SEAWATER GREENHOUSE IN DESALINATION AND ECONOMICS

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ABSTRACT

In hot and sunny desert regions, it is difficult to grow plant in the open field due to the harshness of land and climates. To overcome these difficulties, the use of greenhouses can provide a proper environment to plant growth. In hot climates, however, the greenhouse inside temperature can reach so high value that prevents its utilization or, otherwise, a costly mechanical air conditioning system should be used. In this paper we discuss the Seawater Greenhouse system in desalination and economics. The Seawater Greenhouse is a method of cultivation that provides desalination, cooling and humidification in an integrated system. The desalination process integrated with greenhouses is driven mainly by solar energy. So, sunlight is the weather variable that most influences the performance of the Seawater Greenhouse. The classification and new types of Seawater Greenhouse desalination systems such as hybrid systems has been done on the basis of literature survey till today. A comparative study between different sustainable efforts in low capacity solar thermal desalination systems as well as economics has been done. The researcher's efforts in greenhouse economics is reviewed with explained its effects on developments of method. Also, The simple suggested system irrigation using solar energy is studied. The system can be used to irrigate an area of about 2333 m^2 to producer Tomato, Cucumber, Pepper and lettuce

Keywords: Solar energy; Saltwater Greenhouse; Solar thermal desalination; Economics

1. INTRODUCTION

Water is essential for all known forms of life. Although 71% of the earth surface is covered by water, 97.5% of all sources are saltwater and merely 2.5% of all water sources; (lakes, dams, glaciers, underground water), are potable. Water is mainly used for three types of activities; domestic consumption, industrial and agricultural purposes. Data shows that agricultural usage has the biggest proportion of the total water usage. According to Oron et al. (2008) 60-90% and according Food and Agriculture Organisation (2006) 69% of the all freshwater sources are used for agricultural irrigation. However, owing to the water scarcity of the world and increasing agricultural production rates new water resources need to be found.

Continued growth in demand for water and increasing supply shortages are two of the most certain and predictable scenarios of the 21st century. And desertification continues to creep toward ever more people. Agriculture, with its high demand for water, will be a major pressure point.

With the rapid growth of the human population, demand on water for agricultural purposes has increased dramatically. Many countries and regions in Africa, Middle East, Europe, and Australia are currently experiencing water scarcity problems. In order to overcome water shortages and produce fresh water in the arid regions, desalination systems have been used for producing fresh water from seawater and saline groundwater. Besides freshwater production, desalination systems are also used for decreasing salt concentration of brackish and underground water.

Using greenhouses in agriculture provides a good environment for plant growth and reduces water consumption. Desalination to obtain freshwater from seawater or brackish water has been used in the arid costal regions and areas that have encountered water shortages. Solar desalination systems integrated into greenhouses have been considered for fresh water production to satisfy their water demand

Instead of producing huge amounts of irrigation water in modern desalination plants, small scale but cheap and simple irrigation water production can be obtained by means of greenhouse integrated solar desalination systems. Two main types of greenhouse integrated desalination units have been intensively used in low water availability regions, (i) solar still systems and (ii) humidification and dehumidification desalination units.

At present, the market for renewable energy powered desalination systems is small and current installations are estimated to be 0.02% of the total desalination market, Eltawil et al [2009]. The contribution of each RE desalination technology to this tiny market is shown in Figure (1), Eltawil et al [2009]. As promising as RE powered desalination systems may seem, they are still plagued by major economical and technological limitations that hinder their rapid expansion into the growing desalination market, Eltawil et al [2009] and Garcia et al [2002]. As for the feed water quality used, seawater is the most used, followed by both brackish and river waters (Figure (2)), ESCWA [2009].

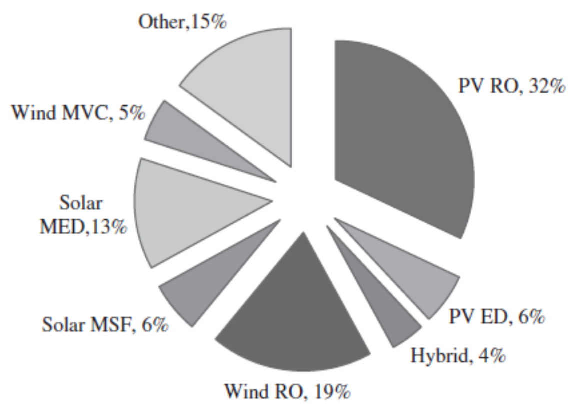


Fig. 1: Contribution of each RE desalination technology to the RE desalination systems market, Eltawil et al [2009].

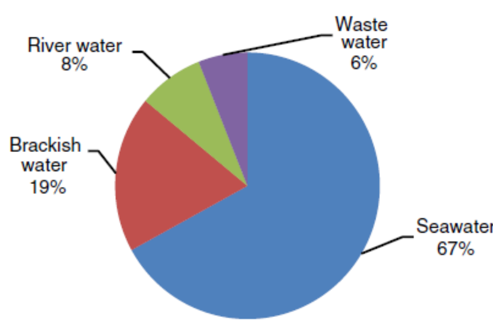


Fig. 2: Worldwide feed water quality used in desalination, ESCWA [2009].

