work, a simple and cheap solar distillation system was introduced. This system is simple, so it can be assembled by any individual in the family as the various parts are widely available in shops and local markets.
Three water samples (sea water, waste water, and tap water) were distilled in this system to evaluate its performance. The results revealed that this system can produce from one to four liters/day depending on its size, which could be increase with the distill system size. Also, the three samples were purified as the water screening revealed. The resulted pure water was in the acceptable range for man drinking and use.

**Index Terms**— Sea water desalination, brackish water distillation, waste water, tap water.

## 1 Introduction

Water is the source of life and its primary need for entirely living creatures. That's why it's hard to live deprived of water [1]. The lack of portable water and the high cost of energy and pollution problems had encouraged finding appropriate solutions to meet these challenges [2]. The usage of renewable energies such as solar power to purify brackish or sea water represents a promising way [3]. Desalination technology has been developed continuously through the last decades. Today, this technology is capable to produce freshwater from sea water [4].

Desalination processes consumes significant quantities of energy to separate salts from seawater [5]. Several Middle East countries such as Oman, Because of the presence of oil wells, have enough money to invest in desalination projects. People in many other areas of the world deprived of this gift that allows them to develop in a similar manner [6]. The estimated installed capacity of desalinated water systems all over the world in year 2000 was about 22 million $m^3$/day. This quantity is expected to increase steadily in the next decades [7 & 8].

The use of renewable energy for water desalination can be considered technically as an advanced option to solve the energy and water problems together [9]. The pace of research and development will be continued to improve the efficiency of the distillation systems and reduce the cost of capital, making these systems competitive with the current distillation systems that are mainly dependent on fossil fuels [10]. Currently, it can be considered that the cost of production of fresh water from desalination systems operates in renewable energy less than other alternatives operates with fossil-fuels in remote areas where it is difficult to get electricity [11].

So far, the application of direct solar thermal desalination is limited to the use of small-sized units, which are suitable to serve limited small communities, in remote areas, where the presence of water is scarcity [14]. Many studies were conducted to increase distillers' productivity by increasing the entering water temperature in several ways. From these attempts: using solar water heater linked to the solar still [15], using solar pond connected to the still [16], increasing the stored energy by adding PCM to the still [16]. Also, ref. [17] added concentrated solar heater with PCM storage media to the solar still. In the same trend, Ref. [18] used aluminum powder to enhance the paraffin wax inside the solar still thermal conductivity. In all these attempts the authors succeeded to increase the solar productivity which allows for the use of such systems on a large scale for the purposes of houses water distillation.

In this study, distilled water for household appliance will be designed and manufactured which can easily be used and maintained for obtaining drinking water for the family. This effort is a part of the hard work done by the Omani Society to raise awareness of the importance of culture and the use of renewable energies on the public and private level [19-47].

## 2 Experimental Setup

### 2.1 Problem Statement

The water resources in the Sultanate of Oman include two types of water resources: The first is the traditional (natural) resources, which is the surface water and the groundwater. This resource represents about 87% of the available water resources. The non-conventional water resources include water desalination and waste water treatment and represent about 13% from the Sultanate water. The primary water source in the Sultanate is rain. Rain falls in the north of Oman areas during the winter months (November to April) and as thunderstorms in the summer. In the south of Oman, rain falls during the summer as a result of the monsoon (June to September). The rainfall is ranging from less than 50 mm in the desert portions and 50 mm in the plains to about 200 mm in the mountain areas [48].

The Sultanate passes with drought periods, which may sometimes last for two or three consecutive years. The average total

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rain falling on the Sultanate's area of about 9.5 billion m3 per year, 80% of which evaporates and the rest flows on the surface and some leaks directly into the groundwater reservoirs [49].

The total volume of renewable aquifers (the amount of annual recharge) is about 1295 million m3 per year, which is less than the equivalent of public consumption with about 25%. This difference is one of the challenges facing the Sultanate in the field of water resources to balance the supply with the demand. Most of the aquifers feeding 70 % are received from the surface water through leakage, and the rest receive directly from rainwater [50].

In recent years, the water resources have increased significantly, through the provision of non-traditional resources derived from water desalination and wastewater treatment, where the proportion of these resources rated up to 16% of the total water use in the Sultanate [48].

