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Review Article

Residual and Desalination Water Treatments using HDH Process- a Review for Potential use in Home Gardens

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Abstract

Home gardens in Mexico represent a pathway toward food sovereignty in both rural and urban areas. The rural family-garden is an agroecosystem with traditional roots where the family lives, together with their animals. A comprehensive review of water treatment from brackish and desalination water by small-scale humidification-dehumidification (HDH) was carried out considering the use of renewable energies. The different HDH cycle provide advantages and disadvantages and present great potential for decentralized small-scale water production applications implemented in agricultural crop irrigation systems. Home gardens can be rural or urban, but the smaller area within the city terraces prevent the use of photovoltaic panels as they will occupy most of the space and reduce the solar radiation required for photosynthesis. Heat pumps can be very useful as the space required is smaller and energy can be reduced if water is sprayed over the condenser.

Keywords: Home gardens; HDH; Solar Energy; Humidifier; Heat Pump

Introduction to HDH technology

Desalination is a process used to obtain fresh water from saline water, such as brackish water or seawater. Since its evolution in the 1950s, its technical and economic feasibility have improved considerably. Membrane, thermal or emergent processes are commonly used being membrane reverse osmosis (RO) used in 69% of the global facilities [1]. A major environmental concern arises from the large volume of brine produced in the desalination process, requiring special management and increasing energy costs. Brine handling is both financially expensive and technically difficult, and therefore most desalination plants discharge untreated brine directly into the environment. Middle East & North Africa represents the largest brine production volume (99.4 m3/day), followed by East Asia & Pacific (14.9 m3/day), Western Europe (8.4 m3/day) and North America (5.4 m3/day). they represent the vast majority in the rest of the global participation. On the other hand, the sectors with the greatest brine production problem are the municipal (106.5 m3/day), industrial (27.4 m3/day) and irrigation (1.1 m^3/day) sectors [1]. The higher the volumetric processing efficiency of the desalination process, the lower the proportion of brine produced relative to the volume of desalinated water produced. Humidification-Dehumidification (HDH) technology has become a viable alternative for small-scale desalination. This technology based on the steam cycle principle, condenses the water vapor to obtain fresh water. Air enters the HDH unit and condenses in the evaporator to produce water vapor. This steam is passes through the condenser and the collected water is stored for later use [2]. Humidification-dehumidification technology has been shown to be an effective alternative to traditional desalination due to its low cost, simplicity, and energy efficiency. The main components of the HDH system are the humidifier and the dehumidifier. In the humidifier, the evaporation process increases air humidity, by maintaining contact between atomized water droplets and unsaturated air. This humidification results from the difference between air and the air-water interface moisture content [3]. In addition, the humidity of the air supplied to the humidifier has a great impact on the performance of the system [4]. To increase the moisture content of the air, HDH systems use devices such as spray tower [5], bubble columns [6] and packed bed chambers [7]. Mass balance design is important in each equipment; For example, the tower diameter-length ratio is a strategic parameter, to mix the air and aerosol optimally. Desiccators or condensers are the major HDH dehumidification equipment, which condense moist air to produce fresh water [2]. In seawater desalination systems based on HDH techniques, desiccators have a greater influence than humidifiers on the volume of fresh water obtained. Indirect desiccators offer a higher heat recovery than direct desiccators, because the warm and humid air from the indirect desiccator is used to pre-heat the seawater [8].

HDH systems can be classified into two large groups: Energy management and consumption including HDH heating type and Cycle configuration within the HDH process. Some relevant performance parameters have been defined including gained-output-ratio (GOR). GOR is the ratio of the latent heat of evaporation of the distillate water produced to the total heat input from the heat source [9]. In Table 1, desalination systems with productivities having unit of L/m^2day or L/m^2h represent plants dependent on the area of the solar still, solar tubes or solar concentrator. Solar concentrator systems tend to produce high amounts of water per day as shown by the plant in Saudi Arabia [10-15]. According to Table 1, GOR values over 3, produced the cheaper pure water in $/L [13-19].