The shortage of water in KSA has been exacerbated by a number of factors, including
1- Increasing population
2- Substantial growth in the standard of living,
3- An increase in agriculture and industrial development.

These and other conditions, such as the limited resources and the difficulty of polluted water treatment, led to the decision of the Saudi government to use desalination as one of the strategic alternative and main sources of potable water for all major metropolitan areas in the kingdom. Although it seems more expensive in area of surface or ground water availability, it is not so in areas 300-500 km from surface fresh water availability or of deep ground fresh water. KSA produces more than 5 Mm^3/d of desalinated water from more than 2000 desalination plants with different technologies: mainly MSF and RO. This represents more than 21% of the desalinated water world production, Fath [2001] Desalted water is transported (after blending with brackish water) to most of the cities for domestic and potable use. The Seawater outside air into the greenhouse. Ventilation is used to control humidity, especially during winter months. Results from the prototype greenhouse in the United Arab Emirates (UAE) are used to calibrate a computational fluid dynamic (CFD) model, Davies [2004]. GH cooling systems provide ventilation air. Even when the evaporative cooling pads are not being used, the fans can be used to bring humidity (high plant water vapour transpiration) and pest and disease growth in high humidity conditions. Most crop plants require temperatures in the range of 10-30°C. High temperature increases the evaporation by transpiration and affects the water stress in the plants. Cooling in summer and hot days as well as heating in winter and cold days are therefore important for GH temperature control. Table (1) shows the general water and environmental requirements for some crops.

Table (1): Main crop requirements inside greenhouses

Crop	T (°C)	RH (%)	Water (L/m^2)
Tomato	15-25	60-65	3
Cucumber	20	60-65	3
Pepper	20	60	3
Lettuce	20-25	60	3
Flower	15-25	60-70	8

2. DEVELOPMENT OF SALTWATER GREENHOUSE LITERATURE REVIEW

A thermodynamic simulation study was performed on the influence of greenhouse-related parameters on a desalination process that combines fresh water production using humidification-dehumidification with the growth of crops in a greenhouse system, Al-Hinai et al [2005].

The humidification–dehumidification process (HD) is a versatile technique that can be adapted for water desalination, Paton and Davies [1996] (Figure (3)). This method has several advantages such as flexibility in capacity, moderate installation and operating costs, simplicity, possibility of using low temperature and the use of renewable energy (e.g. solar, geothermal, recovered energy or cogeneration). Although the common methods of desalination such as distillation and reverse osmosis have been the subject of many investigations, studies of the HD process have been limited.

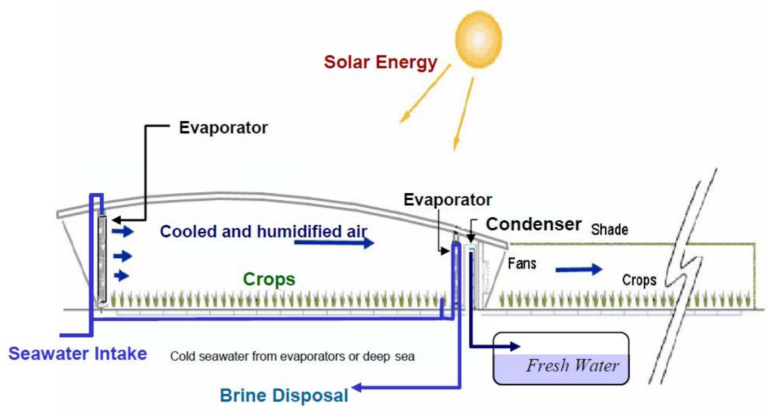


Fig. 3: Seawater Greenhouse, Paton and Davies [1996].

The brackish water greenhouse desalination units are well suited for relatively cold regions affected by dryness but rich in geothermal brackish ground water (Figure (4)), Mahmoudi et al [2010]. Greenhouse cover is normally plastic sheeting and the feed water to the pump is either brackish groundwater or sea water from a beach well; Bottom (b): The Seawater Greenhouse at Al-Hail, Muscat and Oman, Mahmoudi et al 2008.

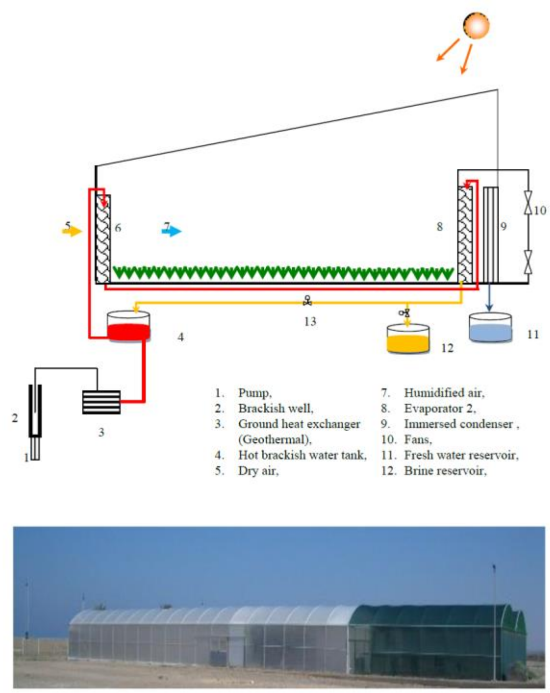


Fig. 4: Water Greenhouse coupled to geothermal system, Mahmoudi et al [2010].