The rapid population growth and overall development pursued by the government of the Sultanate during the past decades has led to higher demand for water across the Sultanate. This water consumption rise has caused demand to intercept groundwater flowing and pulled through wells without proper planning. This work led to destabilize the natural balance of water, and in some areas, the consumption rates has exceeded the storage rates, which caused lower water levels in the aquifer in some coastal areas. This situation leads to lower available water, which a large part of the citizens of the Sultanate depends upon it in their daily lives and livelihoods [50].

According to an available hydrological data, the balance of water in the Sultanate today exposed to water deficit that is estimated at 378 million m3. The deficit in the Batinah region represents 69% of the total deficit in the whole Sultanate due to the rise in agricultural uses rates, where about 50% of agricultural production in the Sultanate is concentrated in the Batinah region. Besides, the phenomenon of the deterioration of water quality of groundwater is one of the challenges facing the water resources sector [51].

## 2.2 The designed system

Desalination system uses solar energy as a source of direct heat needed to purify water. This system consists of several parts, the most important one is the steel segment, where the brackish or salty water is put to generate steam mode. The heating process can be enhanced by using the reflector to sun radiation directed towards the distilled water. A cold glass is used as a condensing part to collect the condensed vapor in the bottom container made of stainless steel. A filter paper was used in addition to lim-estone pieces which were used to get drinking water with better specifications. The recent design can be used to serve the needs of a single family. The designed distiller productivity estimated to be from one to four liters of drinking water a day. This productivity variation depends on the device size whether small or large. The system consists of a simple, and a cheap part can be bought from local markets and easy to be assembled.



The system parts were:

1- Filtration part: this part created from a glass tank contains three conical flasks with filter papers each. The filter papers are used to separate the solid particles and dirt from water. In this container masses of limestone were added to reduce the sea water acidity. Fig. 1 represents the filtration part.

Fig.1, the filtration part

2- The steel part: This steel container can be found in any market, and it is used for cake production in the houses. This steel container will be the room of the non-pure water. This vessel will operate as water evaporator where the brackish and salty water will be evaporated and the dirt and contaminates will still inside it. Fig. 2 shows the steel container. This container selected with non-selective black color to confirm the absorption of all the incident solar radiation. More solar radiation absorbed, the higher the temperature of the water in the container, and then, the evaporation increased.

Fig. 2, the steel container (evaporation part)

3- The Reflector: Three mirrors in this work were used to reflect the solar radiation to the system to increase the water temperature and to enhance the water evaporation process. Fig. 3 illustrates the distillation system reflectors. The mirrors were distributed in a way that it follow the sun rays and direct it to the distillation system all the day time. Thee mirrors were cleand daily to confirm high reflection efficiency.

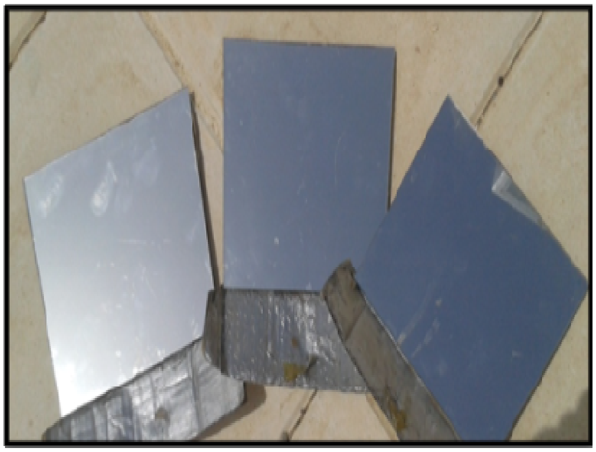

Fig. 3, the reflectors used in the system

4- The condensing unit: This unit is a clear glass with conic surface used to collect the vapor condenses on its surface. The condensing steam drips, slips, and falls inside a center tube (the collector). Fig. 4 declares the condensing unit.

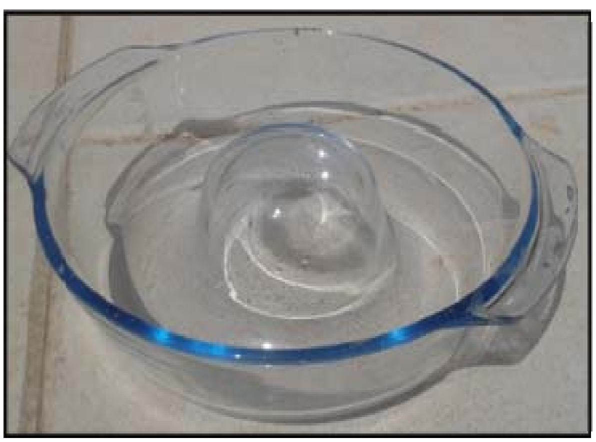

Fig. 4, the condensing unit

5- The inner container: this vessel is made from stainless steel. It is used to collect condensing water (treated water) drops. This packet is available in local markets with suitable prices. Fig. 5 demonstrates the used container. This container was cleaned eavryday before usage and after gathering the produced water to protect the the distillated water from mixing with any pollutants, bacteria, or germs.