Cycle configuration within the HDH process

HDH desalination systems are classified based on configuration or by operating cycles [20]. The different configuration cycles are shown in Figure 1. In both, Figure 1a and 1c, the wastewater leaving the humidifier is returned to the sea. In the first cycle (Closed Air Open Water-CAOW), the air is recirculated within the system and the water is discarded at the end of its cycle although it may not be extremely pure, Figure 1a. The air mixes with the salt water in a heat exchanger and is separated to later condense the moisture into fresh water in the dehumidifier. In the second cycle (Open Air Closed Water-OACW), air is introduced into the system, meanwhile the water recirculates, Figure 1b. The water increases its salinity as moisture is extracted from it. In Table 1, the recirculating water flow at 70°C of the desalination system is 4 kg min-1[17]. The system works with solar energy and an electrical heater from 9:00 to 17:00 hr., providing almost 40 liters/day; This production can be tripled if the electrical heater works continuously. In the third cycle (Open Air Open Water-OAOW), water and air entering the HDH system will always be replaced, Figure 1c. The water produced in Egypt [10] with this kind of plant accounts 123 Lh^{-1}, using up to 150 m^2 of solar collector. In the fourth cycle (Closed Air Closed Water-CACW) the water and the air are recirculated until the desalination process reaches its production setpoint, Figure 1d. HDH efficiency can be further improved through heating of water, air, or both (CITA). Four of the selected HDH systems use this CACW type, Table 1. In the HDH system in Saudi Arabia [13] the recirculating water at 40°C and air flow are of 2$Lmin^{-1}$ and 0.055 kgs^{-1}, respectively, Table 1. As the water flow increases, a higher water production is obtained.

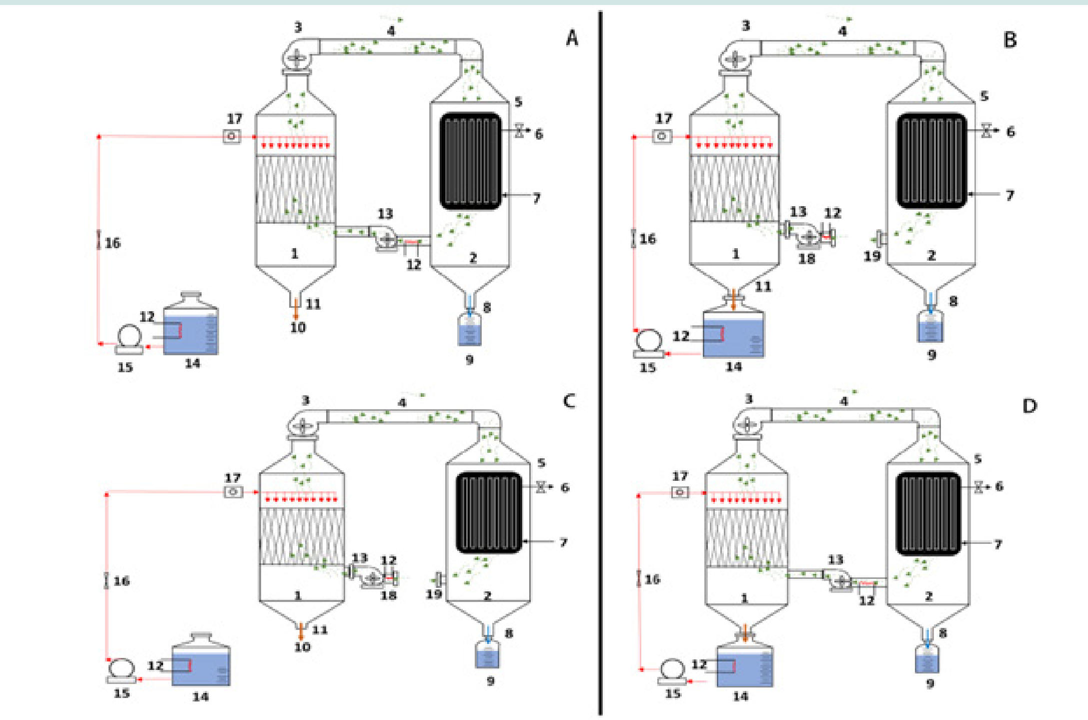

Figure 1: HDH configurationcycles: A = CAOW, B = OACW, C = OAOW, D = CACW, 1 = Humidifier, 2 = Dehumidifier, 3 = Air blower, 4 = Air flow, 5 = Heat Exchange, 6 = Coolant Flow outlet, 7 = Coolant Flow inlet, 8 = Distilled outlet, 9 = Tank Of distilled water, 10 = Waste water, 11 = Brine outlet, 12 = Heater, 13 = Air blower, 14 = Tank Of seawater, 15 = Water Pump, 16 = Valve, 17 = Measurer Flow, 18 = Air intake, 19 = Air outlet.