The solar still system is similar to PV-RO, as it also utilizes groundwater as its primary water source and requires a PV-powered pump as part of the system. The PV panels, inverter, and pump, along with all the pipes and fittings required, are used to pump water from the groundwater table to the solar still. The solar still utilizes solar radiation to evaporate the water; therefore, no external power source is required for the desalination process itself. Figure (5) shows a schematic of a solar still, Jijakli et al [2012].

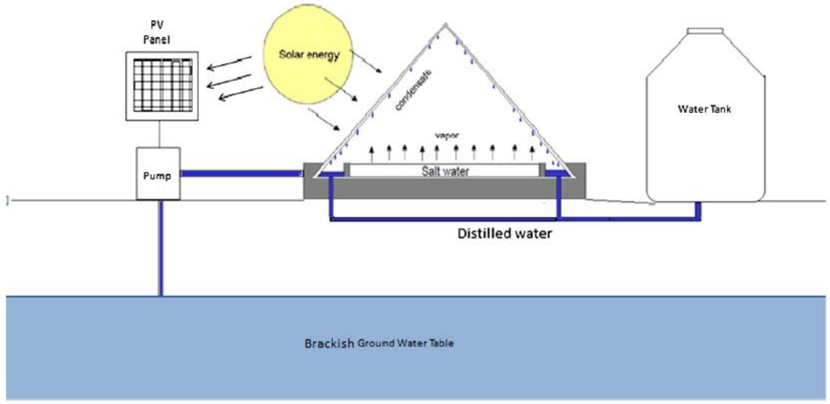


Fig. 5: Schematic of a solar still desalination system assumed for the study, Jijakli et al [2012].

In hot and sunny desert regions, it is difficult to grow crops in open fields due to the harshness of the land and climate. To overcome these difficulties, the use of greenhouses can provide a proper environment for plant growth. In hot climates, however, the inside GH temperature can reach so high value that its use is prevented, or otherwise, a costly mechanical air-conditioning system must be used. Fath 1993 proposed a system to decrease the GH cooling load and utilize the surplus solar energy during the day for natural ventilation of the GH. Fath [1994] and [1997] proposed placing a group of solar stills on the top of the GH roof.

An experimental investigation is presented of the thermal performance of an agricultural greenhouse (GH) with a built-in solar distillation system, Abdulhaiy and Fath [2005]. A set of solar basins partially filled with saline water is placed on the GH roof to implement this function. The overall conceptual configuration of the constructed system is shown in Figure (6). The experimental work was carried out and the GH was constructed at the King Abdul Aziz University, the city of Jeddah, Saudi Arabia. The system transient performance (temperatures, relative humidity, and water productivity) is presented for the summer of July 2004 in Jeddah

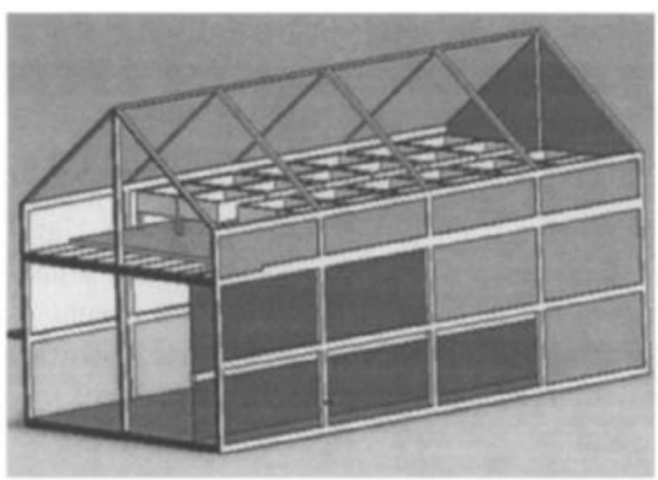


Fig. 6: Overall system schematic configuration Abdulhaiy and Fath [2005].

The seawater greenhouse (SWGH) process makes use of sunlight, seawater and the ambient air to produce freshwater and colder air, creating more temperate conditions for the cultivation of crops at remote and arid coastal areas. The process as depicted in Figure (7) recreates the natural hydrological cycle within a controlled environment, Paton [2001]. The entire front wall of the greenhouse is a seawater evaporator. 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.