Fig. 5, the central container of the system

The new distillation system is a very simple one; the family can assemble it without any external aid. This system only maintenance requirement is cleaning of the black propylene part from any solid material accumulation, changing the filter paper when it is needed, and replacing the glass cover in case of accidental breakage. Fig. 6 shows the assembled homemade distillation system.



### 2.3 Materials

The system is entirely made of recycled materials:

1. The bottom container fixed in palm fronds to ensure negligible heat loss to the surroundings.
2. The inner vessel made of stainless steel, and it was cantered by three mirrors to concentrate sunlight into the evaporation part to increase temperature.
3. The cover on the top is made of the clear thin glass material to increase condensation process as it loses it absorbs condensation heat from the water and eject it to the ambient air quickly.
4. The salt water contains salts and solid material, for thus a paper filters size 42 µm were used to filter the salty water and to decrease the suspended contaminants percentage of the salts.
5. The evaporated water will distil; limestone was used to give the water its general properties of the drinking water.

### 2.4 The assembly procedure

The user will connect the three most important parts (the filtration, the evaporator, and the central parts) as well as the clear glass. Then, the three conical flasks filled with salt water to purify it from solid parts. The pipe from the tank of the conical flask to the salty water container attached to feed water. The three mirrors are arranged around the salty water tank base to concentrate sunlight inside this water to increase its evaporation. The system must be placed in an area where no shadows fall on it during any part of the day. The system will generates freshwater until evening. The purified water can be removed for use.

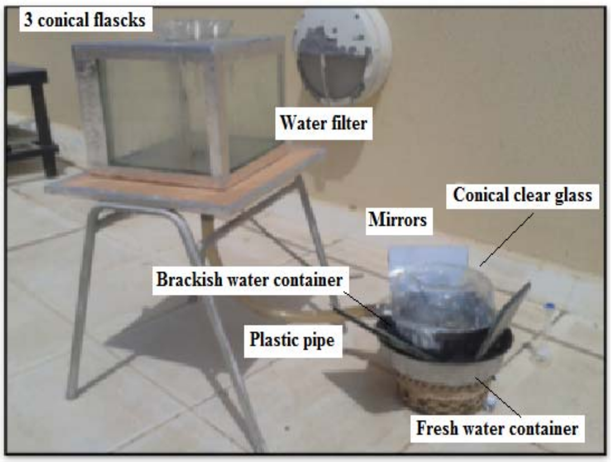


Fig. 6, the homemade distillating system

### 2.5 Tests Procedure

Three water samples were collected (sea water, tap water, and waste water) to test and evaluate the resulted distilled water from the system. Before desalination, the sea water was very concentrated by salts like sodium and magnesium. The sea water colour was close to white since it contains salts. Table 1 represents the tested waters samples parameters before desalination process. The waste water is non-safe water because the parameters indicated in Table 1 are not normal as drinking water and the colour is darker than the other waters. The parameters of tap water are very close to parameters of drinking water, but it is needed to be treated by solar desalination treatment. So, the general goal is to process these samples of waters to be safe drinking water by Homemade Desalination System. The variable parameters values were measured in the Food and Water Laboratories Center of the Omani Ministry of Regional Municipalities and Water Resources.

TABLE 1,
THE PARAMETERS VALUES OF THE WATERS SAMPLES BEFORE SOLAR DESALINATION

| Parameter values | Sea water | Tap water | Waste water |
|---|---|---|---|
| PH | 8.07 | 7 | 7.5 |
| TDs | 40420 mg/l | 110-130 mg/l | 500 mg/l |
| Sodium | 12125 mg/l | 5 mg/l | 21-83 mg/l |
| magnesium | 16.28 mg/l | 9.5 mg/l | 10.01- 19.11 mg/l |

## 3 Results and Discussions

Table 2 represents the parameters values of the sea water before and after the distillating process. All the measured parameters were reduced highly. The produced water is suitable for human use without any danger as it is close to the international and Omani water specifications.

