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Solar Desalination by Humidification Dehumidification, A Critical Review

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Abstract: Most of desalination processes require a large amount of energy derived from natural gas and oil, which are non-renewable energy, for supply heat and electric energy. So, this paper depends on solar energy as a source of renewable energy, and can be powered for producing fresh water. The method used to build up the system is solar desalination by humidification dehumidication, the advantages of this system is can be applied on large and small scale, simple design of equipment, and doesn't require high temperature, so many type of solar collector can be used in humidification dehumidication, also hybrid humidification dehumidication with another driving system achieve high productivity with low cost than humidification dehumidication only, from examples of hybrid systems are thermal PV panels, vapor compression refrigeration system and geothermal energy, all of this could be choice for hybridization with humidification dehumidication system.

Keywords: Solar Desalination; humidification-dehumidification; Saline water; Solar Collector.

1 Introduction

1.1Percent of water all over the world

Fresh water is the most important factor for daily life, as it is required for agricultural, drinking and industrial applications [1]. Despite of two thirds of the earth surface is water, only 1%of the world's water is used [2]. Saline water represents 97 % of the total available water resources on earth. Currently, one fifth of the world's population is facing scarcity in water resources. Another one quarter do have access to water; however, they lack proper treatment methods to make it potable. By 2030, this water shortage is expected to affect up to 40% of world inhabitants. Therefore, finding fresh water resources has become important priority in the strategic plans of most governments as it affects the potential for social well-being of billions of people [3]. The UN World Water Development Report showed that 3.7 billion people are affected by water scarcity, this number may be increase to 5.7 billion in 2050, while at present time 3.5 million people die annually due to inadequate water supply [6]. So the aim of the global desalination market is accelerated rate of desalination from 9% at 2018 to 74% at 2022 [6]. Fresh water can be obtained from saline water by desalination techniques. The available limit of salinity in water is 500 PPM and for special cases up to 1,000 PPM, while most of the water available on Earth has salinity up to 10,000 PPM, and the salinity of sea water range of 35,000–45,000 PPM in the form of total dissolved salts. When salinity in water excesses the limit, it causes many problems as the taste problem, laxative effects, and stomach problems. The aim of a desalination system is to purify and clean sea and brackish water and also supply water with total dissolved solids within the permissible limit not exceed 500 PPM [7].

1.2 Discussion of solar desalination

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Saline water desalination like other water treatments requires the use of energy to produce fresh water. The energy required depends on design of the plant, salinity and temperature of feed water, technology employed and the quality of the produced water [4]. The best technique for saline water desalination is solar desalination process, because solar desalination is renewable energy-powered technology. Solar energy is renewable, eco-friendly, clean in use and available most time. While fossil fuel is non-renewable energy, and also burning fossil fuel produces amount of gasses that have environmental impact such as acid rains and greenhouse effects [2].

Solar desalination processes are classified into two main types: membrane processes and thermal processes. Membrane desalination processes use membranes which transport water across micro porous hydrophobic membranes, such as reverse osmosis (RO), membrane distillation (MD) and electro-dialysis (ED). Thermal desalination processes main idea of this processes are phase change processes, such as humidification dehumidification (HDH), multi-effect distillation (MED), solar still (SS), multi-stage flash distillation (MSF) and vapor compression distillation (VCD) [3]. Production of fresh water in large scale is obtained from MSF, MED and RO. While HDH process is used for small-scale clean energy source for water production.

1.3 Types of solar desalination

Solar still is a simple device, from its advantages is simple fabrication of basin in case of horizontal or inclined, easy maintenance and installation, simple structure and a few moving components. But they aren't economical process due to lower water production and low still efficiency. The ways to improve productivity of solar still are improve the radiation absorption capability of the basin, storage excess energy during cloudy time and increase effective surface area in the basin [1].

Humidification dehumidification technique presents many advantages such as simplicity, flexibility in capacity, moderate operating costs and installation, and possibility of using low temperature energy sources. HDH process is applied when the fresh water demand is rather small. HDH units containing two exchangers: an evaporator where air is humidified with saline water and a condenser where distilled water is recovered. Comparing HDH to other distillation processes, the HD process functions at atmospheric pressure so that the components are not submitted to mechanical solicitations. Productivity of distilled water was found to decrease when the water flow rate increase. The air flow rate was found to have an important effect on the productivity [5].

Solar heating and cooling systems by absorption and adsorption chillers or Solar Heating and Cooling (SHC) systems [8], unlike the conventional methods, adsorption desalination system is simple technique, from its advantages using clean energy, without moving parts, driven also by low-grade heat such as waste heat or solar energy [9]. Such technology is capable to greatly exploit the solar energy to provide space heating and cooling all over the year. In SHC systems, solar thermal energy is generally obtained by solar thermal collectors (evacuated tubes, flat plate parabolic trough, etc.). Produced thermal energy used directly for heating purposes and domestic hot water preparation or supplied to thermally driven chillers for cooling energy production [8].

The majority of the available SHC system layouts include thermally-driven chillers and solar thermal collectors coupled to thermal energy storage systems. Different types of SHC plants based on thermally-driven refrigerating devices are available, such as absorption and adsorption chillers, ejector refrigeration systems [8].

2 Backgrounds

Historically, producing of drinking water from seawater desalination at large scale has been the most expensive method, due to high energy and capital costs. But increasing of the world population was lead to increase solar desalination process [15].

The first desalination plant with commercial scale was during World War II, the total world desalination capacity has increased to 71.7 million m3/day in2010. In 2003 seawater desalination has great expansion of the market. It was found that 1million/m3/ day of fresh water require 8.78 million tons / year of oil to distilled water, which require finding another source of energy solar energy has been chosen, the countries which are used solar desalination must have higher solar radiation [15].

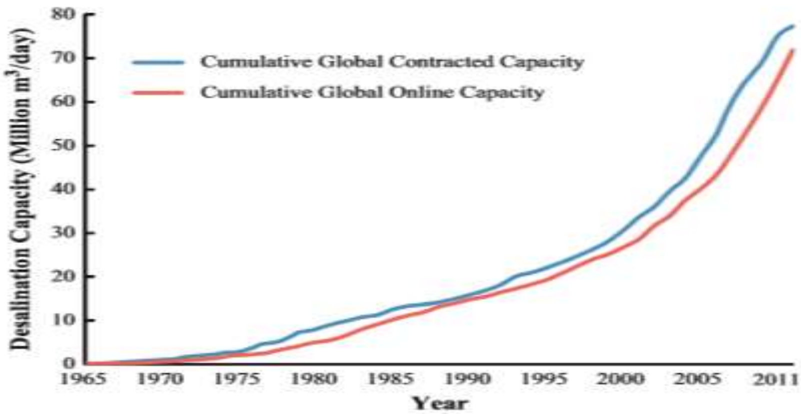


Fig.1. Total contracted desalination capacity, from 1965 to 2010 [15].

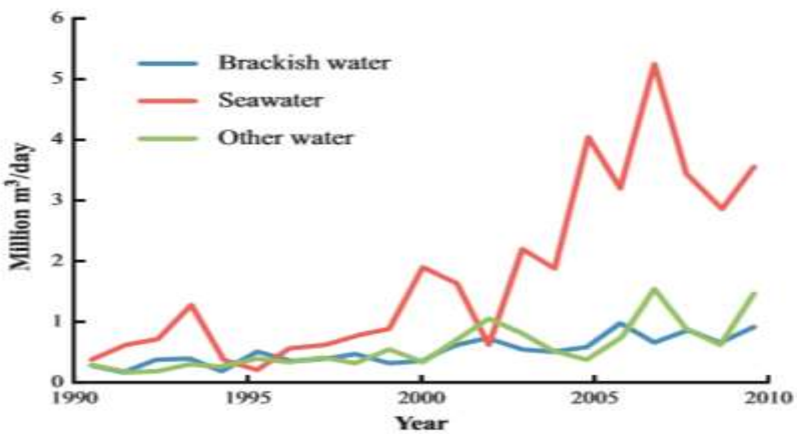


Fig. 2. Annual new contracted desalination capacities by feed water, from 1990 to 2010 [15].

Fig.3. Desalination process grouped based on which substance is extracted [15].

Among all of the above mentioned desalination processes, RO, MSF and MED account for about 95% of the global desalination capacity.

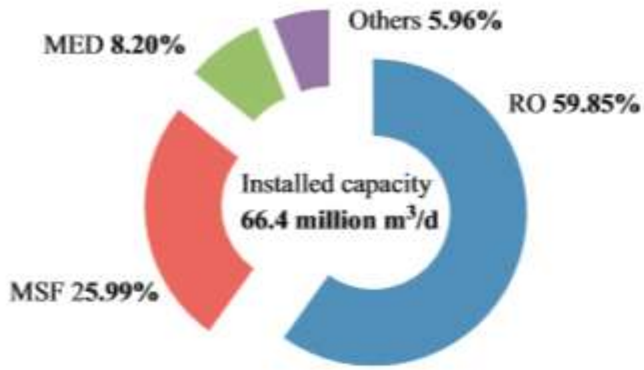


Fig.4. Total worldwide installed desalination capacities in 2010 [15].

3Types of Solar Desalination and Solar Collector

Solar desalinations have many types, some of desalination process depend on solar collector only or photo voltaic. Example of solar desalination Humidification–dehumidification (HDH) technology, Reverse Osmosis, solar still, Membrane distillation, Multi-stage flash, multiple effect distillation and Adsorption desorption solar desalination, all this type will be explained in full details.

3.1Humidification–dehumidification (HDH) technology

Humidification-dehumidification (HDH) desalination process mainly consists of a humidifier (evaporator), dehumidifier (condenser), solar collectors are used for hot water and air supply. In humidification process, the water is brought into contact with an unsaturated air and diffuses into the air [11]. Also saturated steam can be used as carrier gas, which is used to vaporize water from saline feed as distillate [6]. The driving force for this diffusion process is the concentration difference between the water–air interface and the water vapor in air [11]. The saline water loop consists of pump, the storage tank, flow meter, filter, the auxiliary valves and pipe connections. The heating source loop consists of a flow meter, pump and storage tank with a built-in heat exchanger and the necessary hydraulic connections [11].

3.1.1. Humidifier

Humidifier is a device where the saline water is evaporated by using hot dry air, in some cases saline water is also heated, and then water is vaporized and diffused in air, the air becomes moist air. There are many types of humidifier such as: The spray towers, bubble columns, wetted-wall towers and packed bed towers each of these types will be discussed in details.

3.1.1.1. Spray type humidifier

A spray tower consists of a cylindrical vessel in which the water is sprayed at the top of the vessel and moves downward by gravity as droplets and the air stream is continuously flowing upwards. The water droplet gets dispersed within the air. There is minimal pressure drop in gas side and considerable pressure drop in water side due to the spray nozzles. Investigations on a spray tower humidifier have been estimated that the air humidity enhanced with the increase in hot water flow rate in humidifier at a constant inlet water temperature [10].

3.1.1.2. Packed bed type humidifier

A packing material (packed bed) is introduced in the humidifier unit to overcome this drawback which raises the humidifier water holdup capacity and thereby specific humidity of air. An energy analysis has done in solar packed bed humidification desalination with pall rings as packing material. It has been observed that the energy efficiency elevated with the reduction in tower length. Extraction of gas from humidifier has been considerably enhanced the gained output ratio. Using the gunny bag and saw dust as packing material in the humidifier of a HDH desalination. They concluded that the humidifier with gunny bag has better mass transfer coefficient and productivity compared to the saw dust as packing material. A textile material (viscose) has used as packed bed to increase the interfacial area between water and air in a humidifier [10].

Three different materials have been used in packing the humidifier. The differences in the packing materials are in both the coefficient of mass transfer and actual wetted area. The selected materials are available in the local environment at almost no cost (gunny bag cloth), available in the local market at moderate price (plywood slates) or those used in the industry for cooling towers (PVC sheets). When reducing cost of packing material, it would certainly help in reducing the cost per liter of distilled water. The surface area of all materials is kept the same [11].

The dimensions of humidifier are 50 cm width, 80 cm length and 200 cm height. A packing material is fixed inside the humidifier with surface area of 6 m2. The packing is supported such that it does not block the air flow and remains continuously wet. The water is sprayed on the packing material using a hydraulic grid [11].

3.1.1.3. Wetted type humidifier

In wetted wall tower, a thin film of water flows downward through the inner perimeter of vertical pipe by forming a thin layer of water. The air is flowing either through the co-current or counter current direction and mixed with the water and gets humidified. A vertically hanging fleeces made of polypropylene has used in the wetted column tower to saturate the air. Wooden vertical wall covered with a cotton wick reduced the water flowing velocity and keep the walls always in wetted condition [10].

3.1.1.4. Bubble column humidifier

The bubble column humidifier consisted of a chamber with an air supply pipe connected and located at its bottom [12]. The water is filled in a chamber and the air is injected from several orifices which are submerged in the water bed. Thus, the water diffuses into air bubbles and the outlet air gets humidified. The outcome of bubble column humidifier depends on the gas hold-up, bubble velocity, bubble diameter, water and air temperatures as well as the heat and mass transfer coefficients. Inquest on a bubble column humidifier has been conducted by varying the humidifier, water temperature, humidifier water depth and mass flow rate of air. The bubble column humidifier delivered the air with the specific humidity of 0.222 kg of water vapor/kg of air at 75 °C temperature of water and air. It has discussed about the bubble column humidifier desalination and consequence of the assessment shows that the unit yields 8.22 kg/h of fresh water [10]. The measurements were taken at water temperature range from 50–90 0C, air flow rate at 14 kg/h, and water height in the bubble column range from 20–60 cm. It was found that both the fresh water production and humidifier efficiency increase with the air flow rate and water temperature, while slightly affected by the water height in the bubble column [12].

3.1.2. Dehumidifier

Dehumidifier is a device where the water vapor in the moist air gets condensed as the distilled water. The dimensions of the condensation tower are 40 cm length, 200 cm height and 50 cm width. A copper tube formed as a coil is used as a condenser, the length of condenser is 15 m and outer diameter is 1.27 cm. The function of Fins is to increase the surface area of the condenser. The total surface area of the condenser coil and its fins is approximately 6 m2.The cooling water flows inside the coil and the air flows over the finned coil inside the condenser cabinet in a counter direction types of dehumidifier will be explained by the following Bubble column dehumidifier, plate fin tube dehumidifier[11].

3.1.2.1 A bubble Column Dehumidifier

In a bubble column dehumidifier, vapor carried by the air bubbles condenses on the interfacial area between the bubble surface and the cold liquid in the column. The latent heat of vaporization is recovered by a coolant flows inside a cooling coil immersed in the bubble column. The effectiveness of the bubble column dehumidifier is measured at superficial velocity range of 1.9–3.2 cm/sec, the height of water in the bubble column of 4–20 cm, and air inlet temperature of 40–60 o C. It was found that increasing the inlet air temperature and superficial velocity led to increasing in the heat flux and decreasing in the effectiveness. In addition, the height of water in the bubble column slightly affects the dehumidifier performance. Almost all HDH systems

utilizing bubble columns were experimentally investigated at atmospheric pressure. The schematic of a bubble column dehumidifier is hot-humid air is injected through a perforated plate into a pool of cold fresh water to form a bubbly flow. A coolant is circulated inside a cooling coil immersed in the bubble column to receive the heat released from the hot-humid air and control its temperature. The temperature difference between the air bubbles and the water in the bubble column drives the sensible cooling of the air. While the water vapors concentration (or humidity ratio) difference drives the latent cooling and the condensation occurs at the surface of the bubble [12].