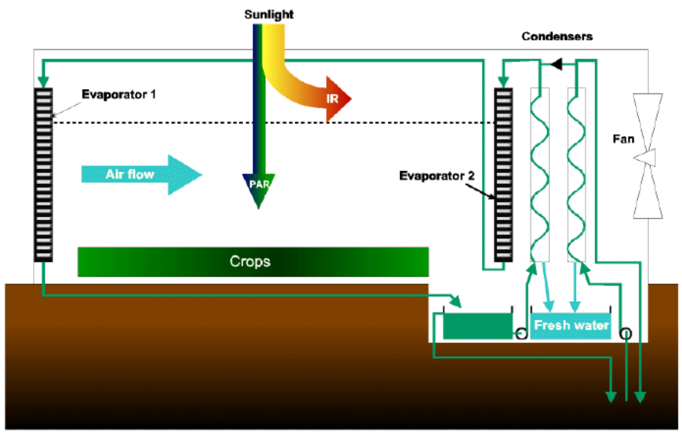


Fig. 7: Section through the seawater greenhouse, Paton [2001].

The performance of a solar still integrated in a greenhouse was studied for Mediterranean climatic conditions in south-eastern Spain, Eugenio et al [2006]. The desalination module was equipped with 28 water basins located at the top of an experimental greenhouse. Figure (8) shows a front view of the greenhouse with the solar still integrated in its frame. Installing the solar still meant the reduction the solar radiation and PAR inside the greenhouse (about 52%).

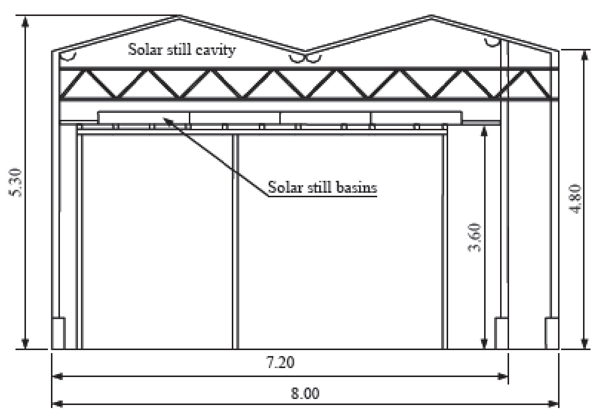


Fig.8: Front view of the greenhouse with the solar still integrated in its frame, Eugenio et al [2006].

The concept analyzed is a water desalination system integrated in a greenhouse roof (Figure (9)), Chaibi [1991]. The basic principle is to allow transmittance of the spectral part of the solar radiation, which is effective for photosynthesis i.e., wavelengths between 400 and 700 nm. The remaining part of the spectrum, which represents about 50% of the total solar energy, can be absorbed and converted into heat for water desalination. This is accomplished by a double-glassed roof structure that acts as an absorber and evaporator,

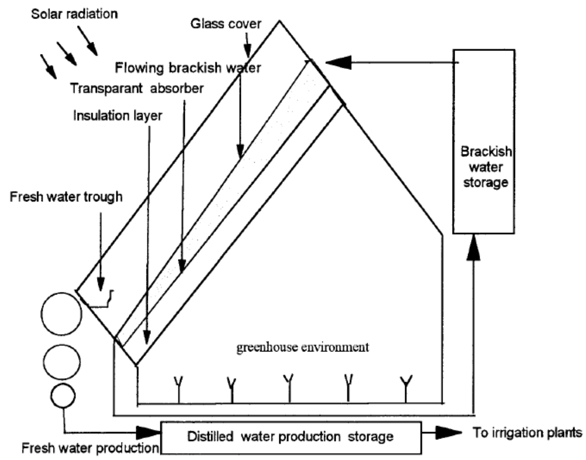


Fig. 9: A water desalination system integrated in a greenhouse roof, Chaibi [1991].

The transient analysis of a stepped solar still for heating and humidifying agriculture greenhouses (GH) is studied by Abdulhaiy [2003]. The still body consists of five stepped basins insulated from the bottom with an inclined glass cover. Air from the GH enters the still from the bottom and flows between the basins and glass cover where it is heated and humidified, and then re-enters the GH Corn the still top. Figure (10) shows a illustrates the overall configuration of the GH still. The body consists of a group of stainless-steel stepped basins (black coated and insulated from its bottom and sides) with an inclined (3-mm window type) top glass cover. The basins contain saline water that are placed on an insulated (Styrofoam) sheet. Air from the GH enters the still from its bottom, flows between the heated basins and glass cover (where air is heated and humidified) and then re-enters the GH

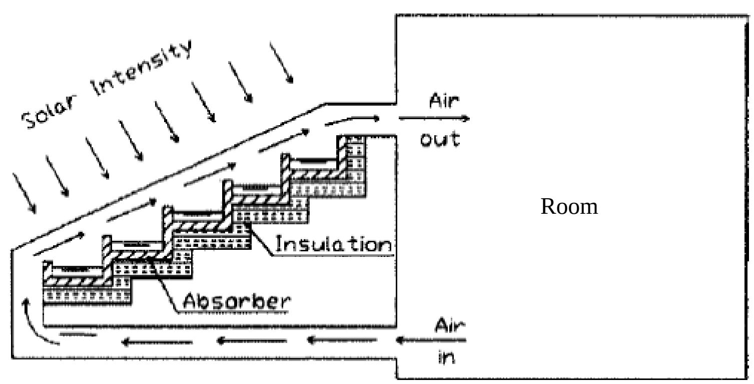


Fig. 10: Solar still for heating and humidifying greenhouse, Abdulhaiy [2003].