Table 3 shows the parameters values of wastewater before and after the distillating process. This waste water full of germs and bacteria that defiantly can hurt the human and cause severe diseases, in spite of that all the measured parameters before distillation process was small compared to salty water. The distillation process reduced its measured parameters in addition to purifying it from the germs and bacteria.

TABLE 2
THE PARAMETER VALUES OF THE SEA WATER BEFORE AND AFTER THE SOLAR DESALINATION TREATMENT

| Measured Parameters | Before Desalination Tretment | After Desalination Treatment |
|---|---|---|
| pH | 8.07 | Approximate 7.6 |
| TDS | 40420 mg/l | (600 – 120) mg/l |
| Sodium | 12125mg/l | >200 mg/l |
| Magnesium | 16.28 mg/l | >200 mg/l |

TABLE 3
THE PARAMETER VALUES OF THE WASTEWATER BEFORE AND AFTER THE SOLAR DESALINATION TREATMENT

| Measured Parameters | Before Desalination Tretment | After Desalination Tretment |
|---|---|---|
| pH | 7.5 | Approximate 7.3 |
| TDS | 500 mg/l | >100 mg/l |
| Sodium | 21-83 mg/l | (10-7) mg/l |
| Magnesium | 10.01- 19.11 mg/l | (7-5) mg/l |

Table 4 reveals the measured parameters values of tap water before and after the distillation process. Tap water has fewer contaminants and pH as well as Sodium and Magnesium contents compared to salty and waste waters. However, the distillation process reduced these parameters values significantly. The resulted water, in this case, is highly suitable for man drinking and usage.

TABLE 4
THE PARAMETER VALUES OF THE TAP WATER BEFORE AND AFTER THE SOLAR DESALINATION TREATMENT

| Measured Parameters | Before Desalination Tretment | After Desalination Tretment |
|---|---|---|
| pH | 7.3 | 7.1-7 |
| TDS | (110-130) mg/l | (3.7-3.1) mg/l |
| Sodium | 7.73 mg/l | Approximate 7.1 mg/l |
| Magnesium | 9.5 mg/l | (4-3.22) mg/l |

### 3.1 Market Research

This product market includes whole Oman especially near sea. The Omani family can use it because the Omani water whether it is tap water or from lakes and wells has high proportion of salts. This product gives a good quality of drinking water. It can produce one liter to four liters per day. Its size is 28.2 cm ×66 cm. It can be made in many scales. The presented design can be used to serve the needs of a single family.

## 4 Conclusions

The water situation is critical for the Sultanate, which requires everyone's cooperation with the state to reduce the pressure on water desalination facilities. From here we set off in this study to design and prepare a very simple distillation system can be assembled by anyone with the family from materials locally available and cheap. Three samples of water been tested: sea water, waste water, and tap water. Important variables that affect the humans health was measured, such as pH, Magnesium, and Sodium ratio in each sample.
The practical results reveal that the assembled system can produce from one to four litres of distilled water for all the day operation. The measured parameters reduced profoundly after distillation, which made the three samples suitable for man use.