Table 1: Desalination equipment´s showing GOR, productivity and system configuration being used in several countries.

Country	Plant	Config cycle	GOR	Productivity	Cost, $/L	Author
Saudi Arabia	HDH+HP	CAOW	3.7-10.4	-	0.008-0.03	[10]
Egypt	SS+HDH	CACW	-	11L/(m2.day)	-	[11]
Iran	CLPHP +HDH+HP	CACW	0.81	8.7L(m2.day)	0.012	[12]
Saudí Arabia	HDH + HP	CACW	4.07	287.8L/day	0.011-0.02	[13]
Iran	HDH + SCV	CAOW	3.43	1.07L/m^2.h	0.0041	[14]
Saudí Arabia	HDH + SC	OAOW	4.23	125L/m^2.day	-	[15]
Egypt	HDH+recirculating	OACW	0.53	4.98L/h	0.015	[16]
	water flow	CACW	0.84	6.16L/h	0.012	
Egypt	HDH+HR+SC	OAOW	0.3	123.7 L/h	0.099	[17]

*GOR= Gained Output Ratio; CS= Cooler System; HP = Heat Pump; SS= Solar Still; SC=Solar Concentrator; SH= Solar Heating; SR= Solar Recovery; PV= Photovoltaic; HR= Heat Recovery; CLPHP= Closed-loop pulsating heat pipe; SCV=Solar Collector Vacuum

Energy Management and Consumption

HDH systems can produce pure water with renewable energy [21]. The energy required by the desalination system to heat the air and or water should be environmentally friendly [9]. However, thermal energy can be obtained after burning fossil fuel or nuclear power [22]. Energy used by HDH desalination systems can be classified as thermal, solar and/or hybrid. The hybrid power source combines more than one power source to maximize system performance and minimize cost [4]. The solar energy can use photovoltaic panels, collectors or solar ponds. The solar collector is the main element of the solar desalination system providing a special heat exchanger and it can include evacuated tube collector (ETC) [23], compound parabolic collector (CPC) [24] and flat plate collector (FPC) [25]. Solar energy subcategories include energy from waste photovoltaics/thermal energy [26], solar refrigerators and heat pumps [27], and thermal power plants [28]. With solar technologies, water productivity is affected by the solar intensity, ambient temperature and wind speed. The amount of water produced increases with time exposed to solar energy, being maximum around solar noon [25].

HDH classification Based on Heating System

HDHs can be classified into three main groups according to the type of heating system used; these are the air heating system, the water heating system, and dual heating system. To improve the productivity of HDH systems, air, water, or both are heated before entering the humidifier. Various energy sources (conventional or renewable) are used to heat the air or water in HDH desalination systems. After air heats up, air temperature increases meanwhile relative humidity decreases. The capacity to transport more water vapor increases, producing a higher quantity of pure water. The water heating system is used to raise the water temperature, increasing the amount of steam during the humidification process, and producing a higher quantity of pure water. The dual heating system combines the air and water heating systems, which increases the amount of water vapor generated in the humidifier, thus improving the productivity of the system. Actually, as the versatility of the energy sources is greater, these heating systems have better freshwater productivity than individual heating systems. Power requirements and economic costs vary depending on the type of feed water, the configuration used, system temperatures, and water mass flow. The CACW type technologies require of less fluid heating because recirculation provides heat-energy saving. The process increases productivity from 20 to 88%, together with lower investment costs [29]. Limited research has been done for double heating cycles where both air and water are heated at the same time. Maximum water is produced at the same heating efficiency when there is an optimal water to air mass flow rate ratio [30]. Mass flow rates of air and water have to be optimized to improve water productivity [31]. HDH system productivity improvement can be analyzed through the generation of specific entropy within each component of the cycle. Irreversibility within the humidifier is relatively low and approaches zero [30], so its effectiveness ranges between 72-100%. Thus, improvements are focused on the dehumidifier, air heater, and water heater. Therefore, to improve the overall performance of the system, the effectiveness of the dehumidifier is really important [30]. An experimental study by Alrbai et al. [32] tested the mist nozzle technique being evaluated positively by reducing the exergy destruction of the desalination process. Maximum GOR value of 3.4 and minimum specific entropy generation of 0.235 were obtained at a mass flow velocity ratio of 0.78. The use of the mist nozzle increases the energy recovered from the freshwater outlet of the humidifier. A common plant uses several pumps in the process [33]. Two centrifugal pumps (0.8 kW) are used in the cooling water loop and cold-water loop. Another plastic magnetic pump (0.55 kW) transports seawater to the nozzles. A smaller 0.15 kW fan drives the airflow within the system, and a PID temperature controller turns on a 3-kW electric heating rod to heat the airflow to a desired value. The seawater temperature at the dehumidifier inlet of the first stage (TW1) is also controlled by a PID temperature controller. With an increase of TW1, the productivity of the freshwater after the first stage decreases slightly. A total of 5.1 kg/hr is obtained by the first dehumidifier, and with two dehumidifiers a total of 20 kg/hr can be obtained.