Project Watergy proposes a new concept of solar collector based on a humid air circuit powered by thermal solar energy, Buchholz [2003]. The collector is formed by a greenhouse connected with a solar chimney, inside of which a cooling duct contains an air-to-water heat exchanger connected to a heat accumulator (Figure (11)). The process starts with the heating of the air inside the greenhouse, which rises to the solar tower by natural buoyancy. The evapotranspiration of the plants and soil is added to the air, which becomes humid. Above the greenhouse, removed from the plant area, the rising air is further heated in a secondary solar collector until it reaches the maximum temperature at the top of the solar tower. In this secondary collector, in order to saturate the rising air while it is heating, a humidification system acts as an additional evaporation source.

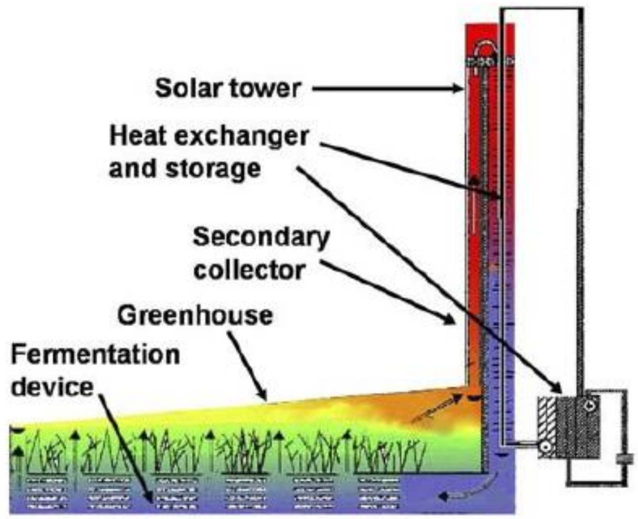


Fig. 11: Scheme of the new humid air solar collector proposed in project Watergy, Buchholz [2003].

Much research has been directed at addressing the challenges in using renewable energy to meet the power needs for desalination plants. Wind energy and solar energy are clean and renewable fuel sources. The feasibility of using wind energy to power brackish water greenhouse desalination units proposed for the development of the southern region of the case study country of Algeria has analyzed, Mahmoudi et al [2009]. It was noted that in only 8 h (i.e. between 9 am and 5 pm), the greenhouse produces 98% of the total freshwater. The seawater/brackish water greenhouse uses sunlight, seawater or brackish water and the atmosphere to produce fresh water and cool air, creating temperature conditions for the cultivation of crops. The process recreates a natural hydrological cycle within a controlled environment. Feed water is pumped from a well. The natural sand acts as a filter and keeps out solid particles and other impurities. Filtered water is sent to the cold tank where it is fed to the condenser and then to the first evaporator. The brine water from the first evaporator turns over to the cold tank (Figure (12)).

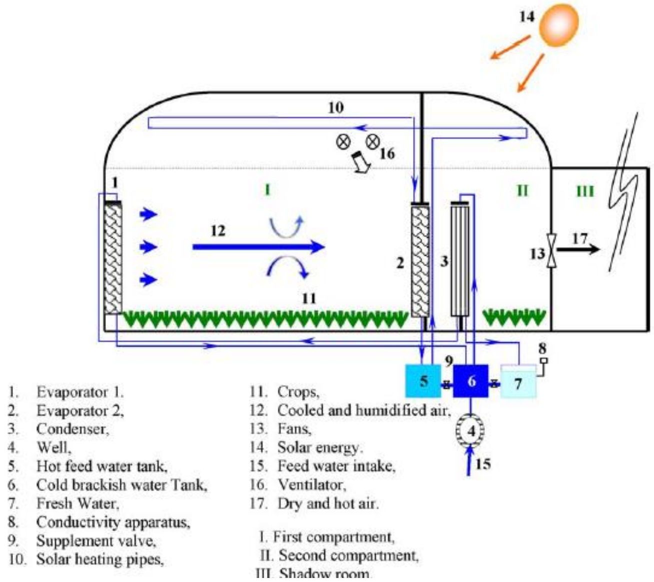


Fig. 12: Process schematic, Mahmoudi et al [2009].

The application in remote and arid locations where the source water is assumed to be brackish is studied by Chaibi [2003]. System principle for water desalination integrated in a greenhouse roof is shown in Fig. The roof transmission is reduced as solar irradiation is absorbed by flowing water on a glass sheet covered by a top glass sheet. Fresh water is evaporated, condensed on the top glass and collected at the roof eaves. For the assessment of this concept compared to conventional, single glassed greenhouses, extensive computer simulations and field experiments were performed in Tunisia. Considerably less extreme climate conditions were registered in an experimental greenhouse with roof desalination compared to a conventional house (Figure (13)).