## 5 References

[1] R.K. Jain, H. Singh, A. Varshney, S. Bajpai, D. Sharma, "Study of Water Distillation by Solar Energy in India, International J of Mechanical Eng. and Information Technology, vol. 3, no. 2, pp. 1004-1009, 2015.
[2] P.A. Reddy, H. Kumar, and V. Natarajan, "Design and Characterization of a Solar-Powered Water Distiller," Published in Department of Physics, Indian Institute of Science, Bangalore, 2013.
[3] Edeoja, A. Okibe , U. Fadoo, "Investigation of the Effect of Angle of Cover Inclination on the Yield of a Single Basin Solar Still Under Makurdi Climate," The International Journal of Engineering and Science (IJES), vol. 2, no. 7, pp. 131-138, 2013.
[4] M.T. Chaichan and H.A. Kazem, "Status and Future Prospects of Renewable Energy in Iraq," Renewable and Sustainable Energy Reviews, vol. 16, no. 1, pp. 6007–6012, 2012.
[5] E. Halawa and W. Saman, "Thermal Performance Analysis of a Phase Change Thermal Storage Unit for Space Heating," Renewable Energy, vol. 36, pp. 259-264, 2011.
[6] A.K. Rai, V. Sachan and M. Kumar, "Experimental Investigation of a Double Slope Solar Still with a Latent Heat Storage Medium," vol. 4, no. 1, pp. 22-29, 2013.
[7] S. Gorjian, B. Ghobadian, T.T. Hashjin and A. Banakar A, "Thermal Performance of a Point-Focus Solar Steam Generating System," 21st Annual International Conference on Mechanical Engineering-ISME2013, School of Mechanical Eng., K.N.Toosi University, Tehran, Iran, 7-9 May, 2013.
[8] B. Chaudhari, A. Chitlange, M. Potdar, S. Naikwade and A. Kulkarni, "Thermal Analysis of Convective Heat Loss for Cavity Receivers in Windy Conditions," World Journal of Science and Technology, vol. 2, no. 4, pp. 50-52, 2012.
[9] S. Mendoza, E. Silva, O. Almazan and R. Guillen, "Modeling Generation Systems from using Solar Sterling Engines Parabolic Dishes (Solar/Dish), World Renewable Energy Forum, WREF, 2012.
[10] A.Z. Salman and S.T. Hamidi, "Experimental Study of the Effect of Reflection Mirrors Orientation on the Performance of Solar Still," Journal of Engineering and Development, vol. 16, no.4, 2012.
[11] K. Swetha and J. Venugopal, "Experimental Investigation of a Single Slope Solar Still using PCM," International Journal of Research in Environmental Science and Technology, vol. 1, no. 4, pp. 30-33, 2011.
[12] Y. Rafeeu and M.Z.A. Kadir, "Thermal Performance of Parabolic Concentrators under Malaysian Environment: A Case Study," Renewable and Sustainable Energy Reviews, vol. 16, pp. 3826– 3835, 2012.
[13] S.S. Sebti, S.H. Khalilarya, I. Mirzaee, S.F. Hosseinizadeh, S. Kashani and M. Abdollahzadeh, "A Numerical Investigation of Solidification in Horizontal Concentric Annuli Filled with Nano-enhanced Phase Change Material (NEPCM)," World Applied Sciences Journal, vol. 13, no. 1, pp. 09-15, 2011.
[14] S. Ramasamy and B. Sivaraman, "Heat Transfer Enhancement of Solar Still using Phase Change Materials (PCMs)," International Journal of Engineering and Advanced Technology (IJEAT), vol. 2, no. 3, pp. 597-600, 2013.
[15] S.T. Ahmed and K.I. Abaas, "Enhancing Water Distillation by using Domestic Solar Water Heater," Eng. Technol. J., vol. 26, no. 5, pp. 217–226, 2008.
[16] M.T. Chaichan and H.A. Kazem, "Water Solar Distiller Productivity Enhancement using Concentrating Solar Water Heater and Phase Change Material (PCM)," Case Studies in Thermal Engineering, Elsevier, vol. 5, pp. 151-159, 2015.
[17] M.T. Chaichan, H.A. Kazem and K.I. Abaas, "Improving Productivity of Solar Water Distiller Linked with Salt Gradient Pond in Iraqi Weather," World Congress on Engineering 2012, London, UK, 4-6 July, 2012.
[18] M.T. Chaichan and H.A. Kazem, "Using Aluminium Powder with PCM (Paraffin Wax) to Enhance Single Slope Solar Water Distillator Productivity in Baghdad-Iraq Winter Weathers," International Journal of Renewable Energy Research, vol. 1, no. 5, pp. 151-159, 2015.
[19] M.T. Chaichan and H.A. Kazem, "Thermal Storage Comparison for Variable Basement Kinds of a Solar Chimney Prototype in Baghdad - Iraq Weathers," International journal of Applied Science (IJAS), vol. 2, no. 2, pp. 12-20, 2011.
[20] M.T. Chaichan and K.I. Abaas, "Practical Investigation for Improving Concentrating Solar Power Stations Efficiency in Iraqi Weathers," Anbar J for Engineering Science, vol. 5, no. 1, pp. 76-87, 2012.
[21] H.A. Kazem, M.T. Chaichan, I.M. Al-Shezawi, H.S. Al-Saidi, H.S. Al-Rubkhi, J.K. Al-Sinani and A.H.A. Al-Waeli, "Effect of Humidity on the PV Performance in Oman," Asian Transactions on Engineering , vol.2, no. 4, pp. 29-32, 2012.
[22] M.T. Chaichan, K.I. Abaas and H.A. Kazem, "The Effect of Variable Designs of the Central Receiver to Improve the Solar Tower Efficiency," International J of Engineering and Science, vol. 1, no. 7, pp. 56-61, 2012.
[23] M.T. Chaichan, K.I. Abaas, H.A. Kazem, H.S. Al Jibori and U. Abdul Hussain, "Novel Design of Solar Receiver in Concentrated Power System," International J. of Multidispl. Research & Advcs. in Eng. (IJMRAE), vol. 5, no. 1, pp. 211-226, 2013.
[24] Z.A. Darwish, H.A. Kazem, K. Sopian, M.A. Alghoul and M.T. Chaichan, "Impact of Some Environmental Variables with Dust on Solar Photovoltaic (PV) Performance: Review and Research Status," International J of Energy and Environment, vol. 7, no. 4, pp. 152-159, 2013.
[25] M.T. Chaichan, K.I. Abaas and H.M. Salih, "Practical Investigation for Water Solar Thermal Storage System Enhancement using Sensible and Latent Heats in Baghdad-Iraq Weathers," Journal of Al-Rafidain University Collage for Science, Issue 33, 2014.
[26] A.A. Kazem, M.T. Chaichan and H.A. Kazem, "Effect of Dust on Photovoltaic Utilization in Iraq: Review Article," Renewable and Sustainable Energy Reviews, vol. 37, pp. 734-749, 2014.