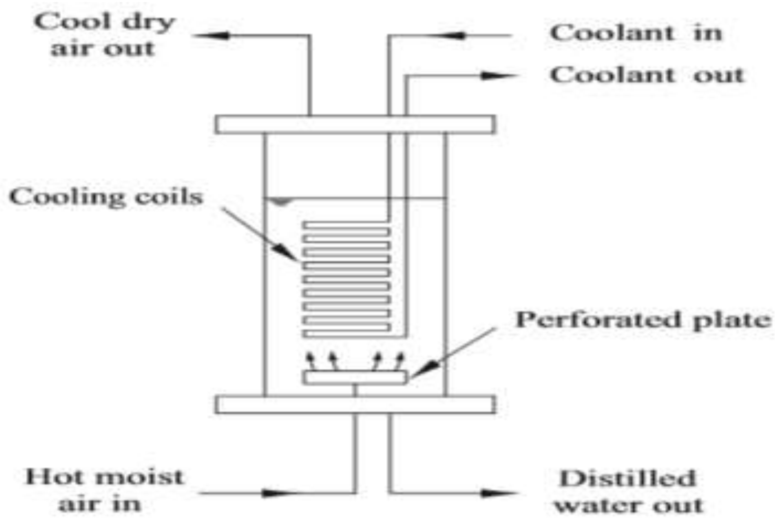


Fig.5. Bubble column dehumidifier [12].

3.1.2.2. A plate fin tube dehumidifier

Plate fin tube dehumidifier is the most economical type for HVAC dehumidification. This type is often adopted for HDH processes. Air flows around the tubes and along the plate-fins in direction of gravity; saline water passes through the tubes. Saline water may be distributed from a port manifold to all tubes, or the tubes may be set up in a multi-pass configuration. Plate fins enhance air-side heat transfer by increasing the air-side surface area. They can be flat, or corrugated or perforated to induce turbulence. The diameters of outside tube are 8.0, 10.0, 12.5, 16.0, 20.0, and 25.0 mm; transverse and longitudinal tube spacing ranging from 15 to75 mm; fin spacing ranging from 1.4 to 6.4 mm; and fin thickness from 0.127 to 0.203 mm. To prevent excessive fouling and erosion seawater velocities between 1.5 m/s and 2.4 m/s are recommended. Plate-fin tube heat exchangers in HVAC systems typically consist of Cu tubes with Al fins, permitting high thermal conductivity at moderate cost. Circular tubes are expanded to press-fit the surrounding plates. In a corrosive atmosphere, however, this standard Cu-Al combination forms an electrochemical cell which induces corrosion. CuNi alloys, which have a higher corrosion resistance, are standard for the tubes of marine plate-fin tube heat exchangers. For seawater operated HDH dehumidifiers the SOLDES project recommends CuNi 90/10 for the tubes, Al or Cu for the fins, and stainless steel 304L for the frames, casing and collecting basin. Another paper reported corrosion of these dehumidifier materials after only six months of operation. the heat exchanger is not only subdivided into one dry and one wet section, but is discretized into several segments in the air flow and saline water flow directions to achieve a two-dimensional solution instead of an average outlet state for this 2 or 3dimensional problem. The air and saline water outlet states are determined for given air and saline water inlet conditions and heat exchanger geometry [13].

3.1.3. Packed bed Humidifier Dehumidifier

This desalination unit is occurred closed air opened water loop, with dimensions of 1.2×2×0.5 m containing both the humidification and dehumidification towers. The unit is divided into two unequal compartments separated by a partition. The unit is insulated with glass wool mates from all sides with thick 50 mm. The unit is kept at 200 mm above ground level to enable the collection of brine, distillate water and for easier handling of the unit [11]. Silicon sealing is applied at all sides to make sure that the unit is leak proof. A partition wall is made of a double layered wall with a thermal insulation between the two layers to provide a closed air loop. The partition leaves gabs of 20 cm height at the top and at the bottom of the unit. An electric fan is supported at the top of the condensation tower to provide the forced circulation of air. The bottom of the desalination unit is shaped as a tray which is inclined at the horizontal plane by 15º towards the outer side walls to collect the brine and distillate water. The dimensions of the condensation tower are 200 × 40 ×50 cm. A copper tube formed as a coil is used as a condenser of 15 m length and outer diameter equal1.27 cm. Fins are used to increase the surface area of the condenser. The total surface area of the condenser coil and its fins is 6 m2.

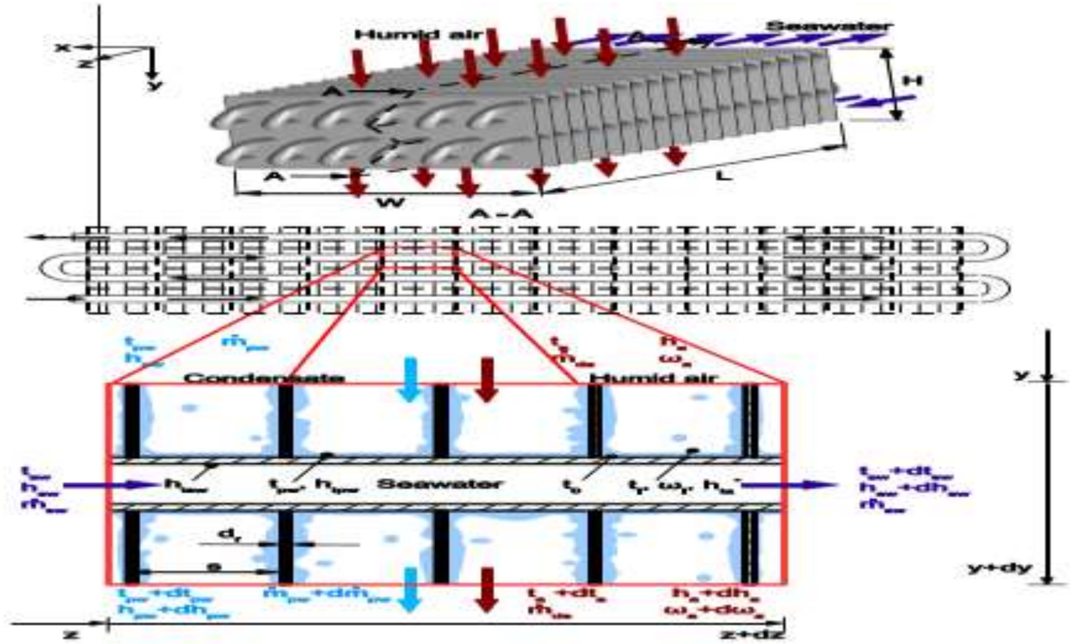


Fig.6: 3D view of the plate-fin tube heat exchanger (top) with sectional view A-A and discretization [13].

The cooling water flows inside the coil and the air flows over the finned coil inside the condenser cabinet in a counter direction [11]. The dimensions of the humidifier tower are 200×80 ×50 cm. A packing material is fixed inside the humidifier with a surface area of 6 m2. The packing is supported such that remains wet all the time and does not block the air flow. The water is sprayed on the packing material using a hydraulic grid. A movable door is provided to easily change of packing material [11]. The heating source loop consists of an electric heater and a storage tank with built in heat exchanger. The capacity of tank is 100 l. The heat exchanger is made of copper tube with length 15 m and diameter 1.27 cm formed as a coil. The tank is supported on a stand made from iron angles. The storage tank and the connecting pipe lines is thermally insulated using glass wool to minimize the heat losses to the surroundings. A second 0.5 hp pump is used to circulate the heated water through the unit. In order to carry out experiments indoors, the storage tank is provided with a 6-kW electric heater powered through a temperature controller [11]. By comparing performance of packing material during HDH it was found that the effect of packing materials is more pronounced on-air exit temperature than at inlet. Gunny bag gives higher values of the exit air temperature at the condenser compared to other packing materials, under both natural and forced flow condition. The highest humidity ratio is given by Gunny bag cloth, but in case of wooden slates the difference between humidity ratio at inlet and exit of the humidifier is much larger which leads to a higher unit productivity. The maximum productivity is obtained from wooden slates is5.4 l/h and inverses to about 5.8 l/h using forced circulation for air and inlet water temperature at humidifier 85 0C [11]. The inlet water temperature at humidifier is directly proportional to the air temperature at inlet and exit of condenser, exit temperature of water at condenser and the humidity ratio when flow rate is constant. To increase mass and heat transfer coefficient and also the productivity it's better to used forced circulation. While exit temperature of water at condenser decrease by increasing water flow rate and also increase in all remaining parameters. Velocity and flow rate of air increase by using forced circulation and all parameters also increase except air temperature and humidity ratio at condenser inlet [11].

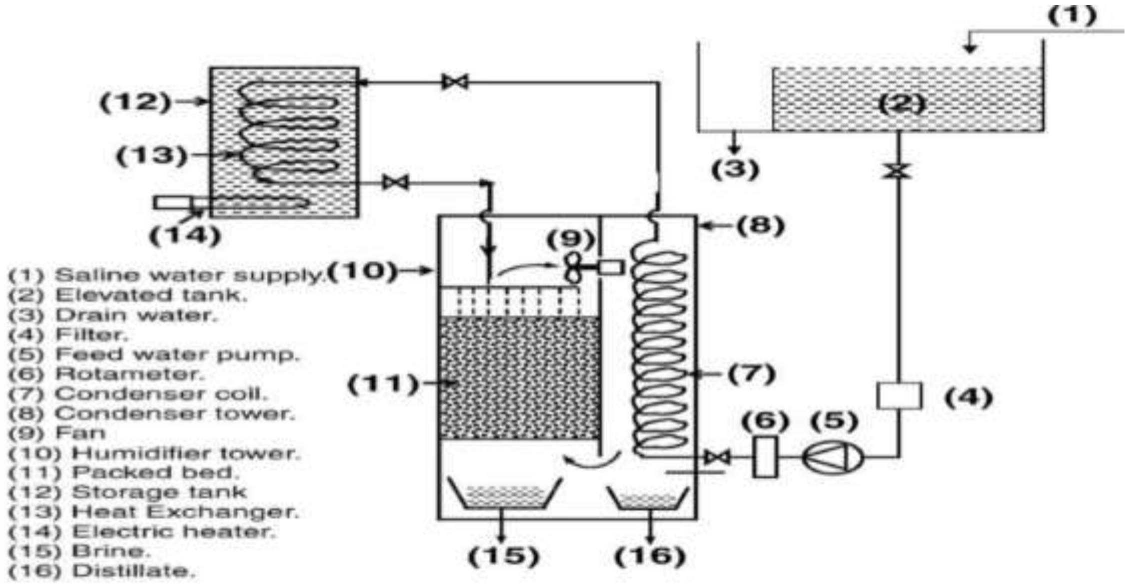


Fig.7. Packed bed humidifier dehumidifier [11].

3.1.4. HDH bubble column

Air is supplied from the compressor (1) to be heated and humidified in the bubble column humidifier (3), and then it flows to the dehumidifier (9) where it is cooled and dehumidified. For the water loop, hot water in the humidifier coil is circulated between the coil and a constant temperature bath (not shown in the schematic), and cold water in the dehumidifier coil is circulated between the cooling coil (6) and the constant temperature bath (20). The bodies of the bubble column humidifier and dehumidifier are made from transparent PVC tubes of 10 mm thickness, 100 mm inside diameter, and 250 mm height [12].

The heating and cooling coils are made of seamless copper tubes with outside diameter9.5 mm, thickness 0.9 mm, and spiraled inside the bubble column with vertical height 90 mm. This height does not include the two vertical pipes that connect the coil to the outside tubing. These two pipes are insulated with 3 mm thickness insulation tape to reduce the convection heat transfer with air. The cooling and heating coils in the dehumidifier and humidifier respectively are connected to constant temperature baths with an adjustable range of 0–80 0C. An air sparger (14) made of stainless-steel cylindrical box outside diameter 98 mm and height 18 mm is located at the bottom of the bubble column where air is injected into the water. The top cover of this box is a perforated plate with 83 holes of 1 mm diameter drilled on its surface with staggered distribution of 9 mm pitch. The two bubble columns are supplied with small tanks (16) to charge, empty, and adjust the water level inside the columns [12].

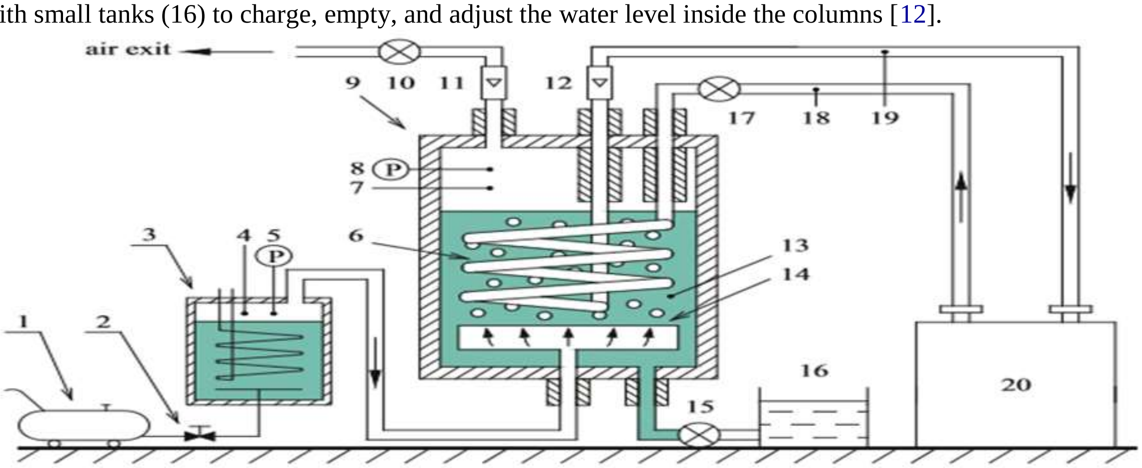


Fig.8: HDH bubble column (1) Air compressor, (2, 10) pressure valves, (3) bubble column humidifier, (4, 7, 13, 18, 19) thermocouples, (5, 8) absolute pressure sensors, (6) cooling coil, (9) bubble column dehumidifier, (11, 12) rotameters, (14) perforated plate, (16) make-up tank, (15, 17) flow control valves, and (20) constant temperature bath. [12].

The flow extends from the homogeneous bubble flow with gas velocity less than 4 cm/s to the heterogeneous one with gas velocity more than 10 cm/s. It is noted that the industrial bubble columns are usually operated at the heterogeneous bubble flow regime. These flow regimes are applied to bubble columns of high aspect ratios (height-to-diameter) ratio more than 5. But the gas holdup is affected by the column height at aspect ratio less than 5. The initial water height is 5 cm and the inlet air temperature is 45 o C and the temperature of water in the column is 15 oC [12]. Parameters are affected by each other as the exit air temperature is inversely proportional with the superficial velocity, while it slightly affects by pressure, increase in mass transfer coefficient lead to increase heat transfer coefficient which account for decrease the exit air temperature, mass transfer coefficient is proportional to superficial velocity. When increasing the pressure lead to decreases the bubbles size and increases the gas holdup which increases the specific area and the total heat transfer rate. The total heat transfer rate increases by about 18% when the pressure increases from 1 bar to 2 bars at a superficial velocity of 12 cm/s [12].

3.1.5. HDH desalination process driven by photovoltaic thermal energy recovery (PV-HDH)

This system has been designed in order to reduce capital cost. A closed air and open water cycle were used for this system. Air was fed to the air gap at the back of the PV by using an electric fan. The air would then cool down the PV panel, become heated in the air gap and then humidified in the humidifier by sprayed saline water. The outlet air from the humidifier was saturated with moisture and passed to the dehumidifier shell where it would be dehumidified by cooling it down to another saturation point (designed as 20 °C) with the aid of cooling water (CW) fed to the tubes inside the dehumidifier shell. This would ensure the partial condensation of the saturated vapor in the air and production of freshwater in the dehumidifier, the partially dehumidified air can be recirculated to the PV panel to continue the cycle [14].

Each m2 of PV would produce 278 kWh of electrical energy or an average of 31.7W/Yr of electrical power and 833 L of water, the thermal energy consumed for water production in the PV-HDH system for each m2 of PV was 240 kWh/m2 • y, While producing a functional unit of 139.2 L/d of water from the PV-HDH system using 61m2 of PV. The total electrical power required by the system components approximately 493 W, while for functional unit 1.44 KW [14]. The system productivity was partially improved from 5.2 to 5.3 L/m2 by decreasing airflow rate from 0.1 to 0.001 kg/s using natural circulation system. A PV panel of surface area of 1 m2, the outlet air from the humidifier was considered to be saturated with vapor (RH=100%), the dehumidified air temperature was set at designed saturated temperature of 20 °C [14].