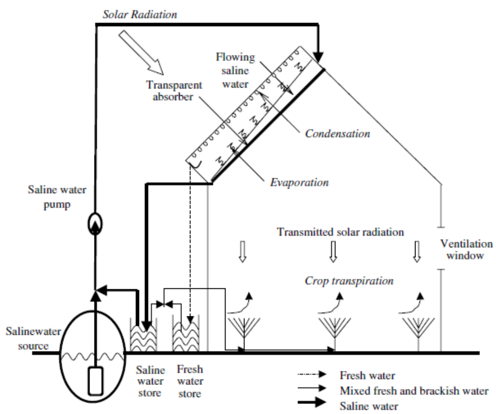


Fig. 13: System principle for water desalination integrated in a greenhouse roof, Chaibi [2003].

Development of a humidification–dehumidification system in a Quonset greenhouse for sustainable crop production in arid regions studied by Perret [2005] (Figure (14)). Preliminary testing of the performance of the greenhouse showed an increase in water vapour close to saturation after the second wall of cooling pads. The temperature of the water flowing in the dehumidifiers was always lower than the dew-point temperature of the air passing through them.

Hence, condensation could occur and was observed on the dehumidifier. However, condensation was insufficient to result in a measurable quantity

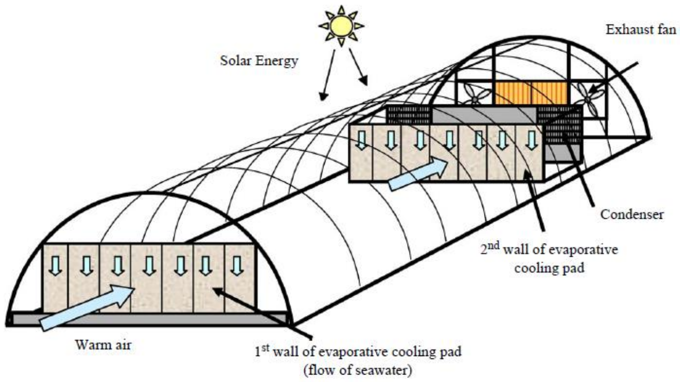


Fig.14: Schematic view of the Quonset greenhouse with humidification–dehumidification system, Perret [2005].

Validation of a simulation model for water desalination in a greenhouse roof through laboratory experiments and conceptual parameter discussions studied by Chaibi [2001]. The paper describes laboratory experiments with a small roof module and presents measurements compared to simulations obtained in order to validate the thermal part of the model. Equations, parameters and simplifications used in the model are briefly described. Figure (15) shows a small roof module was built for the study. The most important indication is that geothermal water at elevated temperatures combined with this roof technology is the alternative with the highest water production capacity.

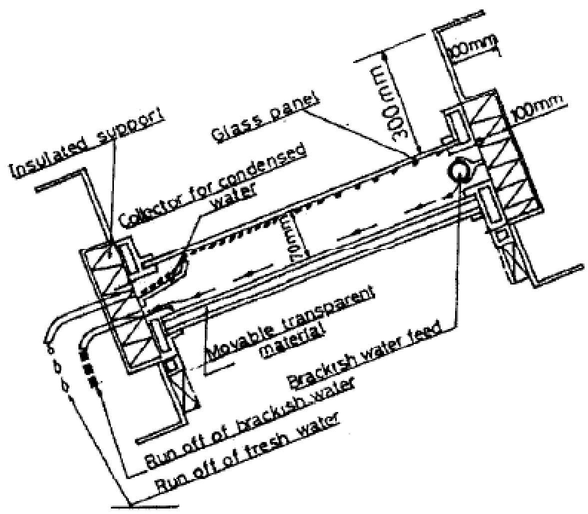


Fig. 15: Cross section of the solar still greenhouse module, Chaibi [2001].

A novel integrated system for fresh water production in greenhouse is proposed and evaluated to improve performance of fresh water production from seawater in greenhouse by two major changes: first, using a direct contact dehumidifier (DCD) instead of common indirect condensers and second, applying amore efficient and economical solar water heater (SWH) system (Zamen et al 2013). Schematic of proposed system is shown in Fig. 16.

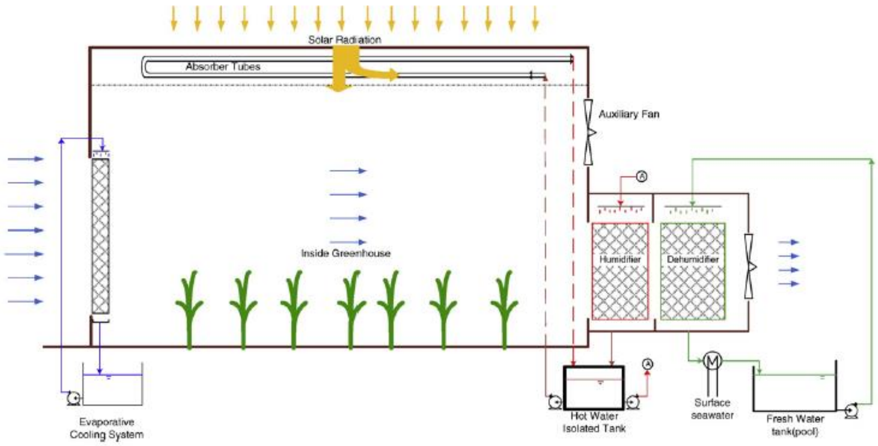


Fig. 16: The proposed system, Zamen et al [2013]

Al-Helal 2009 has put distinct research results in the study of performance evaluation of a fan-pad evaporative cooling system under different climatic conditions in Saudi Arabia. Weather data for Riyadh representing arid climate, Jeddah representing humid climate and Abha representing moderate climate were analyzed. An evaporative cooler consisting of cooling pad, variable speed suction fan, electrical heater for water heating and electrical high pressure steam boiler for producing low pressure steam for heating and humidifying. Figure 17 shows combined schematic of the evaporative cooling, heater and boiler.