[27] S.S. Faris, M.T. Chaichan, M.F. Sachit and J.M. Jaleel, "Simulation and Numerical Investigation of Effect Air Gap Thickness on Trombe Wall System," International Journal of Application or Innovation in Engineering & Management (IJAIEM), vol. 3, no. 11, pp. 159-168, 2014.

[28] M.T. Chaichan and K.I. Abaas, Performance Amelioration of a Trombe Wall by using Phase Change Material (PCM)," International Advanced Research Journal in Science, Engineering and Technology, vol. 2, no. 4, pp. 1-6, 2015.

[29] M.T. Chaichan, H.A. Kazem, A.A. Kazem, K.I. Abaas and K.A.H. Al-Asadi, "The Effect of Environmental Conditions on Concentrated Solar System in Desertec Weathers," International Journal of Scientific and Engineering Research, vol. 6, no. 5, pp. 850-856, 2015.

[30] M.T. Chaichan, K.I. Abaas and H.A. Kazem, "Design and Assessment of Solar Concentrator Distillating System Using Phase Change Materials (PCM) Suitable for Desertec Weathers," Desalination and Water Treatment, pp. 1-11, 2015.

[31] M.T. Chaichan and K.A.H. Al-Asadi, "Environmental Impact Assessment of Traffic in Oman," International Journal of Scientific & Engineering Research, vol. 6, no. 7, pp. 493-496, 2015.

[32] M.T. Chaichan, S.H. Kamel and A.N.M. Al-Ajeely, "Thermal Conductivity Enhancement by using Nano-Material in Phase Change Material for Latent Heat Thermal Energy Storage Systems," SAUSSUREA, vol. 5, no. 6, pp. 48-55, 2015.

[33] H.A. Kazem and M.T. Chaichan, "Effect of Humidity on Photovoltaic Performance Based on Experimental Study," International Journal of Applied Engineering Research (IJAER), vol. 10, no. 23, pp. 43572-43577, 2015.

[34] H.A. Kazem, A.H.A. Al-Waeli, A.S.A. Al-Mamari, A.H.K. Al-Kabi and M.T. Chaichan, "A Photovoltaic Application in Car Parking Lights with Recycled Batteries: A Techno-economic Study," Australian Journal of Basic and Applied Science, vol. 9, no. 36, pp. 43-49, 2015.

[35] H.M.S. Al-Maamary, H.A. Kazem and M.T. Chaichan, "Changing the Energy Profile of the GCC States: A Review," International Journal of Applied Engineering Research (IJAER), vol. 11, no. 3, pp. 1980-1988, 2016.

[36] H.A. Kazem, M.T. Chaichan, "Experimental Analysis of the Performance Characteristics of PEM Fuel Cells," International Journal of Scientific & Engineering Research, vol. 7, no. 2, pp. 49-56, 2016.

[37] M.T. Chaichan, B.A. Mohammed and H.A. Kazem, "Effect of Pollution and Cleaning on Photovoltaic Performance Based on Experimental Study," International Journal of Scientific and Engineering Research, vol. 6, no. 4, pp. 594-601, 2015.