Water Treatment in Home Gardens

Rural home gardens include trees, crops and animals living nearby the family; Animals occupy small spaces and are located in the vicinity of the houses [34]. Rural parcel area varies between 100 m2 and half hectare, being the water requirements 1000 lt day-1 [35]. A heat-pump for removing salts in water is shown in Figure 2. This system can be used in communities close to the sea or in municipal cities were sewage water can be treated [35]. The heat pump system consists of a compressor, a condenser, an evaporator and an expansion valve which are enclosed in the green window of Figure 2. The heat source for the solar pump is the condensation vapor of the R134A refrigerant and reaches 90°C. The water desalination system comprises a humidifier, dehumidifier, pumps and a fan. The process begins with the seawater being fed to the heat pump condenser, where the incoming water is heated and steam is generated. The water vapor is collected and condensed, releasing fresh water as the end product [35]. Distilled water is discharged into a container and the salts are discharged from the heat pump to complete the desalination cycle. The reverse osmosis desalination process begins with a tank of salt water, Figure 3. Saltwater is pumped through a series of filters that remove large particles and contaminants to ensure water quality. The filtered water is then pumped through a separation membrane, which separates the salt water (brine) from the fresh water. The brine is collected in a brine receiving tank, while the fresh water is pumped into a fresh water storage tank. This fresh water can be used for a variety of uses, such as irrigation, food production, drinking water supply, etc. The energy to run this plant is solar, which makes it more efficient and respectful of the environment. Solar energy is collected by solar panels, which are then stored in batteries for later use. These batteries supply electricity to the pumping and filtering systems, which are necessary for the operation of the desalination plant. Reverse osmosis filtering can be an option for rural areas as there is more space to install 28 m2 of solar PV (Table 2). Urban terrace gardens are installed on the top of the house and their average area is 50 m2 and as the space is small a heat pump is more practical, Figure 2. In urban gardens, recycled sewage-waste water is used as the incoming water. The water is cleaned and used for human needs, meanwhile wastewater can be applied to the vegetables [34].