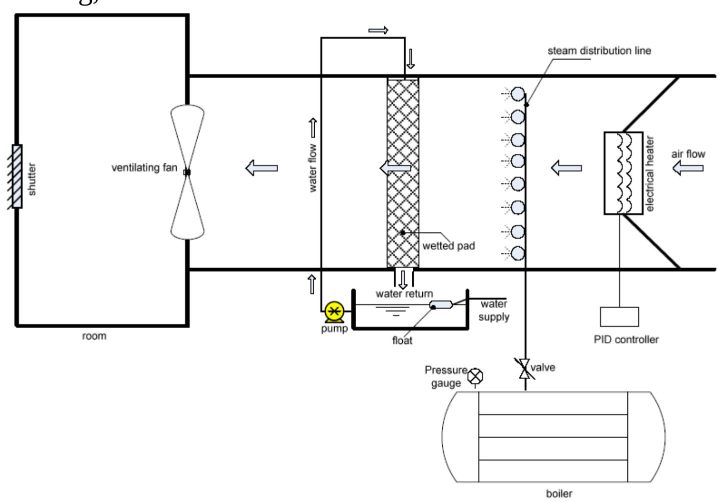


Fig. 17 Combined schematic of the evaporative cooling, heater and boiler, Al-Helal [2009]

Salehi et al. 2011 simulated the Saltwater Greenhouse considering condition of the Bandar Abbas City in Iran to find optimal operating condition and system configuration. So, different configurations are developed and investigated in this study. In this system ambient air is passed through the two evaporative cooling pads, which plant growth area is placed between those pads, by fans that placed end of the building, and then returned taking humidity on the tube-and-fin condenser. Figure 18 that is water exist from first evaporator is passed under the greenhouse floor, is the effective cycle and produces more water than other cycle.

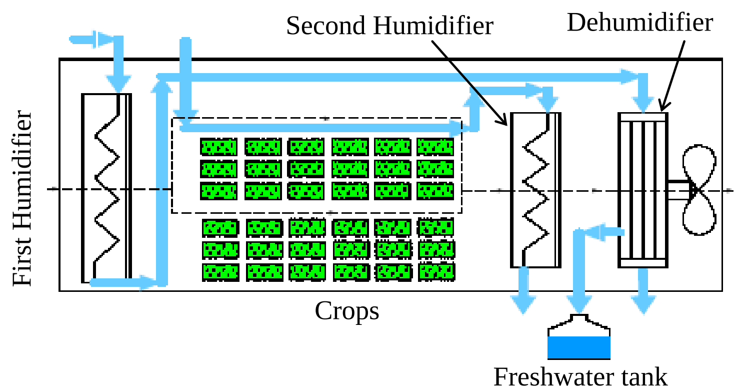


Fig (18): Optimum configuration for Seawater Greenhouse cycle [2011].

3-ECONOMICAL AND SUSTAINABLE ASPECTS OF SALTWATER GREENHOUSE

The economic factor is an important role for the decision makers at any field. Cost analysis of Saltwater Greenhouse systems usually aims to estimate the cost of a liter or a cubic meter of fresh water, and calculates the contribution of each cost item to the total cost of agriculture. This identifies immediately the most significant cost items and attracts the attention to what should first be examined for possible improvement and cost reduction (Banat and Jwaied 2008). The economics of any Saltwater Greenhouse depend on a number of factors, including the local climate, growing methods and greenhouse styles. While Saltwater Greenhouse system economics are influenced by these factors also, they benefit from several key advantages, regardless of crop, market or region.

Goosen et al. Goosen et al 2003 determined the influence of Seawater greenhouse-related parameters in arid coastal regions that are suffering from salt-infected soils and shortages of potable groundwater in the Arabian Gulf.

Eslamimanesh and Hatamipour 2010 made an economical study of humidification–dehumidification desalination pilot plant in order to estimate the economic benefits of the process in comparison with a small-scale reverse osmosis (RO) system.

Banat and Jwaied 2003 presented an economic assessment performed to estimate the expected water cost, which is the ultimate measure of the feasibility of the two solar powered stand-alone membrane distillation units (compact and large).