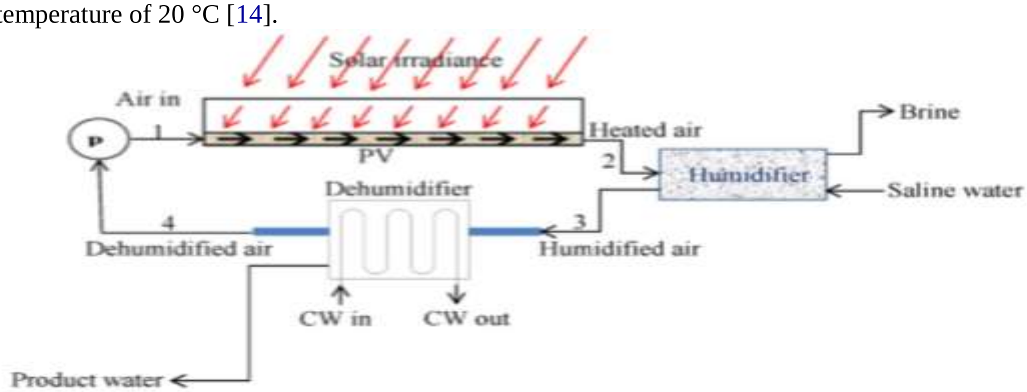


Fig.9: Humidification–dehumidification desalination with PV [14].

From advantages of PV-HDH can obtain thermal and electric energy at same time, thermal energy for heating saline water and electric energy to run the mechanical equipment of the PV-HDH system such as fan, pump and PV inverter in the system. But disadvantages of this system, during cooling effect of the moving air would lead to the removal of thermal energy from the PV. This thermal energy recovered from the PV panel would ensure the removal of up to 75 W/M2of heat available to the PV. This recovery reduced the electrical efficiency of the PV cells. During the night hours in some winter months the production of water reaches to minimum value 0 L/m2 • d while the production of water reaches to maximum value 0.528 L/m2 • d during summer especially in August [14]. Another study of thermal PV showed that, thermal efficiency decreased by increasing the temperature of the air entered to the humidifier. Another meaning, increasing the condensation temperature reduced thermal efficiency of the PVT humidifier, due to the increase in the evaporation rate in the humidifier. The maximum thermal efficiency was around 75.6%, which was observed at the mass flow rate of water is 0.15 kg/s and the condensation temperature at 20 °C [123].

3.1.6. Non-solar methods for extracting water from humid air

The Methods of water extraction from humid air are depend on refrigeration (absorption and vapor compression), mechanical, adsorption and absorption. From this methods are Atmospheric water vapor processing this method is based on surface cooling by heat pumps, concentrating water vapor and controlling convection in a tower structure, Dew collection, it happen due to night sky radiation cooling, that have an insufficient quantity of water production, more efficient method proposed would be to pass deep-sea cold water through suitable heat exchangers for dew condensation and finally adsorption-absorption method will discussed in details at section 3.7 [105].

Geothermal energy is continuous, abundant, and uninterrupted. So, the systems operated by the geothermal energy source can operate all day. The underground heat is efficiently can used to run HDH systems. It can provide water temperature in a range of 60–90 oC. The discharge of geothermal energy after heating saline water also used to preheat the air flowing to the humidifier the mass flow rate of fresh water produce is 250 kg/h [122]. Another way to produce distilled water is flash-binary geothermal systems for simultaneous power production and water purification, the heat from the outlet saturated liquid of the flash chamber are separated into the binary cycles in two ways: in parallel and Series Parallel configuration. In the Parallel configuration, however, the saturated liquid stream is firstly divided into two streams by the splitter, then the two flows heat up the ORC and HDH units separately. It should be noted that the parameters of the systems are taken from the Sablan geothermal power plant In the Series configuration, the flash chamber's outlet liquid stream firstly passes through the organic rankle cycle unit's evaporator, then goes to the heater of the HDH unit, the result showed that increasing the effectiveness's of the humidifier and dehumidifier, lead to higher GOR, Changing the working fluids of the ORC unit result in an insignificant effect on the Pareto fronts, however, the variations of the flash chamber pressure showed remarkable effects in the optimization objectives, Series configuration had a better performance compared with the Parallel system [121].

3.1.7. Multi-effect humidity process (MEH)

The "multiple effect" used here is not in reference to the number of constructed stages, but to the ratio of heat input to heat utilized for distillate production (GOR>l), efficient evaporation and condensation can be achieved at high temperature nearly 100 o C, this method have two types based on the open-water/ closed-air cycle with production of 1000 L/d when the unit was operated continuously for 24, and second type is based on the open-air/ closed-water cycle in this type each 1 m3 saltwater with 1% salt produced 330 L of distillate water and a brine concentration with 15% [105].

3.1.8. Multi- stage HDH

The multi-stage HDH desalination system with different salinity levels is occurred at closed-water system, figure 10 shows flow sheet of multi-stage HDH desalination system, Air is entered into H1, and saline water is heated by heater then air and hot saline water is direct contact, some of the air is injected into the dehumidifier, The remaining once flows into H2, this step leads to increase temperature and humidity ratio of air, the hot humid air flows to DH1 and transfers heat to the cold saline water, at dehumidifier, the air exited from the humidifier is injected and mixed with the air from DH1. The mixed air enters into DH2, it is cooled, which lead to more vapor is condensed. The mixed air enters into DH3 to preheat feed seawater. Then, it enters into DH4, to be cooled by a lot of seawater in order to produce more freshwater. The cooled air is discharged into the surroundings, while the condensate water is collected and flows to the freshwater tank. The feed seawater is first heated in DH3. Then, it is mixed with the reflux saline water. The mixed saline water enters into DH2 and DH1 respectively, where the hot humid air preheats it. The preheated saline water enters into the heater and is heated to a desired temperature. After experiment the result shows that the optimal mass flow rate of air with respect to the maximum water productivity is nearly 730 kg/h at any salinity of water. Increasing salinity lead to decreases the evaporation rate and water productivity, when increase salinity of water by 1%, decrease evaporation rate and water productivity by 0.66% and 0.75% respectively [107].

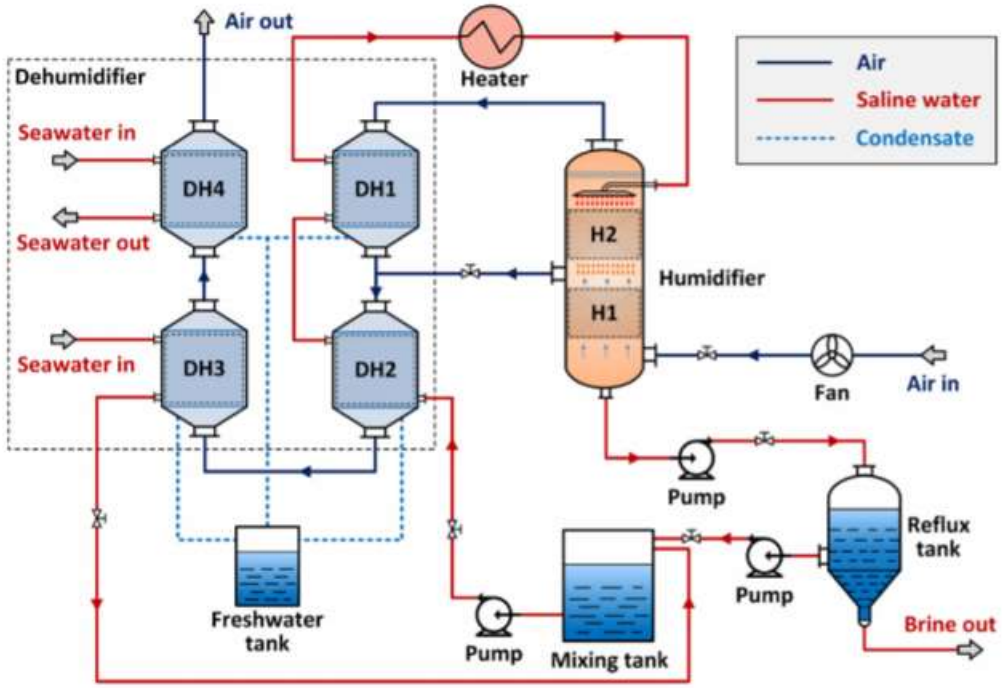
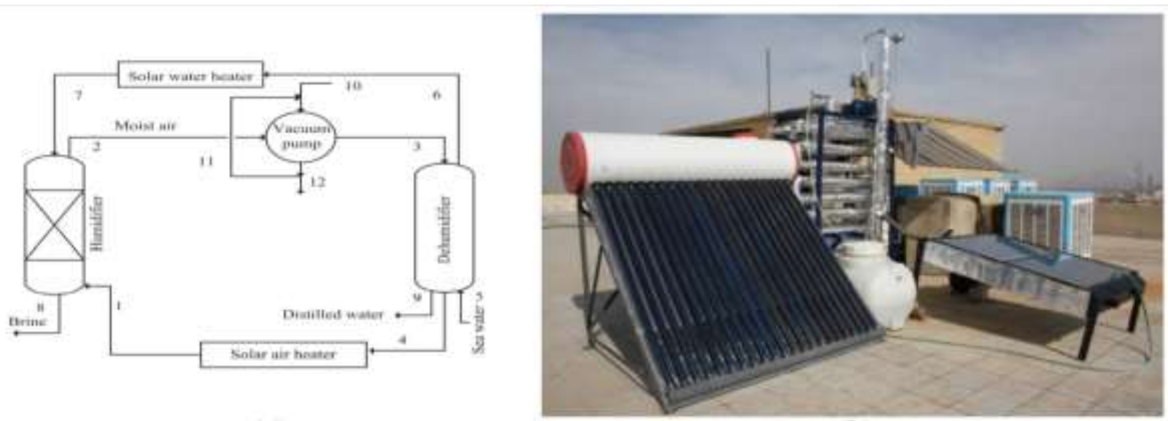


Fig. 10: Flow sheet of multi-stage HDH desalination system [107].

3.1.9. Vacuum HDH

Vacuum humidification-dehumidification desalination is applied at piolet scale, in this experiment the dehumidification occurs at over atmospheric pressure, and the humidification occurs at sub atmospheric pressure, figure 11 shows vacuum HDH in flow sheet and in experimental setup. The saline water and air are heated by a flat plate solar air heater, and an evacuated tube solar water heater, the hot air in stream 1 enters into the humidifier, which gains vapor from heated saline water in stream 7, The exit humid air from the humidifier in stream 2 is direct contact with the saline water streams of in streams 10 and 11, which leads to heat transfer and then the vapor condenses. The exit air from stream 3 passes to first separator, and then separate the air in stream 3 and water in stream 12, the feed water in stream 5 is preheated by air in stream 3. The exit preheated water from the outer tube side of the dehumidifier is entered to the solar water heater. The desalinated water in stream 9 and the air in stream 4 are separated from the exit air of the dehumidifier in the second separator, the result showed that the best operating conditions for the humidifier are at the solar intensity of 1123 W/M2, pressure of 70 KPa, and ratio between water to air is 1.8 [108].



(a) (b)

Fig.11: VHDH desalination system: (a) flow diagram, (b) setup photo [108].

3.1.10. HDH process using hygroscopic solutions

The role of the hygroscopic solution is to increase the surface area and thus the percentage of evaporation on the rotating belt, which lead to increase rate of distillate water, hygroscopic solutions consists of kaolin or calcium chloride. When the wet solid is exhibited to thermal treatment, two processes happen; first, is the energy transfer, in which heat is transferred to evaporate the liquid at the surface, second is the transfer of entire liquid to the solid's surface and leads to evaporations process, in this study many trials used that contains water and CaCl2 or Kaolin with different percentages, the different between CaCl2 and Kaolin is CaCl2 is used as a desiccant, because it has ability to adsorbs much water to eventually dissolves in its crystal lattice water, Kaolin is used for the decolonization of wastewaters by the electro-coagulation methods, this study resulted that, the amount of water evaporation when using kaolin/water solution is three times larger than evaporating only tap water in continuous solar drying system with rotating belt, The overall efficiency was 61 % after using kaolin. On the other hand, 8.7 % was the maximum efficiency attained without using kaolin [109].

3.1.11. Pressure drop

The pressure drop in HDH process increase when the flow rate of air increases, flow rate of air is proportional to velocity of air. Which mean increase in air velocity directly leads to increase in pressure drop. But, increasing air flow rate improve the evaporation rate. The increase in the airside pressure drop is have two reasons. First, the transfer coefficient is proportional to the air temperature, the liquid mass flow rate, and humidity ratio increase as the liquid mass flow rate. Second, the increasing liquid mass flow rate results in the decrease in the cross-sectional area of the air flow channel in the humidifier. Which lead to, the gas volume flow rate increases. Also, rise in temperature of the liquid results in the increase in the pressure drop. But the evaporation rate of the system rises when the liquid top temperature, the increase in the air temperature and humidity ratio leads to the increase in the volume flow rate of the gas stream. Which the increase in the pressure drop [110].

3.1.12. Hybrid system

The main advantage of hybridization is reduce the water cost when compared to the non-hybrid system, when adding a reverse osmosis-pressure exchanger to a humidification dehumidification system, the cost of fresh water production can be reduced from 6.56 $/m3 to 0.13 $/m3, and also the specific electrical energy consumption and specific thermal energy consumption, are 2.71 kWh/m3 and 14.68 kWh/ m3 respectively. This study resulted that hybridization of the systems saves costs up to 10% at 4×10^{-6} $.MJ−1 [111].

The solar assisted air heater and wind tower at closed and open water cycle, figure 12 shows description of this system, the air enters from head of tower and then flow through the clay conduit column, the function of this clay is provide the water particles for evaporative, cooling of air with increased surface area for interaction between air and water, There are two ways to supply the cooled air that has been humidified by evaporative cooling. Firstly, it can be supplied to the floor 2 then can be directed towards the floor1 and through roof to the floor 2. The air is cleaned by latter approach allows the removal of dust particle in floor 1(which is actually basement. This humid air enters in humidification dehumidification desalination system for giving fresh water as a byproduct of the arrangement after contributing to achieve thermal comfort in floor 2. In proposed system a double pass solar air heater is provided that enhances the moisture absorbing capacity of air by rising its temperature so that it can be humidified up to saturation state in humidifier and carries maximum amount of water vapor corresponding to the temperature of the air. The flow of air with saline water is counter flow, the resulted showed that mass flow rate of air equal 0.032–0.035 kg/sec in solar air heater with maximum productivity of 5 and 4.2 kg/day for closed and open water cycle respectively, mass flow rate of water equal 0.035–0.038 kg/sec in dehumidifier has been found suitable increase productivity by 200% [112].

Biogas is used in order to supply heat to HDH process, figure 13 shows biogas with HDH system, at rotary evaporation vessel (humidifier), the biogas slurry was added and heated in a water bath, the vacuum pump open in order to begin the test when the water bath temperature reaches the desired value. The biogas slurry in the rotary evaporation vessel was heated to supply water vapor during the evaporation process; at the same time the cold air was entered the rotary evaporation vessel by the vacuum pump, and was humidified by the steam. The hot moist air with a great amount of steam was condensed into water in the condensation tube (dehumidified) and passed to the balloon flask. The liquid in the balloon flask is the dilute phase, and the remaining solution in the rotary evaporation vessel is the condensed phase. The effect of heating time, heating temperature, air flow rate and initial pH on the efficiency of water removal and nutrients (chemical oxygen demand, ammonia nitrogen, total phosphorus, and soluble salt) recovery was investigated. The study resulted that the HDH system could be effectively used to concentrate the biogas slurry. The recovery of ammonia nitrogen, total phosphorus, and soluble salt in the condensed phase achieved 96% when the initial pH was 6 of biogas slurry, the heating temperature was 70 oC, the heating time was 30 min and the air flow rate was 10 L/min. Under these conditions, the mass concentrations of ammonia nitrogen, total phosphorus, chemical oxygen demand, and electrical conductivity in the dilute phase were 157.49 mg/L, 0.66 mg/L, 8.70 mg/L, and 0.55 mS/cm, respectively, which was far below the mass concentrations of them in raw biogas slurry. Water removal efficiency of 34.12% and ammonia nitrogen recovery of 98.04% were obtained by the response surface methodology optimization when the heating time was 48.54 min, air flow rate was 10 L/min, heating temperature was 61.92 oC, and initial pH was 4.8 [113].