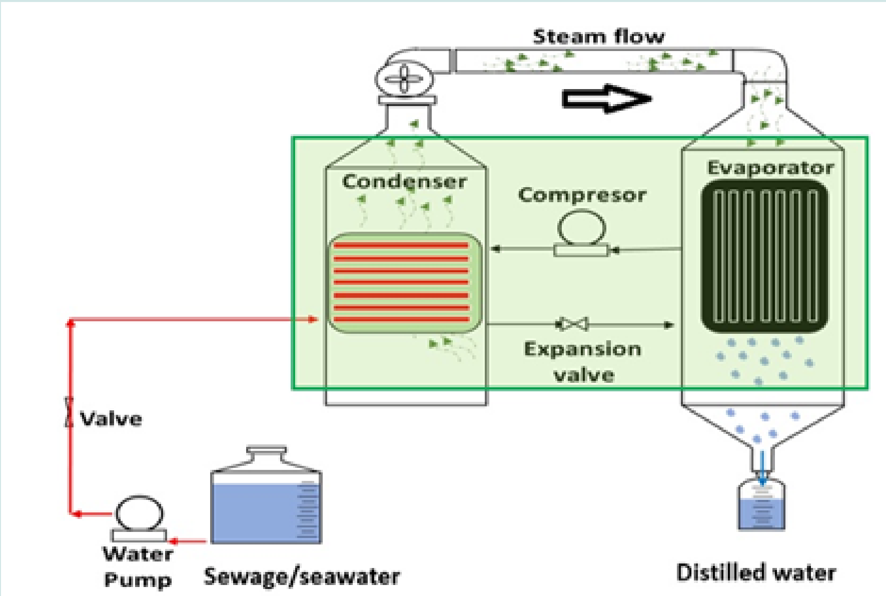

Figure 2: HDH system with heat pump for city building.

Table 2: Size and energy comparison of modern desalination systems.

	Reverse osmosis	Heat pump
Energy	10 kWh	11 kW
Solar panels	28 m2	
Length	1 m	1 m
Wide	1 m	0,5 m
Height	1 m	1 m

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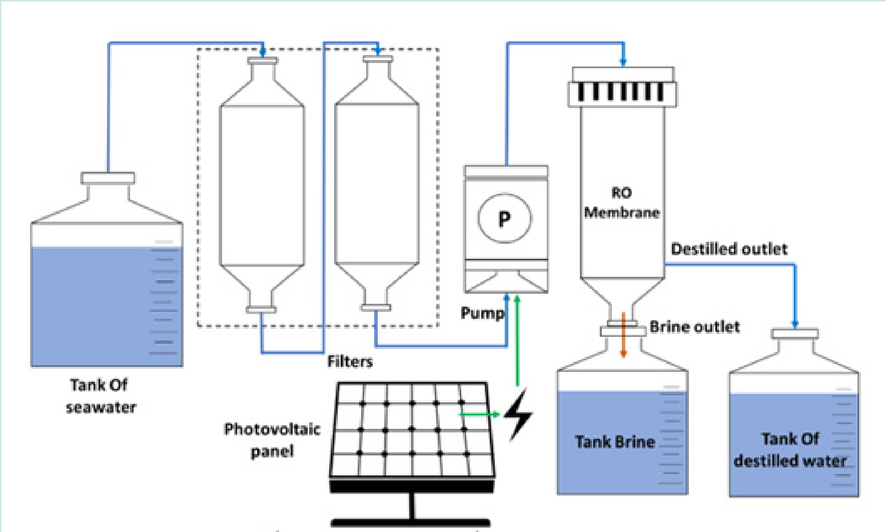

Figure 3: Reverse osmosis water treatment.

Discussion

Mexico City's water stress increases due to rapid urbanization and the effect of extreme meteorological events. Water supply rely on ground water and from external sources [36]. A study made in the Mexico City Metropolitan Area showed that aluminum, ammonia, iron, and manganese exceeded the normal standards, meanwhile arsenic, boron, and chrome was found in some areas [37]. In the city's water used for human needs and vegetable production will be the one that will be recycled from the home sewage. The use of saline irrigation water during lettuce growth in South Korea increased the level of salinity in the soil affecting lettuce growth and yield [38]. Desalination is being presented as an alternative to water scarcity in certain areas. The use of desalinated water in irrigation and fertigation are essential for agricultural production demonstrated that fertigation has numerous benefits compared to the application of fertilizers and water separately [38,39]. Reverse osmosis and heat pump HDH are compared in Table 2, checking their size for a similar energy consumption. This is important as the difference between both is the type of energy used. Very clean water is required for human and animal consumption, but filters can help to remove some special and dangerous salts. Other salts can be used within the terrace garden, where the soil acts as a buffer filtering some salts and avoiding vegetable contamination. Sensors applied to soil and vegetables will measure pH, EC, Cu, Ca and Mg. A study has shown that increasing levels of wastewater treatment, such as decontamination, disinfection, and biological treatment, has a direct correlation with decreased environmental and human health risks [40].

Conclusion

This review concludes that family gardens can obtain the treated water they need daily and start to produce their own food. Water can be used for their needs and even re-used water can be applied as fertilizer for the growth of better crops. Heat pumps are very interesting as they can work all day long and do not require too much space. Although reverse osmosis is getting cheaper, the system requires more maintenance as the salts clog the filters.

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