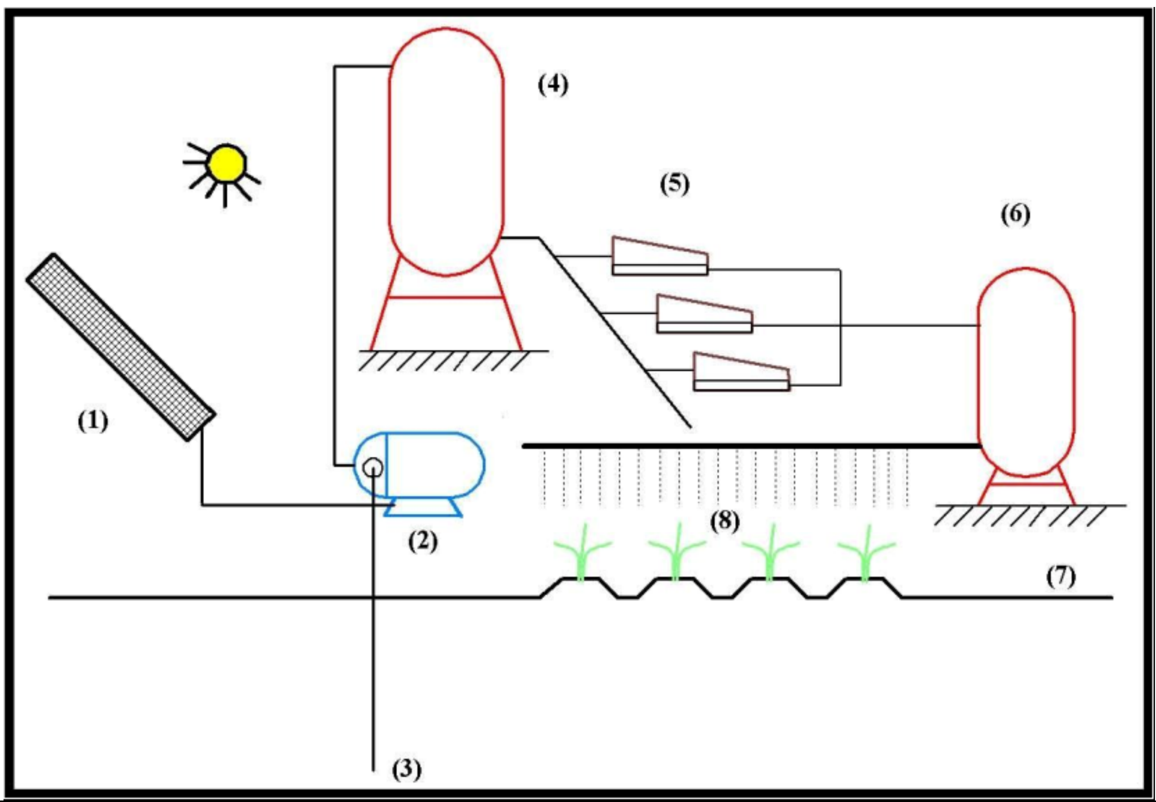
4- SIMPLE SUGGESTED SYSTEM FOR ARID REGION IRRIGATION

A simple system for arid region irrigation is currently studied. That system is based on a dual using for solar energy. Figure 17 shows the proposed system. The first usage is in photo cells as a power source while the second usage in a solar distillatory as a fresh water source. The photocell (solar cell) transmitted the solar energy into electrical energy. The produced electrical energy is used for the pumping purpose as shown in Fig 17. The pump shown in Figure is used for pumping the underground brackish water to the brackish water reservoir. The water level is adjust to 5 cm in each solar stills. The distillate water are collected from different solar stills in distillated water reservoir. An irrigation mechanism is used to distribute the distillate water for the irrigation.

DESIGN PARAMETERS

Water reservoir tank = 1000 liter
Under ground water level = 30 m
No of solar stills = 200
The pumping power required calculated as follows

Power = ρ g Q H
= 1000 x 9.81 x (1000 x 0.001)/3600 x 30 = 600 Watt
With an efficiency 0.8
The solar cells output = 750 Watt
The a mount of distillate water from solar still = 5 L/Day for each solar still(Kabeel et al 2012)
The total amount of distillated water = 200 x 5 = 1000 Liter per day
From Table 1
The water required for irrigation for Tomato, Cucumber, Pepper and lettuce is 3 L/m^2 per week
The distillate water from the system can be irrigate (1000/3)x 7 = 2333 m^2



1-PV panel	5- Solar stills
2- Pump	6- Distillate water
3- Underground water	7- Ground surface
4- Brackish water reservoir	8- plant

Figure 19 proposed system diagram

5-CONCLUSIONS

Based on the review and discussions, the following could be concluded;

1. The Saltwater Greenhouse systems showed significantly higher distilled water output especially adopting technological aspects compared with conventional systems under the same operational conditions.
2. Some of the reviewed technical developments are in research stage or/and are in a small scale. So, a lot efforts are required in that field
3. The distillation process uses very little energy; it needs about 2 kW to drive pumps and fans for each 1000 m^2 greenhouse..
4. When the solar still is integrated with greenhouse, distillation took place after solar noon and during the night due to the low absorption of solar irradiation contrary to what happens in traditional solar stills.
5. The suggested system for irrigation is based on dual using of solar energy in electricity generation and brackish water desalination. That system can offer a fresh water for an irrigation to an area about 2333 m^2. That area could be suitable for the production of Tomato, Cucumber, Pepper and lettuce

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