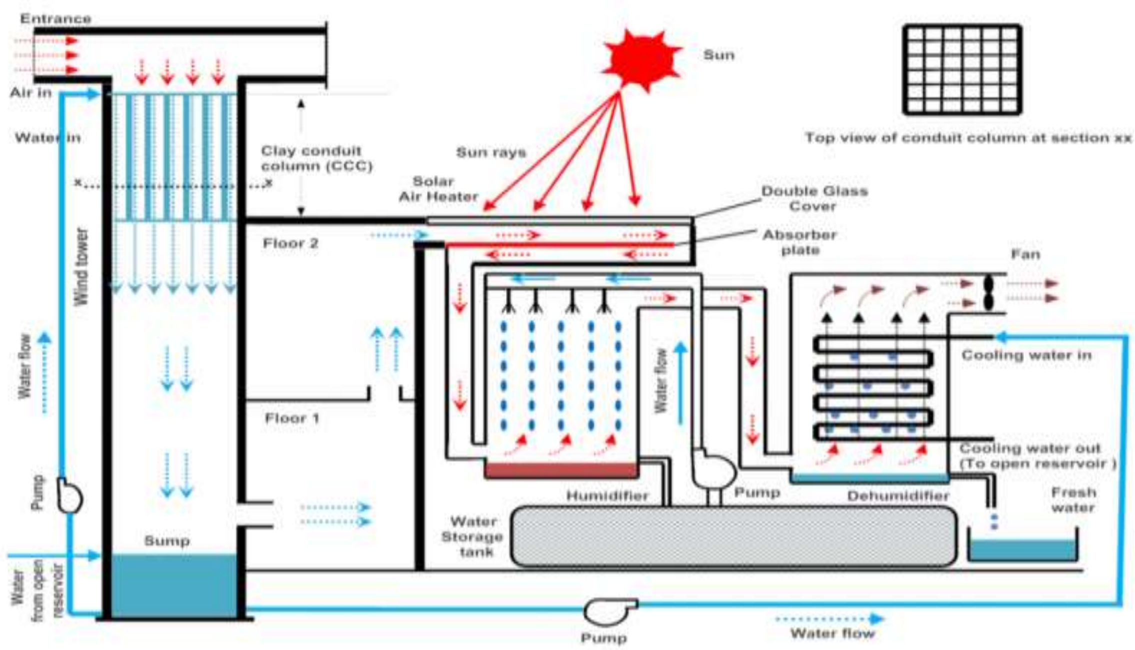


Fig. 12: Solar assisted air heater and wind tower at closed and open water cycle [112.

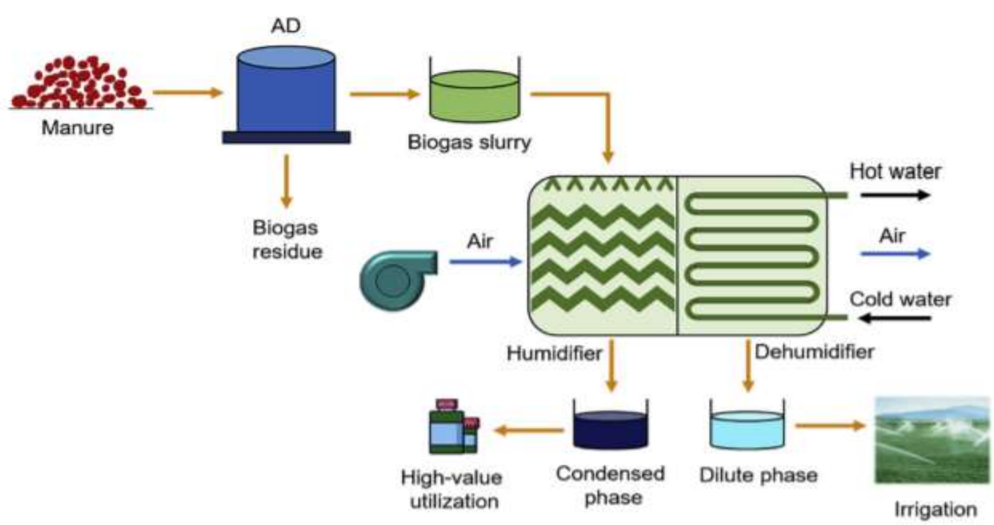


Fig. 13: The biogas with HDH system.

3.1.13. Different type of refrigeration cycle with HDH system

This study mainly depends on hybrid desalination system of a HDH unit with an ethane ejector expander transcritical refrigeration cycle, its function not only produce of fresh water but also cooling load, The thermal energy of the ethane in ejector expander transcritical refrigeration cycle is fed into the HDH system as a heat source for producing distilled water. In this element, the saline water is directed to an open loop, while air stream circulates in a closed loop. Also, a Recovery heat exchanger is proposed to heat the brine after the humidifier to chill heater outlet stream. The saline water goes through an evaporation process with air and the remains are discarded from the humidifier in forms of brine, while air is humidified in the humidifier. Finally, distilled water is produced as air exits the humidifier and flows into to the dehumidifier and the cold air returns back to the humidifier, the result showed that the maximum freshwater was 17.3 m3 /day can be achieved when a two-stage HDH unit is used with a single-stage compression ethane ejector expander transcritical refrigeration cycle, in cogeneration-based gain output ratio, exergy efficiency, and cooling load of 6.56, 17.13% and146.9 kW, respectively [114].

Absorption refrigeration system is a type of refrigeration cycle that can coupled with HDH system to produce distilled water and to provide a cooling effect for air conditioning purposes. The solution used in the absorption system is lithium bromide. The saline water stream of HDH system is used to cool condenser and absorber of the absorption refrigeration system while attaining a sufficient heat to drive the HDH system, as shown in figure 14, the integrated system consists of a double-effect absorption refrigeration system and an HDH system. The seawater is heated by a heat recovery obtained from the cooling process of the double-effect absorption refrigeration condenser and absorber, the main components of the HDH system are a packed-bed humidifier and dehumidifier, while the double-effect absorption refrigeration system is composed of two desorbers, condenser, absorber, evaporator, two unmixed heat exchangers, four throttling valves, and two solution pumps. The resulted showed that, produce freshwater of 1145 L/h and a cooling capacity of 62.45 TR. The optimal condition reported that GOR is 4.54, COP is 1.29, and energy performance is 5.83 [118].

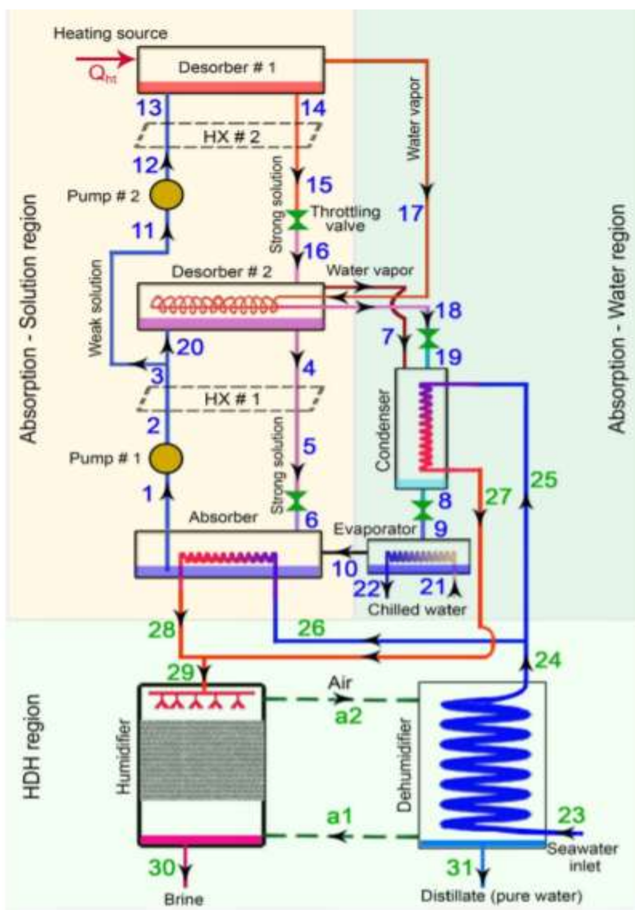


Fig. 14: Flow sheet of absorption system coupled with HDH system [118].

Another type of hybridization is hybrid system of HDH and the wick solar distillers, the packing materials are the wooden cellulose and aspen pad, the point that studied at this study are the fan was fixed at the outside distillers to exit the excess vapor from the stills and condensate it in the dehumidifier, the forced and natural air circulation with different fan speeds of 500, 1000, and 1500 rpm were studied, the performance of the system was tested with different packing materials of aspen pad and wooden cellulose, the humidifier was fed by the drained excess brine hot water from wick solar stills. From this study it was concluded that, the cellulose paper have higher productivity than the aspen pad, the optimal values of the flow rate of water and the fan speed are 4 kg/min and 1500 rpm, respectively, when using the cellulose paper, the forced air circulation produced higher productivity than the natural circulation by 34%. The condenser only improved the distillate by 16.6% compared to 3% improvement due to providing vapor drain only [119].

3.1.13.1. Hybrid HDH with vapor compression refrigeration (VCR)

Heat pump can be hybrid with HDH system, heat pump is a thermal system with a high performance of energy conservation because of its high coefficient of performance, vapor compression refrigeration have multiple objectives, as space cooling and water desalination, so integration of HDH system with vapor compression refrigeration cycles has a great result, for example maximum GOR of 4.07, RR of 4.86%, COP of 4.85, and productivity of 287.8 L/day. The minimum SEEC of the system was found to be 160.16 kWhr/m3 [115].

The waste heat rejected from the domestic air conditioning unit is utilized as the process air for powering the HDH system, figure 14 shows flow sheet of waste heat, the main components are vapor compression refrigeration air conditioning system, humidifier packing material and finned tube heat exchanger (dehumidifier) respectively. The desired temperature of VCR system was about 20 °C, The heat rejection rate at the VCR condenser unit is primarily depends on the atmospheric conditions such as ambient air temperature and ambient relative humidity, and this study concluded that the waste heat energy from domestic air conditioning system can be effectively improve production of freshwater from domestic wastewater, improvement in the dehumidifier unit can improve its heat recovery potential which can subsequently lead to improved GOR [116]. Another study showed advantages of VCR, using indoor air in evaporative condenser and subsequent condensation of hot moist air in evaporator on system performance was found. The condenser was cooled with low temperature indoor air will greatly improve the system performance. Heating, cooling loads of evaporative condenser and evaporator have a great effect of HDH desalination. Integration of HDH desalination with VCR system lead to reduced area required for HDH desalination and energy consumption, experimental result showed that annual desalination and cooling output are 25.884 m3 /year and 4.26 MWh/year respectively. The exergy efficiency of the system is 39.34%. The cost of desalinate water is $0.0096/L. [117]. another study showed that, the heat wasted from an industrial exhaust can be recovered by a heat exchanger in order to use in HDH system. A conventional waste heat source HDH system, it exchanges heat with the outlet moist air from the humidifier or saline water from the dehumidifier, heating the inlet air and water into the dehumidifier and humidifier. A waste heat driven HDH that operates both during day and night has more productivity compared to a solar driven HDH without energy storage [120]. Another study concluded that For Humidification-dehumidification and refrigeration cycles system with direct utilization of VCR cooling effect in single stage dehumidifier, it was showed that the mass flow rate and conditions of the atmospheric air inlet to the system widely affect the system performance. Analysis of the steady state and transient operation of solar Humidification-dehumidification and refrigeration cycles with simultaneous use of external cooling sources and VCR cooling effect indicated a more efficient performance in hot and humid climates. Simultaneous use of heating and cooling load of refrigeration systems in Humidification-dehumidification and refrigeration cycles showed that performance enhancement. Particularly, VCR cycles have been received more importance compared to Vapor absorption refrigeration cycles in hybrid with HDH systems. Heating effect of the refrigeration cycles has been used to increase the temperature of air and saline water. But, the cooling effect of refrigeration cycles has been used for a variety of purposes, including a decrease in the freshwater production and the temperature of inlet saline water for more air dehumidification, recovering the waste heat of brine, decreasing the freshwater temperature in direct contact dehumidifiers and more efficient air dehumidification [127]

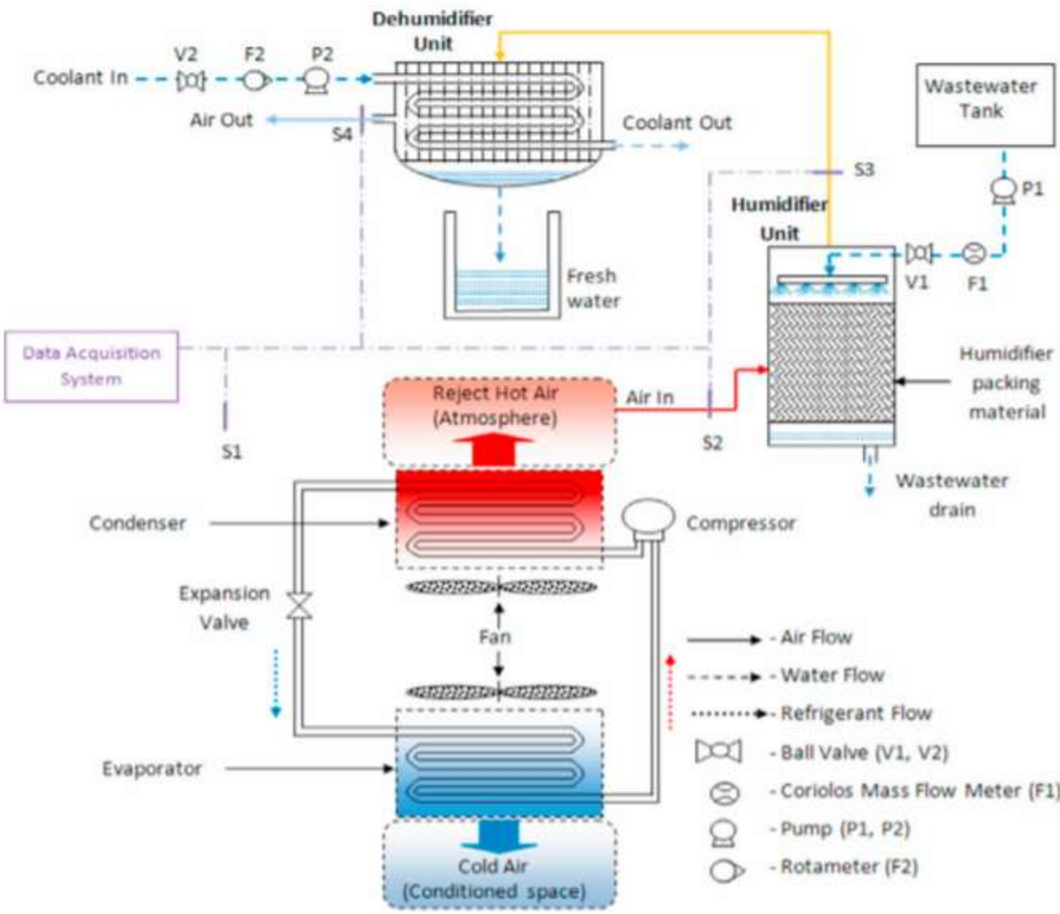


Fig. 15: Waste heat powered HDH system [116].

3.1.14. Types of HDH system

There are four types of HDH as shown in figure 15, from many experimental it was shown that, the closed cycles of air and water improve energy recovery due to the input energy used for water and air heating is preserved in the process. The process air is used for water preheating within the dehumidifier and the brine decreases the required input energy for heating the saline water. Low productivity despite high energy consumption encourages researchers to improve the system performance. It has been known that water heated at HDH system has higher performance when compared to air heated HDH process due to the higher heat capacity of water compared to air [120].