[38] H.A. Kazem, A.H.A. Al-Waeli, M.T. Chaichan, A.S. Al-Mamari and A.H. Al-Kabi, "Design, Measurement and Evaluation of Photovoltaic Pumping System for Rural areas in Oman," Environ Dev Sustain, 2016. DOI 10.1007/s10668-016-9773-z.

[39] M.T. Chaichan and H.A. Kazem, "Experimental Analysis of Solar Intensity on Photovoltaic in Hot and Humid Weather Conditions," International Journal of Scientific & Engineering Research, vol. 7, no. 3, 91-96, 2016.

[40] M.T. Chaichan, A.H. Al-Hamdani and A.M. Kasem, "Enhancing a Trombe Wall Charging and Discharging Processes by Adding Nano-Al2O3 to Phase Change Materials," International Journal of Scientific & Engineering Research, vol. 7, no. 3, pp. 736-741, 2016.

[41] M.T. Chaichan, H.A. Kazem, A.M.J. Mahdy and A.A. Al-Waeely, "Optimal Sizing of a Hybrid System of Renewable Energy for Lighting Street in Salalah-Oman using Homer software," International Journal of Scientific Engineering and Applied Science (IJSEAS), vol.2, no. 5, pp. 157-164, 2016.

[42] M.T. Chaichan, "Enhancing Productivity of Concentrating Solar Distillating System Accompanied with PCM at Hot Climate," Wulevina, vol. 23, no. 5, pp. 1-18, 2016.

[43] A.H.A. Al-Waeli, A.S.A. Al-Mamari, A.H.K. Al-Kabi, M.T. Chaichan and H.A. Kazem, Evaluation of the Economic and Environmental Aspects of using Photovoltaic Water Pumping System," 9th International Conference on Robotic, Vision, Signal Processing & Power Applications, Malaysia, 2016.

[44] H.A. Kazem, M.T. Chaichan, A.H. Alwaeli and M. Kavish, "Effect of Shadow on the Performance of Solar Photovoltaic," WREN/WREC World Renewable Energy Congress, Rome, Italy, 2015.

[45] H. Mazin, H.A. Kazem, H.A. Fadhil, S. Alawi and M.T. Chaichan, "Global linear, nonlinear and ANN-based modelling of monthly diffuse solar energy," WREC XIV Proceedings, University POLITEHNICA of Bucharest, Romania, June 8 – 12, 2015.

[46] H. Mazin, H.A. Kazem, H.A. Fadhil, S. Alawi, Q Mazin and M.T. Chaichan, "Linear and Nonlinear Modelling for Solar Energy Prediction on the Zone, Region and Global," World Renewable Energy Council/Network (WREC XIII), London, UK, 3-8 August, 2014.

[47] H.A. Kazem, S.Q. Ali, A.H.A. Alwaeli, K. Mani and M.T. Chaichan, "Life-cycle Cost Analysis and Optimization of Health Clinic PV System for a Rural Area in Oman," Proceedings of the World Congress on Engineering 2013, vol. II, WCE 2013, London, U.K., July 3 - 5, 2013.

[48] http://www.mrmwr.gov.om/new/Page.aspx?id=82&li=8&Type=W_Sec&Slide=false#

[49] http://www.omantourism.gov.om/wps/portal/mot/tourism/oman/home/experiences/nature/springs/!ut/p/a1/jdHLUoMwGIbha3HBNvlJCAd3lFJEKEhTFLNxqIMUh0OlWLx8U8aNM0qbXWaed5EvWOAMizY_VWU-VF2b1-e70F-swHA5AR28ZOOAz7dcc6JHqi-IBM8SOJ59pxkhACwCCQI3CbZ0rYKtXtfHm4SvIlcDb8nOwIjSlLkAhF7Xwz_Hhks9z3v8hMXE9GgVPrhLFWJTBcnMtc65Q4HABaCRCyBmP2BuqAnMLTGBmafeY1HtGjS-NggQIczUqUEZWKY19XIqu91Rs8SiL96KvujRZy-_eD8Mh-OtAgqM44jKrivrAlUfCvxV7LvjgLNfEB-aNM2-_Mp_Z_UptG--AaaZIW0!/dl5/d5/L2dBISEvZ0FBIS9nQSEh/

[50] http://www.miyahuna.com.jo/ZaraMaeen.aspx

[51] https://www.paew.gov.om/?lang=ar-OM