3.1.15 Membrane-based liquid desiccant air dehumidification method (MLDAD)

Membrane-based liquid desiccant air dehumidification is a separation process flowed by the vapor pressure difference. Different from the conventional liquid desiccant air dehumidification, MLDAD uses semipermeable membranes in order to separate desiccant liquid and processing air, to allow water vapor molecules in the air side to transfer through the membrane and be absorbed by the solution. In this process, the vapor is removed from the air stream, and the carryover of solution droplets in the air is also able to be eliminated. Develop membranes customized for MLDAD applications, which have high permeance for water vapor transport and can work at different range of temperatures and pressures, the materials for liquid desiccant, should be non-toxic and inexpensive, does not crystallize, [125].figure 16 shows to type of membranes used in this process which are The parallel-plate membrane contactor and the hollow fiber membrane contactor, while figure 17 shows membrane-based liquid desiccant air dehumidification systems driven by many type of energy as solar energy, industrial waste heat and electrical energy, this study concluded that the performance of the counter flow parallel-plate membrane contactor was better than that the cross-flow one, while the pure counter flow parallel-plate membrane contactor was more difficult in channel sealing in the practical applications, while the hollow fiber membrane contactor, the counter flow hollow fiber membrane contactor was preface for the small flow rate of air, while the cross-flow one could control the pressure drop with the large air flow rate [126].

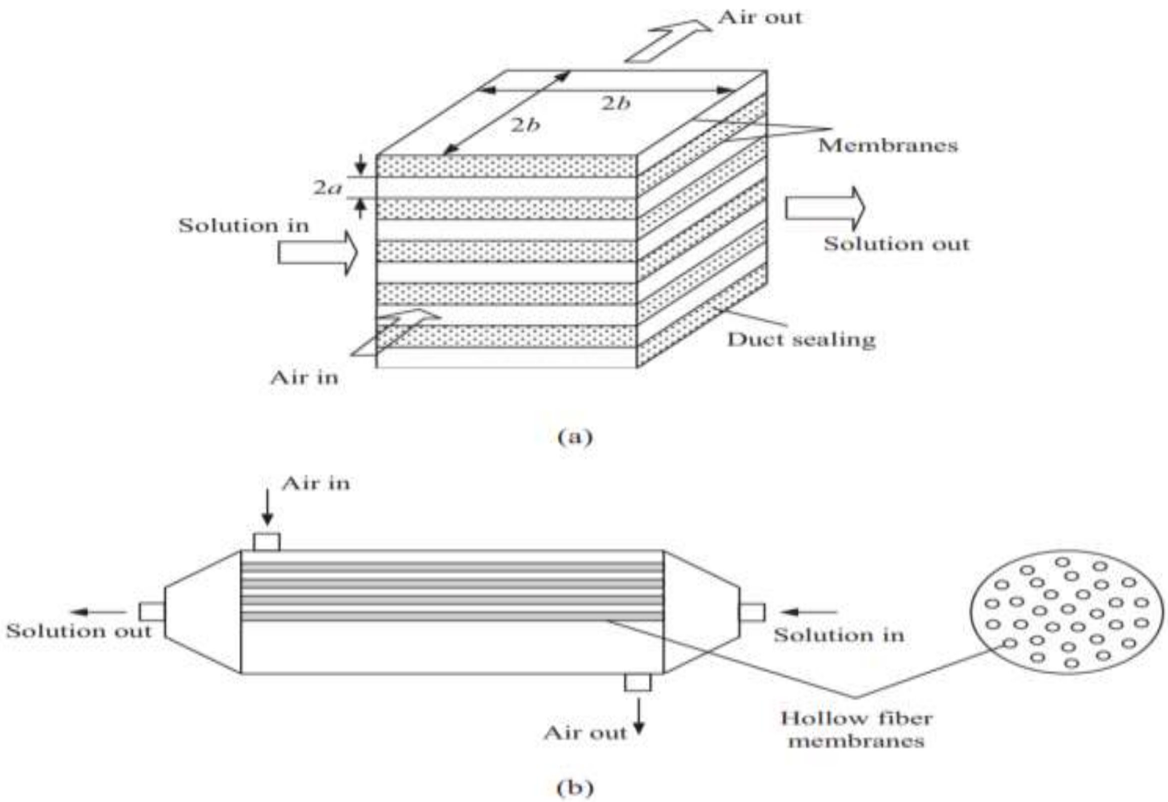


Fig. 17: (a) The parallel-plate membrane contactor (PMC); (b) The hollow fiber membrane contactor (HFMC) [126].

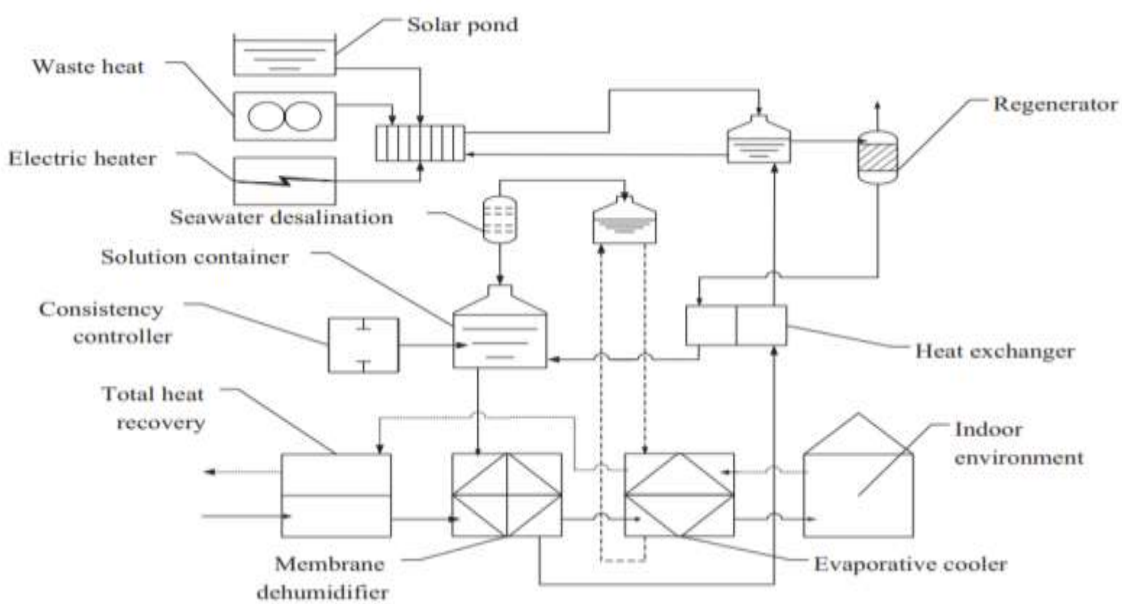


Fig. 18: The membrane-based liquid desiccant air dehumidification systems [126].

Table 1: Different type of Humidification-Dehumidification desalination.

Type of process	Method of working	Reference
A single-stage humidification–dehumidification using solar collector.	This process consist of heating source, humidifier and dehumidifier. The mathematical model is applied to simulate this unit in steady state condition. Equations of modeling is applied in humidifier and dehumidifier but neglect solar collector. In humidifier discuss energy and mass balance for air and water, while at dehumidifier energy balance for both dry air and water and mass balance for humid air.	[22]
Experiential set up for Humidification Dehumidification	This paper describe theoretically how HDH is happen depend on heating both water and air, but doesn't contain mathematical mode. The air is passed by the air blower and flows through a PVC pipe with diameter of 75 mm that is heated by two electric heaters. An airfoil fan-type blower is driven by two-phase electric motor. The blower discharge rate is controlled using throttle valve, through which the air velocity is regulated. The airflow inlet into the evaporator chamber from 32 holes with diameter of 10 mm located at both side of the PVC pipe end, which is submersed in the water of the evaporator chamber. The airflow humidified by passing through water level in evaporator chamber then leaves from the outlet pipe. The evaporator chamber is made of steel with thickness 0.9 mm, square cross section 500 x 250mm and height 700 mm. The water level in the evaporator chamber is controlled by external graduate level and two electric heaters are used for heating the water. The water level is stay constant due to water storage tank, which is used to provide the water makeup and the flow rate is controlled by valve.	[23]
Desalination by air passing through saline water	This type consist of three main components air compressor, evaporator and condenser. The desalination system consists of two loops, one for air and second for cold saline water. In the air loop, air is passed from the air compressor to the evaporator, is regulated by a control valve, and then is passed through flow meter. The airflow inlets into the evaporator chamber from 44 holes with diameter of 1.5 mm located at top side of the copper pipe, which is submersed in the water of the evaporator. The air flows through water level in evaporator and carry the water vapor to dehumidifier. Then, the water produces through a tube to the desalinated water tank in the water loop, the cold saline water for evaporator and dehumidifier is supplied from an external source. The external graduate level is used to control water level in the evaporator chamber and three electric heaters for heating the water. The water level in evaporator is maintained constant and is regulated a control valve. The cold-water passes through inner tube of the dehumidifier.	[24]
Solar desalination of HDH with modeling of solar collector	In this paper researchers focus on modeling of solar collector, heat balance of absorber plate and energy balance of cover glass, liquid and gas(water and humid air) The tower is equipped at the top with an air condenser and the fresh water is produced by condensed the humid air flow.	[25]
Porotype of solar desalination Humidification-de Humidification	The summary of this paper is dimensions and material of constriction of air solar collector, water solar collector, humidifier, Evaporation chamber and Condensation chamber	[26]
humidification dehumidification desalination system using a heat pump	HDH systems is hybrid with heat pump in order to improve performance of process, this paper contain equation of conversion mass and energy of dry air and water in both heating and cooling (humidification & dehumidification). The overall performance of system is improved and obtaining the maximum GOR and yield is 2.08 and 2.79kg/h, respectively.	[27]
Pre & Post treatment	This process consist of two treatment process pre-treatment heating	[28]

by humidification dehumidification	saline water to 50 o C before enter humidifier, then post-treatment which consist of humidifier and dehumidifier. Solar collector heat both water and air, this paper also discuss economic analysis, the water production capacity is 1000 L/day.	
	This paper explain energy balance and effectiveness for systems not for component (air or water) as energy balance of air and water heater, mass and energy balance for both humidifier and dehumidifier, and effectiveness of humidifier and dehumidifier. Also get calculation for Gain-Out put Ratio and Recovery ratio, Gain-Out put Ratio (GOR); the produced freshwater multiplied by the latent heat of vaporization to the thermal energy input. Recovery ratio (RR): the fresh water produced to the inlet seawater to the cycle	[29]
Evacuated tubes for heating air in HDH process	Evacuated tube collector reach high temperature (will be explained in full details) so it is used for heating air in HDH, this paper included design of solar air heater, pad humidifier and dehumidifier, the relative humidity improved from 89% to 97% , flow rate of water 18.3 L/min with overall heat loss coefficient 1.60	[30]
Solar thermal energy combined with humidification-de humidification	This paper discuss many types of solar air collector which are simple flat plate, finned plate, matrix type, corrugated plate, Corrugated plate, Overlapped Transparent Plate Type, Transpiration Collectors, design parameters of solar air collector. And also explain solar water collector and classification cycle of humidification-dehumidification	[31]
Using parabolic solar air collector in humidification-dehumidification	This paper explain two configuration of open water-open air HDH systems, first configuration parabolic collector is placed at beginning, while at second configuration the parabolic collector is placed between humidifier and dehumidifier. Design and operating parameters of the system, modeling of parabolic solar air collector and modeling of humidification-dehumidification are mentioned in this paper.	[32]
Carrier gas other than air for humidification-dehumidification process	The efficiency of HDH systems increase with increase in soar radiation, the specific cost of water production was 0.035USD/L in this system, there are many methods are used to improve productivity of HDH process as reducing size of dehumidifier which affect cost of water production by direct contact of HDH systems and use different type of carrier gas other than air, it was observed that Helium and Hydrogen have lower molecular weight which is preferred in improve high rate of heat transfer while Carbon dioxide has higher molecular weight which lead to ensure high rate of mass transfer.	[33]
Evacuated tube collector in HDH system	Using Evacuated tube collector in HDH system is a good idea, this paper discuss modeling equation for Evacuated tube collector and HDH system and also modeling assumption for building the system	[34]
Comparison between seven models of humidification-de humidification	Seven mathematical models were studied model A, B, C, D, E, F &G, the mathematical models consisted of mass balance, heat balance of the gas and distillate phase, and energy balance in the solar collector, humidifier and dehumidifier, the driving force at the top and bottom of the humidifier. A comparison is made and showed that Model C and D had the most efficient predictions.	[35]
Suitable condition for humidification-de humidification	for open and closed air cycle the mass flow rate of saline water is 0.08 kg/s and the mass flow rate of air is 0.05 kg/s, annual productivity are 6170 L/m2 for closed air cycle and 5791 L/m2 for open air cycle, productivity increases by increasing the temperature of water at the inlet of the humidifier, This due to the heat capacity of water is higher than that of air. It also increases by decreasing the temperature of cooling water and increasing its mass flow rate. The most efficient among the proposed systems is closed cycle of heated air and water. when the saline water temperature increases from 60 to 90 ˚C, the fresh water productivity of the system increases from 59.41 to 182.47 kg/h.	[36]

Thermal performance of humidification dehumidification	As maintained before its preferred to heat water before enter HDH system, in this paper heating water using water solar collector first describe Process description, the major component of the unit is solar collector, absorber plate in solar collector its upper surface painted matt black to increase the absorptivity of the system, in evaporation tower using packed bed to increase the contact surface and lead to improve the humidification rate, the condensation chamber contains polypropylene condensation plates through which the cold salty water circulates for preheating. Process modeling for water solar collector, evaporation tower and condensation tower are described in this paper	[37]
solar desalinator with solar humidifier and subsurface condenser using DoE	Another paper discuss modeling of solar HDH, include the rate of evaporation heat between water and air, the convective heat transfer coefficient and specific humidity of saturated air, Relative humidity, energy balance, heat transfer coefficient, relative humidity and humidity ratio, and also express Experimental design and analysis.	[38]
Solar Energy Driven Humidification-Dehumidification Desalination Systems	This paper describe type of solar collector in full details, with different type of each one, first one is flat plate solar collector, evacuated tube collector, Fresnel lens collector and Parabolic trough collector. Also this paper describe solar collector combined with desalination system as HDD system powered by Flat Plate Collector, or any type of solar collector mentioned.	[39]
Humidification dehumidification desalination system with a packed bed dehumidifier	This paper study modeling of the HDH desalination with packed bed dehumidifier which are waste heat recovery exchanger and recuperate, Packed bed humidifier and dehumidifier, Air-blower, Pump, Economic models and Evaluation criterion. It was concluded that when the air mass flow rate is 0.15kg/s GOR and peak values of the water production are 1.44 and 84.60kg/h, area of water production increases from 0.81m2h/kg to 3.69m2h/kg when the air mass flow rate rises from 0.1kg/s to 0.5kg/s	[40]
Modeling of many types of HDH system	This paper discussed modeling for many type of humidifier or dehumidifier as Multi-tray bubble column dehumidifier, Packed-bed humidifier, Single-stage HDH system and Two-stage HDH system and also performance parameters as gained output ratio (GOR) and recovery ratio (RR). When the heat duty is equally divided over the available area better system performance is achieved. The effect of thermodynamic balancing is much larger on energy efficiency than on water recovery.	[41]
Humidification-dehumidification-adsorption desalination method	This is new type of HDH systems which is integrated to adsorption desorption unit, its function is water vapor adsorption between the humidification and the dehumidification stages, the study first discuss Process description of unit, then mathematical modelling which are humidification-dehumidification units, Unit of water vapor adsorption. The two main advantages are higher recovery ratio and higher gained output ratio.	[42]
Air saturator for humidification-dehumidification desalination application	A new idea of HDH system is obtained which is air saturator, the working air in the wet channel is humidified while moving towards the exit of the air saturator because of the presence of heated water, degree of saturation of the working air tends to decrease while moving towards the exit of the air saturator because of air humidification process, the wet air tends to absorb more moisture. In order to attain maximum outcome from the air saturator, the study of mathematical modeling is explained as Mathematical modelling of Maisotsenko air saturator, dehumidifier and brackish water storage tank, Performance criteria and Modeling setup. It was observed that the temperature of water inside the air saturator has importance role to maximize the evaporation rate, and it is also observed that the absolute humidity of the exit air from the air saturator is increased by approximately 46% when the water temperature is varied from 30°C to 60°C for an infiltration flow rate ratio	[43]

	of 0.6.	
Humidification-dehumidification desalination system with a heat pump	Integrating HDH system with heat pump is the idea of this paper, this work includes Water heated, Closed Air Open Water HDH Cycle, and the Modified Air heated, Closed Air Open Water HDH Cycle, heat pump cycle, Mathematical model of the system and Cost of desalinated water. It reported that maximum GOR of 10.6 and 6.3 is be obtained at feed seawater temperature of 56°C and 29.2°C for air heated and water heated cycles, while recovery ratio of about 3.8% and 6.4% was reached for both water heated and modified air-heated system at the feed seawater temperature of 30.8°C and 55°C	[44]
Performance evaluation of HDH desalination systems with and without heat recovery	This paper contains System description and mathematical modeling for HDH system with and without heat recovery for open water open air HDH system and closed-water open-air HDH system. It was concluded that GOR increases as the components effectiveness increases, dehumidifier effectiveness was found to be more influential compared to the humidifier effectiveness	[45]
Thermo-economic analysis of a water-heated HDH	This paper includes Mathematical models of the HDH desalination system but the new step in modeling is thermodynamic model and economic model. It was reported that thermodynamic performance is sensitive to the balance condition of the dehumidifier, the thermodynamic and economic performance is improved by effectiveness elevation	[46]
Thermodynamic of a semi-open air, HDH system	The idea of this paper is depend on loop of air (semi opened air), as the humid cooled air stream (F) transfers to ambient, and remain of it mixes with fresh air and goes into the humidifier, the air has a semi-open loop circulation. For the case of F = 1, the system has a closed loop, and F = 0 signifies open loop air circulation, mathematical modeling is discussed, firstly the assumption that build modeling, then equations (mass balance for humidifier and dehumidifier, heat and entropy balance, heater and mixture of air streams). It was reported that semi-open air loop at air-heated semi opened air opened water can improve system performance, the impact of ambient temperature is more effective than the relative humidity of the ambient on system performance.	[47]
HDH systems using direct-contact dehumidifier	This paper depends on idea of direct contact at dehumidifier with mathematical modeling for Model of the plate low grade heat collector as well as the hot water recuperate, Model of the direct contact humidifier and dehumidifier and Evaluation of the HDH desalination system. It was concluded that after the energy analysis of the HDH desalination system, a maximum value of GOR is 2.01, which is consistent with the minimum value of the total specific entropy generation.	[48]
Effect vapor absorption cooling on (HDH) desalination	The main idea of this paper is investigation of vapor absorption refrigeration parameters on overall energy utilization factor, This study can be used to control the operational conditions of vapor absorption refrigeration to improve the desalination and cooling together, the equations used are effectiveness of dephlegmator, Q for cooling and overall energy utilization factor. It was reported that the optimum strong solution concentration is decreasing with increasing separator temperature, increasing with increase in dephlegmator effectiveness and increasing with increase in circulating water temperature.	[49]
dual purpose solar collector on humidification dehumidification desalination system	The idea of this paper is integrated HDH with a dual purpose solar collector, the dual purpose solar collector is used to heat the water and air needed for the distillation process, the water flows through the riser tubes while air flows over the top surface of the absorber plate, the hole study of this paper is theoretically without any modeling equations. From this study it was concluded that dual purpose solar collector is designed with a packed bed humidification dehumidification distillation	[50]

	unit, the system is investigated in terms of hot water and cooling water in actual solar condition and mass flow rate of air. It is observed that the system capacity increases with the flow rate of air, hot and cold water.	
Modification on pressure at humidification-dehumidification desalination system	The idea of this paper depends on change in pressure, pressure at evaporation less than atmospheric and subsequent condensation, using of two vacuum desalination processes applying solar heaters, the description of the processes in this paper is theoretically without any modeling equation, it was concluded that the second process has maximum GOR than first one by 139.13%, while the distilled water production rate is lower by 5.71%.	[51]
Study of two stages HDH and cooling plant	Desalination yield has been augmented in this paper with two stage HDH integrated cooling plant, experimental and simulation studies are applied on pilot plant, the modeling equations contains exit air enthalpy, mass of dry air, inlet and outlet heat transfer of dehumidifier and energy utilization factor. It was concluded that the benefit of the second stage desalination by increasing the desalination yield and also additional cooling effect suitable for air conditioning applications. Nearly 100 mL of desalinated water is resulted per m3 of air.	[52]
Study of a solar vacuum humidification-dehumidification desalination system	Another study of using vacuum in HDH system, the experiential on this paper doesn't include modeling equations but include material and methods and experiential set up. It was reported that The decrease in the humidifier pressure from 90kPa to 50kPa leads to increase in the rate of desalinated water up to 1.07L/h·m2, and also the GOR to 3.43 than the other parameters.	[53]
optimization of HDH system driven by absorption-compression heat pump cycle	The main idea of this paper is HDH desalination system driven by an absorption-compression heat pump cycle, the system is hybrid with both heating capacity of the discharged brine as a waste heat for an absorption-compression heat pump cycle and mechanical power of an absorption-compression heat pump cycle for the HDH system, this paper contains description of the system, modeling of the system (Thermodynamic assumptions, Energy analysis in case of steady state and Thermo-economic analysis). It was concluded that in cost optimal design the optimum values of produced fresh water, GOR, cost of freshwater, specific work consumption, and exergy destruction of the overall system are calculated 0.4697kg/s, 7.261, 2.217$/l, 325.5kW, and 143.9kW, respectively.	[54]
Integrated solar cooling to HDH systems by modeling	This paper include operation of a low-temperature thermally driven desalination system, the process is a closed air cycle unit and is based on a single-effect HDH technique, Two different configurations have been compared: an integrated solar cooling and desalination system and separated solar cooling and solar desalination units, the paper has two main part, first is description of the process, second modeling which contains HD desalinator modeling, Absorption chiller modeling. It was concluded that absorption chiller performance has negative effect by increasing sea water temperature. The integrated solar cooling and desalination configuration allows for a higher fresh water production, while the absorption chiller efficiency is decrease because of higher cooling water temperatures.	[55]
HDH desalination system driven by heat pump	The idea of this paper is integrated heat pump with HDH, the system consists of heat pump unit, plate heat exchanger, humidifier and dehumidifier, first explains System description and then modeling (assumptions for model establishment, Sub-model of heat pump unit, Sub-model of plate heat exchanger, Sub-model of humidifier, Sub-model of dehumidifier and System performance). It was concluded that GOR of the system is evaluated to range from 1.843 to 4.154 and the average value is 2.532.	[56]
Analysis of a heat	This paper also include integrated heat pump with HDH, but cycle with	[57]

pump driven humidification-dehumidification desalination system	direct contact dehumidifier, the idea of heat pump supply the cooling and heating loads of the HDH cycle, the modeling of this system consists of HDH cycle (Humidifier, Dehumidifier), Heat pump (Compressor, Condenser, Expansion valve and Evaporator). It was concluded that two methods can be put in place to ensure coupled behavior and no additional cooling demand. First, by varying the mass flow rate ratio of seawater to air and then by changing the mass flow rate ratio of seawater to fresh water.	
Open Type Solar Desalination System with HDH	The idea of this paper is an open solar distiller with HDH, Dry air enters into the distiller is heated up and humidified by solar radiation, when the temperature of glass is lower than or equal to the dew point of the humid air, the vapor condenses on the inner side of the glass cover and runs down where the fresh water is collected. It was observed that the productivity decreases with increasing the evaporation rate and increasing air velocity inside the distiller, low productivity at high air velocity is due to the latent and sensible heats transfer to the glass cover.	[58]
Energy recovery from a vapor compression refrigeration in HDH	The main idea of this paper using humidification dehumidification desalination process to improve the coefficient of performance of a vapor compression refrigeration system, by recovering waste heat from the condenser and the evaporator, this paper includes Experimental setup and Data reduction without any modeling equations. It was concluded that to improve performance of coefficient of performance a refrigerator unit by reducing the refrigerant temperature (sub cooling) in the condenser and by increasing the refrigeration temperature (super heating) at dehumidifier.	[59]
solar dish Stirling engine combined humidification-dehumidification desalination	This paper include new idea which is zero energy building that mean promising solution for dealing with the current issues of high pollutant gas emissions and substantial energy load, which is made possible by applying renewable energy resources and energy storage technologies, potable water and power zero energy building using solar irradiance, which supply a solar dish Stirling engine to generate power and heat. The proposed structure uses the power output of the Stirling engine to drive the air blower and provide the energy load of the building, the suitable design for HDH closed air open-water humidification dehumidification (HDH) desalination process	[124]

3.2. Reverse Osmosis

Osmosis is a phenomenon in which water passes through a membrane from the lower salt concentration side to high salt concentration side. To reverse water flow a pressure larger than osmosis pressure is applied, Membrane tolerance pressure range between 60000KPa to 8000KPa natural osmotic [15]. The first reverse osmosis solar powered plant with photovoltaics was installed in Jeddah, Saudi Arabia, in end of 1981. The power is 8 kW (peak) and the RO system uses two membrane stages of hollow fibers to produce 3.2 m3/d fresh water [106]. RO is a process based on membrane desalination technique that consists of three units, a pretreatment unit, a RO unit and a post treatment unit. By using a high-pressure pump to pass pretreated water through a semi permeable membrane, which allows water to pass through low concentration side and prevents salt particles from passing. The energy needed of a RO plant is especially dependent on desalination capacity. Therefore, RO plants are built out of simulations to allow for capacity flexibility and reduction in required energy [3].

Several studies have been carried out to investigate the feasibility and economics of standalone PV-RO systems. It was proved that a standalone brackish water PV-RO plant can be effectively operated under variable solar radiation (400 to 1200 W m−2) with high quality product even under low solar radiation. But, the productivity of the process decreased with the decrease of radiation intensity. The efficiency of standalone PV-RO desalination units was successfully increased by many methods such as tilting angle adjustment, adding solar tracking, and cleaning systems for PV arrays systems. It was shown that adding continuous single and double axis tracking to a PV panel powered RO unit resulted in an increase in the permeate gain of 43% and 62% respectively. Many studies showed that arranging PV arrays in two rows with V-trough solar concentrator system and using the feed water for cooling the PV arrays and heating the feed water resulted in 60% energy saving. It was also shown that adding PRO (pressure retarded osmosis) as an energy recovery system can result in increasing the permeate rate by 20 times [3].

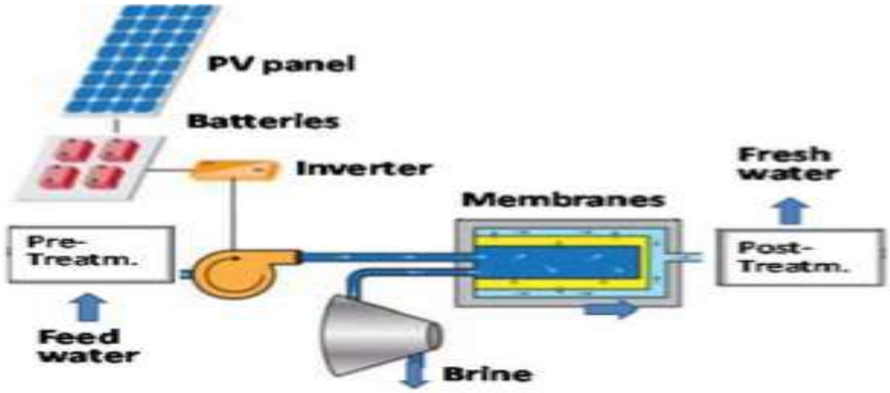


Fig.19: PV-RO powered desalination plant [3].

Several theoretical studies have been carried out to compare the economics of different PV-RO systems. One study has shown that standalone PV-RO required the highest upfront capital cost, but produced the lowest operating cost as compared to PV-RO hybrid with other energy source such as grid or diesel. Another study has shown that using a buffer tank for permeate storage increased the productivity between 36% and 28% depending on the applied pressure. Finally, a study has shown that a super capacitor can be used effectively as an energy regulator between the PV and pump to maintain PV-RO productivity [3].
From advantages of RO compared with thermal desalination non-corrosive equipment, less energy consumption nearly 10-fold less than thermal techniques, small footprints and relatively safe operation, RO would be the key technology to reduce the overall carbon footprint of desalination. Due to these advantages RO has increased more than 60% in total desalination market. It can be predicted that an annual compound growth of more than 10% in the next years. Although all advantages of RO, the energy requirement is still more than double of theoretical specific energy demand of desalination process While thermal desalination now mostly exists in the places enriched in petroleum resources for example Middle East [17]. The specific energy consumption (SEC) of RO ranges from 0.9 to 29.1 kW h/m3 and 2.4–17.9 kW h/m3 for brackish and seawater, respectively. From reasons that make RO more expensive high cost of renewable energy (PV cells) than traditional sources combined with limited operational hours. These plants have been used lead acid batteries in order to store electricity. But these batteries have short life time, especially in hot climate, and therefore require regular replacement that increases the overall desalination cost; also, these batteries suffer from power losses during charging and discharging cycles which lead to decrease efficiency with age [17].
Comparing between PV-RO & PV-HDH, It was showed that PV-HDH produced 2.28 kg of fresh water per m2, this system has reduced the environmental impact by 83.6% compared to PV-RO desalination system [10].The salinity of feed water for both system are equal 35000PPM, by adjust material and energy requirement for production of distillate water it was found that. For the PV-RO system, the production was 250 L/d of water. While for the PV-HDH system the production was139.2 L/d of water. That means 1 life of PV-RO equivalent to 1.8 life of PV-HDH. The recovery ratio of the PV-RO system has been provided as 0.4 it means that 60% of the feed flow rate has been lost to the brine, the maximum salinity of the brine obtained from this system would be 73,333 PPM. This value for the salinity of brine from the PV-RO system is higher than the roughly 40,000 PPM obtained as the salinity of brine from the PV-HDH system [14].

3.2.1. PV-wind-RO

The idea of PV-wind system is that each source can compensate for lack of availability of the other, the small-scale have production capacity of 5m3/day, the cost for the hybrid system can be reduced if multiple wind turbines are used [6].

3.2.2. Forward osmosis

In this process a pressure difference across a semi-permeable membrane lead to water transport, as it enables natural diffusion of water from the feed to a higher concentration solution, it doesn’t require hydraulic pressure, making it a low-energy compared with Reverse osmosis for desalination, the osmotic pressure is obtained by hydrogel which have a water-absorptive layer that provided, and a dewatering layer to release the water absorbed during Forward osmosis [6]. Reverse osmosis has highest percent for application as mention before, the following table (Table 2) discusses another study that related to reverse osmosis.

Table 2: Different method of Reverse osmosis desalination process .

Type of process	Method of working	Reference
Thermal and electric solar powered desalination process	This paper classified into three main parts, firstly is discussion of water, saline water and fresh water condition for fresh water is 500–100 ppm salinity, secondly Solar energy technologies their cost-effectiveness, energy efficiency, and challenges, finally desalination cost-effectiveness, energy efficiency, and challenges, the most famous type of solar desalination is reverse osmosis this paper explain theoretically and also many type of solar desalination as Multi-effect desalination and multi-stage flash desalination and solar still.	[60]
Thermosiphon-powered reverse osmosis	New type of energy powered is thermosiphon, thermosiphon is an economically competitive approach for the withdrawal of thermal energy from molten salt. Thermos phoning depends on the environmental properties, materials and area available for thermal energy collection and storage, and the extent of heat exchange. This system designed for 1 MW of thermal energy. The outlet temperature of the molten salt from the tank is 550 °C. The thermal stability of most molten salts can only be guaranteed at maximum temperature range between 400–600 °C.	[61]
Solar thermal-powered desalination in reverse Osmosis and Membrane Distillation	Most of solar energy is used in thermal (heating) or electric but in this paper solar energy is also used in cooling process in refrigeration cycle, all this energy is coupled with desalination process as RO, MD and Eutectic freeze crystallization. The desalination technique is the most energy efficient. It consumes between 2 and 8kWh/m3 of electricity (the thermodynamic limit is about 1kWh/m3 for 35g/l seawater at 50% recovery and costs less than 1 $/m3. In this paper explain theoretically three type of solar desalination.	[62]
Solar thermal-powered desalination	This paper discuss theoretically two types of solar desalination Membrane distillation and reverse osmosis, for reverse osmosis classified into two part medium and large water demands (more than 100m3/d) and small water demands (less than 100m3/d) but for thermal solar reverse osmosis. And also explain Some equation can help in modeling process as the corresponding matter and energy balances, the corresponding thermodynamic equations, mass and energy balances and definition of recovery rate	[63]
Solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage	This paper includes modeling of reverse osmosis, not only with solar energy (PV) and wind energy but also with Battery storage system and Hydrogen storage system. For Wind turbine modeling contains Wind turbine power generation, the wind turbine life cycle cost equations, for PV contains the PV power generation, PV efficiency equations. The hydrogen storage system and Battery storage system contains the charging and discharging equations. While Reverse-osmosis desalination contains equations for daily desalination water production capacity and cost of chemicals of the RO desalination unit.	[64]

Reverse osmosis systems hybrid with PV and WT power	This paper includes description of the hybrid system which are wind turbine (WT) and photovoltaic (PV) panel, State of charge and economics of battery hybrid with WT and PV and Power and economics model of Reverse osmosis	[65]
Reverse osmosis with hybrid systems in Brazil	This paper also describe Cost analysis using three different energy sources of reverse osmosis with hybrid energy as Photovoltaic Solar Energy, Thermal energy from natural gas, and Thermal energy from biogas in Brazil and some modeling equations as production flow rates required to satisfy the defined populations' energy needs, electrical power equation, Levelized Cost of Energy for solar power and biogas power and operation and maintenance costs.	[66]
Thermal water pump coupled with reverse osmosis membrane	Most of paper explain reverse osmosis system but in this paper explain thermal water pump and organic rankle cycle coupled to reverse osmosis thermal water pump connected to a reverse osmosis membrane. The feed water (Saline water) is pulled through the low-pressure feed water suction line into the cylinder. The high-pressure feed water delivery line supplies the feed water at the required pressure to the RO membrane. In order to achieve a higher delivery pressure, the design of the piston & cylinder arrangement of the thermal water pump is modified. The maximum working fluid temperature is 64°C to produce 1m3 of desalinated water from 3.8m3 of feed water with an initial salt concentration of 1184ppm. The fresh water production rate of obtained was 1.27L/h.	[67]
Design of Solar Organic Rankine Cycle with Reverse osmosis desalination	The idea of this paper is combined of Solar Organic Rankine Cycle with Reverse osmosis desalination, this system is the most energy-efficient technology for saline water desalination within the small to medium power output range up to 500 kW of the power cycle, firstly dissection of solar thermal reverse osmosis, secondly design recommendation without any modeling equations. It was concluded that this system has low specific energy Consumption of the desalination process but the desalination process but also by the relatively high values of the solar to mechanical energy conversion efficiency attained with the solar ORC within the power output and hot source temperature range of application of said technology.	[68]
Energy demand and environmental impact for Reverse Osmosis	The aim of this paper is to reduce environmental impacts and the energy demand of reverse osmosis desalination, firstly discussion of Energy consumption, secondly analysis of Costing and finally discerption of Environmental impacts. It was concluded that the cheapest cost of saline water Reverse Osmosis water is 0.5 US$/m3 but for the same design and similar equipment, the cost may be as high as by a factor of 2.5.	[69]
Environmental impacts in seawater reverse osmosis desalination	This paper is focused on Environmental impacts on Reverse Osmosis with the construction and operation of intake systems and the disposal of concentrate, main point is Review for both intakes and outfalls.	[70]

Transport theory and characterization method of Reverse Osmosis	The idea of this paper is historical date of the membranes, its characterization and transport theory from nineteen-fifties, it was concluded that the top dense layer of the Reverse Osmosis membrane neither homogeneous nor uniform, because It has a heterogeneous, material transport through the top layer of the Reverse Osmosis membrane does not take place by molecular hopping from one site to the other in a uniformly distributed macromolecular segments but it happens through channels of different origins.	[71]
Nano porous membranes with sub-Nano pores in reverse osmosis desalination	Type of membrane used in this paper is 2D Nano porous membranes with sub-Nano pores, firstly the study explains Carbon-based 2D Nano porous membranes, then Graphene. It was concluded that graphene or other 2D Nano porous membranes both of them need porous support to withstand high operating pressures 2D Nano porous membranes have stimulated a new area in desalination membranes science and technology.	[72]
Beneficial use of reverse osmosis brine	Most of sea water Reverse Osmosis desalination plant generated of brine that has potential adverse impact due to its high salt concentration, so the idea of this paper is over view of recent research works and technologies to treat sea water Reverse Osmosis brines for its beneficial use. It was observed that Reduction of water volume or salt concentration is the approach to mitigate the adverse effect of sea water Reverse Osmosis brine.	[73]
Renewable energy system as a potential energy source for water desalination using reverse osmosis	The main idea of this paper is integrated renewable energy for small and large-scale water desalination plants, the renewable energy used are of Photo Voltaic and Wind Turbine, the study contains modeling for both Photo Voltaic and Wind Turbine. It was conclude that sizes ranging of PV energy based desalination systems are 0.8m3/d to 60,000m3/d with an approximate cost of US$ 34.21/m3 to 0.825/m3. While for Wind energy based desalination plants are 1m3/d to 250,000m3/d with an approximate cost of US$ 15.75/m3 to 0.66/m3.	[74]
Reverse osmosis desalination powered by photovoltaic and solar Rankine cycle power system	The aim of this paper is to improve productivity of the desalination plants and also the types of solar collectors, membrane, heat transfer fluid and working fluid used in the Rankine cycle. It was concluded that it is not preferred to use battery in PV system because it cause high capital and replacement cost of batteries, most of PV-RO does not use preheating for the feed water technique cost of the solar Organic Rankine Cycle in Reverse osmosis can be reduced by 30% after commercialization.	[75]
Forward and Reverse osmosis	This paper include reverse and forward osmosis techniques, coupled to the solar energy resource (photo voltaic or solar thermal), firstly describe parameters that effect on PV-RO performance, Modified and hybrid PV-RO, Reverse Osmosis by Solar Collectors with Organic Rankle Cycle and finally Solar Forward Osmosis	[103]

3.3. Solar Still

Solar still or direct still system, the heat collection and distillation processes occur in the same device, where solar energy is used directly for distillation of saline water by means of the greenhouse effect. Water vapor rises to the transparent cover by natural convection and condenses there. Factors that affected solar still output are thermal insulation, brine depth, vapor leakage, cover slope, shape material, climate. Researchers developed many kinds of solar still systems, such as: solar stills with heat recycling; multi-stage/multi-effect solar stills; solar stills with condensers; solar stills coupled with solar collectors; solar stills under low pressure; solar stills with heat storage; and hybrid solar still/PV systems [15]. The efficiency of solar still is lower than 45%, this is due to the high heat loss from its glass cover but the productivity increases when the solar still is operated under low pressure, while during the summer months still efficiency is 75%. When the solar still was operated without a condenser, the yield decreased to 70% [105].

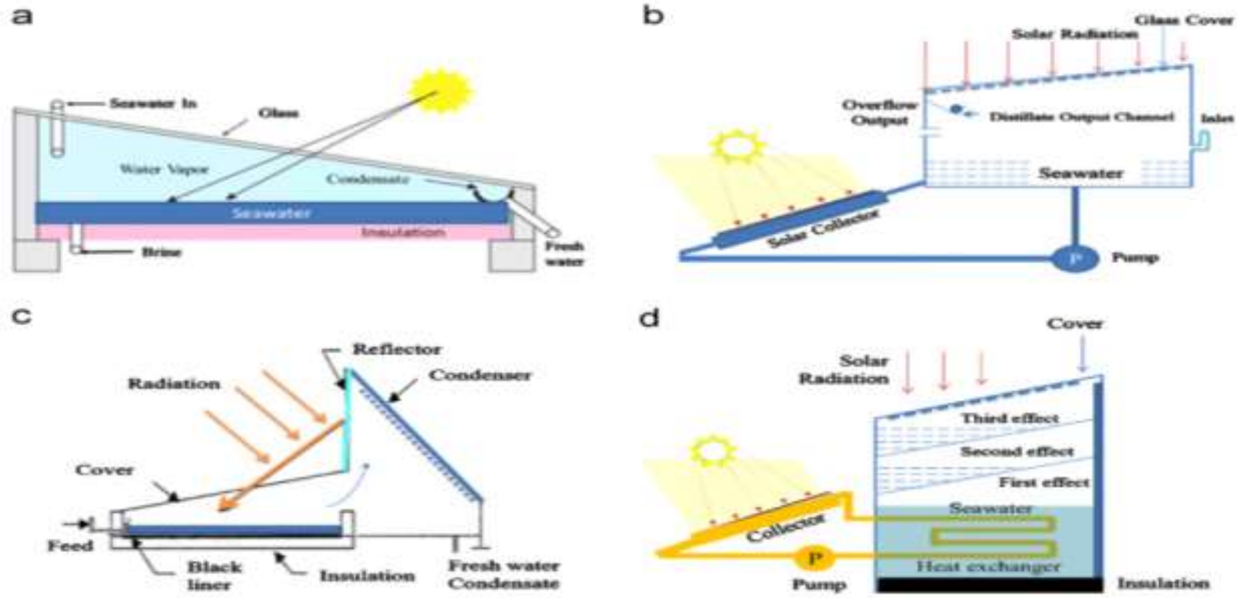


Fig.20: Schematic of solar still (a) Single stage solar still (b) Solar still with collector (c) Solar still with condenser (d) Multi-stage solar still [15].

3.3.1. Types of passive solar stills

More details for passive solar still in case of Egypt is discussed at Table 3

Table 3 : Types of passive solar still in Egypt [2].

Types of Still	**Absorbing area (m^2)**	**Daily Production (L/day)**	**Daylight hours**
Single slope single basin	1	3.72	10-19
Single slope single basin with fins	1	3.50	9-20
With corrugation	1	3	9-20
Pyramidal still	1.5274	4.50	6-18
Concave wick still with cooling cover	1.44	3	10-20
Stepped type still continues water circulation	1	5.23	10-19

3.3.1.1. Single basin solar still

Double slope single basin solar still is designed with a basin area of 0.7 m × 0.9 m and glass cover tilt angle of 30° with respect to the horizontal plate the energy efficiency of the still is31.63% for water depth of 2 cm in the basin. Single slope single basin solar still, with basin absorbing area of 1 m2, the basin was made of galvanized iron sheet with thickness range of 1.5-2 mm. The daily efficiency of the still is approximately 37% and 42% when using salt and sea water as a feed water [2].

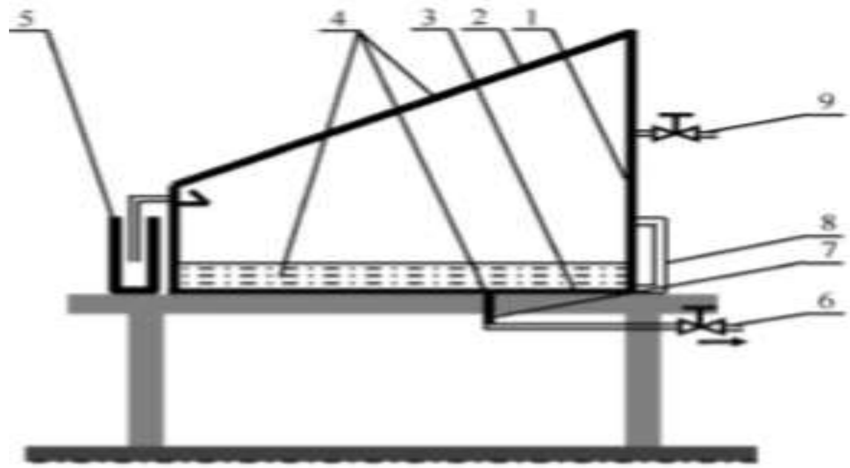


Fig.21: Single slope single basin solar still (1) solar still frame, (2) glass cover, (3) absorber plate, (4) digital thermometer, (5) water vessel, (6, 9) control valve, (7) water drain and (8) graduate level. [2].

3.3.1.2. Finned and corrugated solar stills

Two solar stills with fins and corrugated plate are designed with an effective absorbing area of 1m2.compaerd the performance of the modified stills with the conventional one [2].

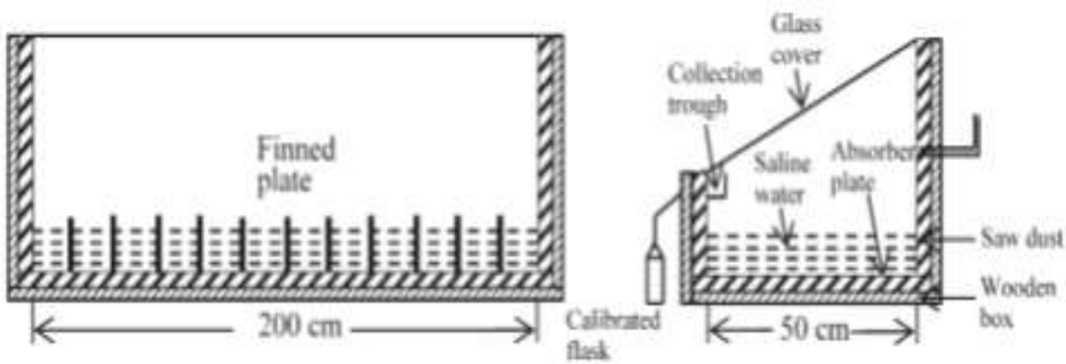


Fig.22: single slope basin solar still with fins [2].

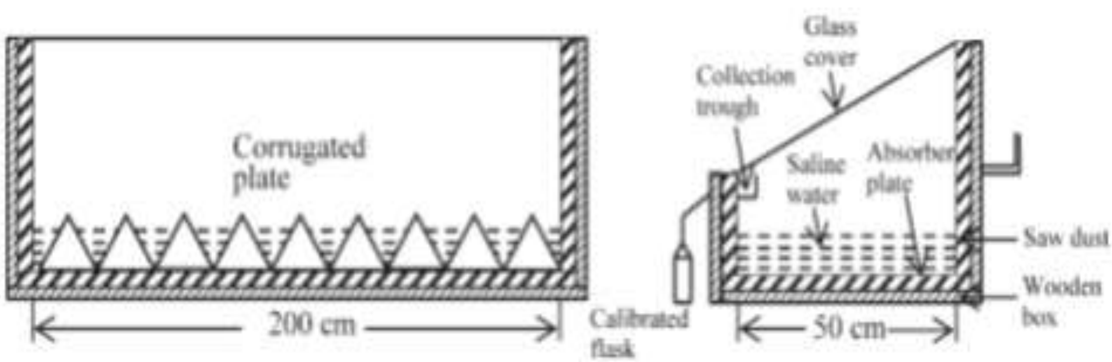


Fig.23: Single slope basin solar still with corrugated plate [2].

The fin materials are manufactured from copper, glass, aluminum, mica, iron, brass and stainless steel, it is preferred to use manufactured fins from mica or glass to avoid corrosion when it contacts with saline water. It was found that finned solar still enhanced heat transfer coefficient by 3.6 times compared to conventional solar still [10], the experimental results showed that integrating fins at the basin liner of the still increase the productivity by 40% compared with the conventional solar still. While using corrugated plate increases the productivity by nearly 21% [2]. Another study showed that by using porous fin in the basin of solar still obtained maximum fresh water output of 7.5 kg/m2 day, the presence of porous fins improves the distillate yield by 42.3% while a pin-fin absorber connected with a condenser, The pin-fin absorber increased the distillate by 14.53% and condenser by 32.18% compared to the conventional one, the distillate yield increases with increase in height and number of fins, Another study using wick on pin-finned shows that the daily productivity increased by 12% compared to conventional one Tests on the influence of square and circular fins in single basin solar still has been found about 36.7% and 26.3%higher fresh water compared to conventional solar still [10].

3.3.1.3. Still with phase change material (PCM)

Paraffin wax is used as phase change material as a latent heat storage medium under the basin liner of the single basin still using the PCM beneath the absorber plate enhances significantly both productivity and efficiency of the still [2]. The most common

material used as energy storage material is Paraffin wax, Peak daily yield of 7.54 kg/m2 with paraffin wax and 4.51 kg/m2 without paraffin wax [10].
The selection of phase change material depends on the maximum water temperature in the basin that can be obtainable, a triangular solar still with the phase change materials found rise in fresh water yield ranging from 3.5kg/m2 day to 5.5 kg/m2 day, another study combines V – corrugated absorber with phase change material as energy storage medium providing of phase change material in solar still has increased the night time output by 72.7% but reduced the daytime productivity by 7.4% [2].

3.3.1.4. Sun tracking solar still

To improve the productivity and also the efficiency of the solar still, a computerized sun tracking device is used to rotate the solar still with the movement of the sun to obtain optimum sun radiation, It is concluded that using sun tracking system increases the overall efficiency by about 2% and improves the productivity of the traditional fixed solar still by 22% but the total designed cost is relatively high [2].

3.3.1.5. Pyramidal and triangular-shaped solar stills

The cross-sectional view of the hemispherical solar still. The daily distillate output of the system increases by a factor of 1.25 by lowering the temperature of the cover due to the effect of cooling water. The efficiency is evaluated as 34%, and increases to 42% with the top cover cooling effect. Comparison between two solar stills the pyramid-shaped and the single basin solar stills, the pyramid shaped solar still is found to be slightly less efficient than the conventional one. Two pyramidal-shaped solar stills are designed. The first one is a 0.2 m2 Poly Vinyl Chloride (PVC) Pyramidal still and the other is a 0.6 m2 triangular-prism PVC solar still. The designed solar stills are lightweight, compactable and reasonably sized. This case is achieved by utilizing flexible plastics. The pyramidal still can easily fit in a back pack, while the triangular prism still, can be rolled up and attached to a back pack. The pyramidal and triangular-prism stills yield an average of 0.5 l/day and 0.9 l/day of distilled water, respectively [2].

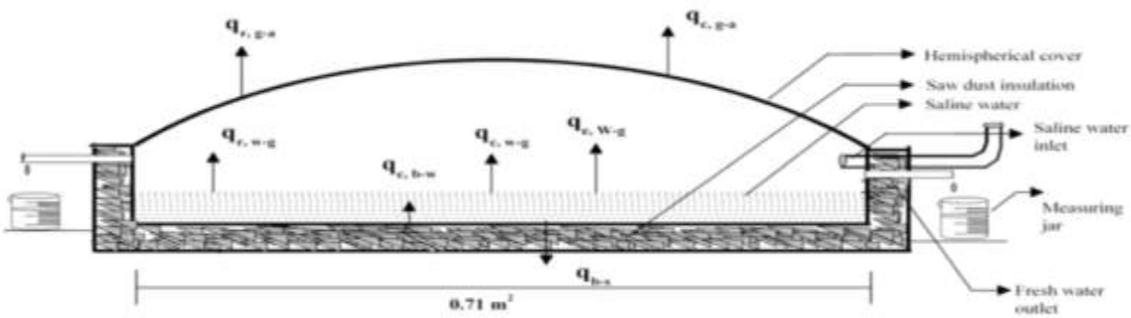


Fig.24. Cross sectional view of a hemi spherical solar still [2].

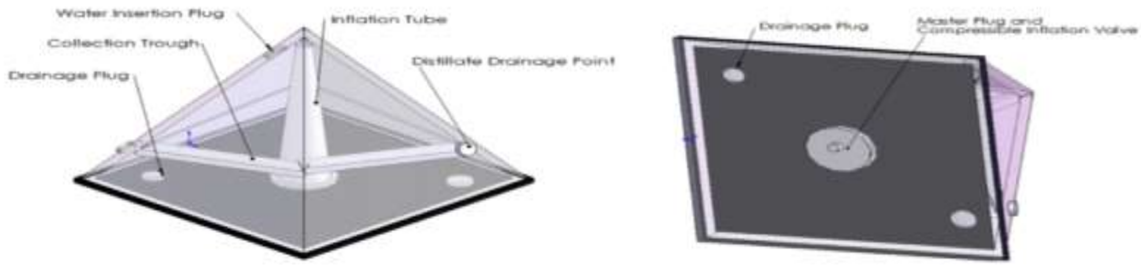


Fig.25. Pyramidal solar still [2]

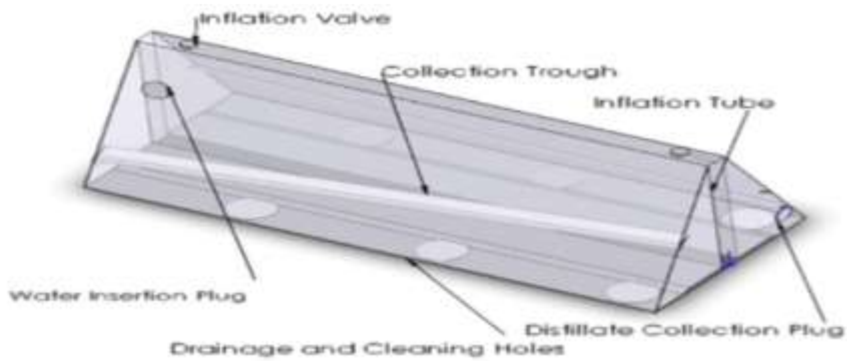


Fig.26. Triangular solar still [2]

3.3.2. Types of active solar stills

Using active mode of operation establishes by coupling with thermal energy source as evacuated tube collectors, flat plate concentration techniques and reflectors.

3.3.2. 1. Basin type still coupled to flat plate collector

Slope hybrid photovoltaic active solar still, with 0.05 m water depth the single basin solar still is coupled to two flat plate collectors connected in series; the annual productivity of the hybrid active solar still is 3.5 times higher than the passive solar still [2], the single slope single basin solar still equipped with a flat plate solar collector, spraying unit, perforated tubes, external condenser and solar air collector [2].
The solar still coupled to the flat plate solar collectors and condenser shows the better performance over conventional basin solar still by 141% in case of sprayed hot water and 132% in case of a jet hot water in active circulation mode [2].
The built-in flat plate collector basin (FPCB) solar still, the basin is divided into six small compartments. These compartments are used as basins. The gaps available between these six compartments are designed as five rectangular fins. These five rectangular fins are used as an absorber plate for the flat plate collector and horizontally placed in the basin. Five pipes are used as risers and these are connected with the upper and lower header pipes. This arrangement is placed above the horizontal absorber plate (rectangular fins). Jute cloth and black gravels are used in the basin to improve the evaporation rate and heat capacity of the still. They inferred that the FPCB solar still gives a maximum distilled water productivity of about 5.82 l/day with an increased ratio of productivity of about 60% higher than the conventional one. The efficiency of the still is reached about 60% [2]. Another study using flat plate water heating collector in order to increase the basin water temperature, Maximum daily fresh water yield of 10.06 kg/m2 for active solar still and 7.8 kg/m2 for passive solar still [10].

3.3.2. 2. Solar still coupled to an evacuated tube collector

The developed system consists of two different parts connected to each other. The first part is a conventional single basin solar still and the second part consists of an evacuated tube solar collector. It is found that the maximum rate of distilled water and the efficiency of the solar still are 1.02 l/m2 h and 22.9%, respectively. A double layers wick type solar still coupled to an evacuated tube collector it was found that the productivity increases by about 215%when hot brackish water is fed continuously, especially during night, compared to conventional one

[2]. From experiential study it was found that Evacuated tube solar collectors generates higher temperature compared to the conventional flat plate solar thermal collectors, the maximum basin water temperature was about 94 °C. Integration of thermosyphon heat pipes in solar still has been resulted the efficiency of 29.2% and the maximum hourly fresh water of 1.02 kg/m^2 [10].

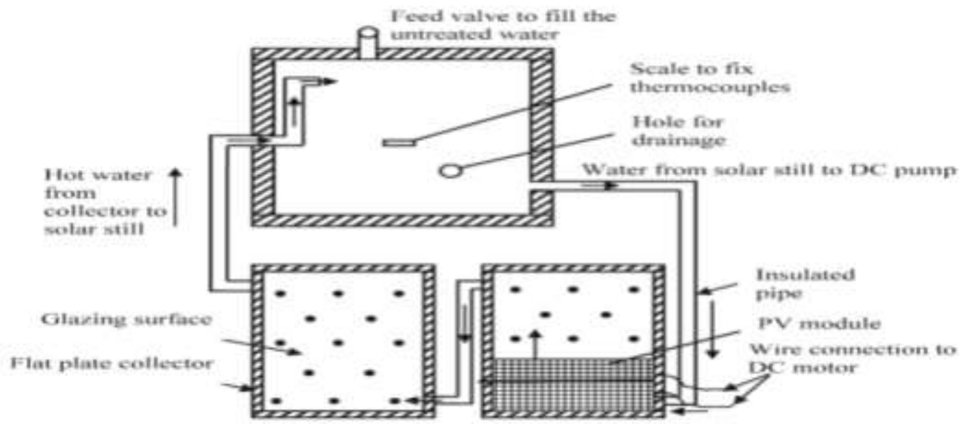


Fig.27: Schematic top view of a hybrid (PV/T) active solar still [2].

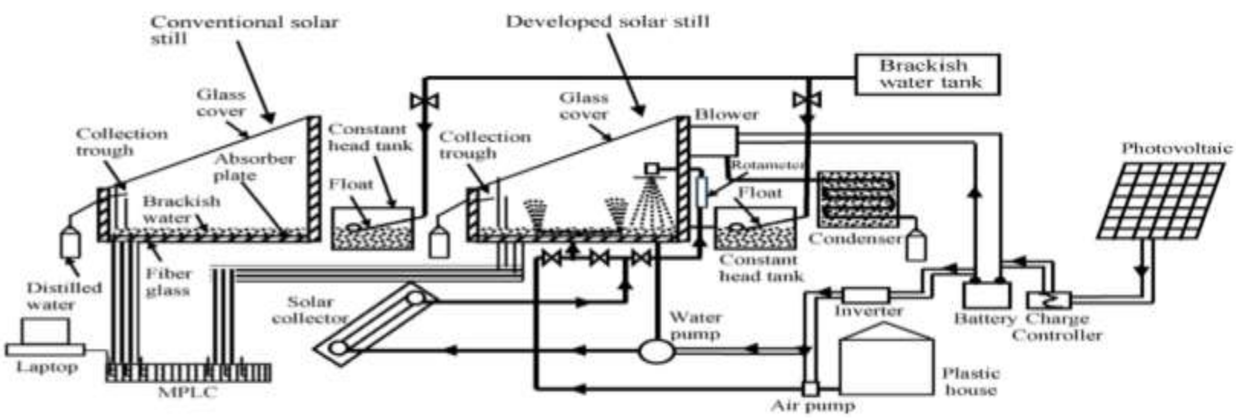


Fig.28. A schematic diagram for the hybrid experimental set up (conventional solar still and developed solar still) [2].

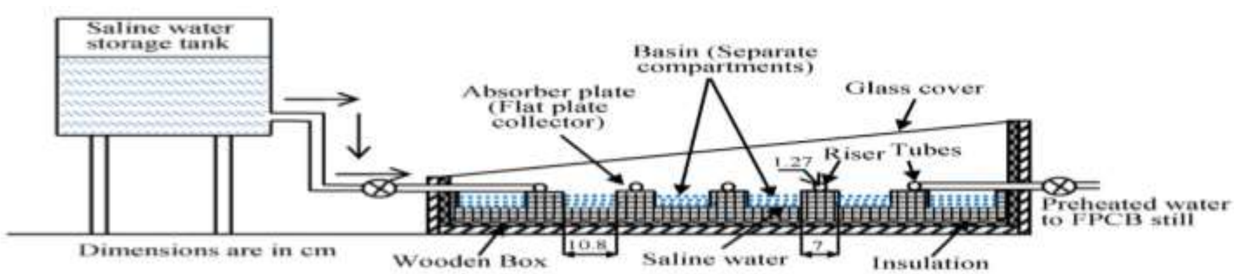


Fig.29. Built-in flat plate collector basin still- sectional view [2].

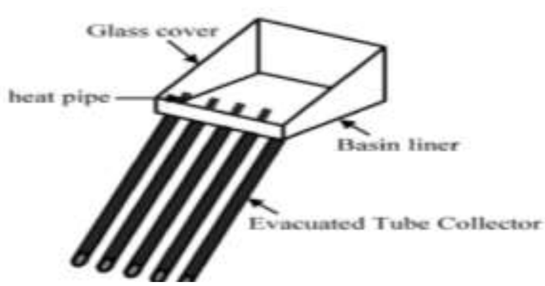


Fig.30. Single basin solar still with evacuated tube collector [2]

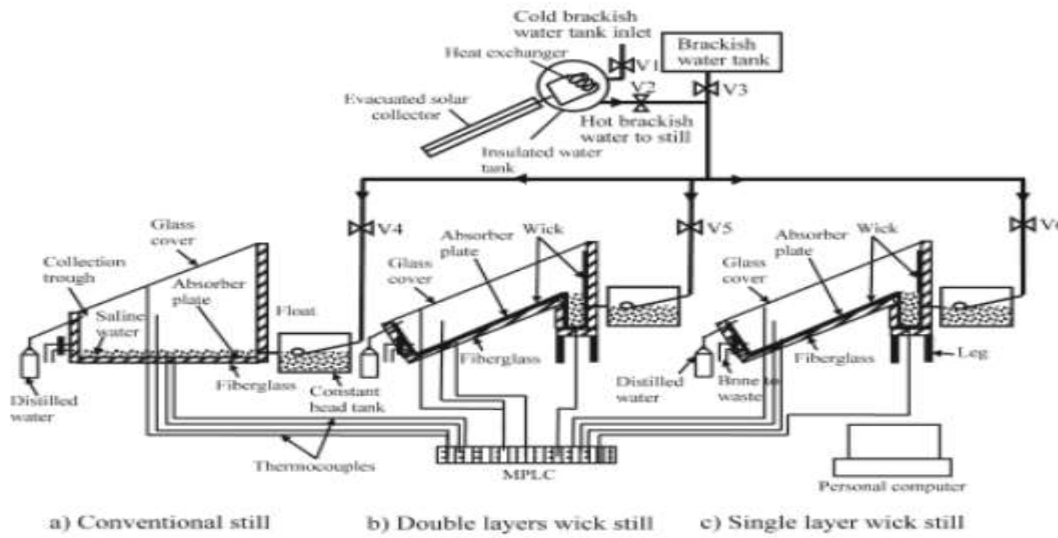


Fig.31. A schematic diagram of conventional still, double layers wick still and single layer wick still [2].

3.3.2. 3. Multi-effect active solar still

The three stages are mounted on top of each other and the saline water is fed into each stage from the tank located at the top of the third stage. The results showed that a significant improvement of the overall productivity is obtained. The total daily yield is found to be about three times of the maximum productivity of the basin-type solar still [2]. The performance of four-stage active solar still, the performance of the system in continuous and non-continuous modes is compared. The collected distillate production is hourly measured during the whole 24 h. It is reported that by increasing the number of stages, the positive effect of the performance in case of continuous mode increases outstandingly. It is also predicted that a 5-stage system would produces 25% more fresh distilled water in continuous mode compared to non-continuous mode [2].

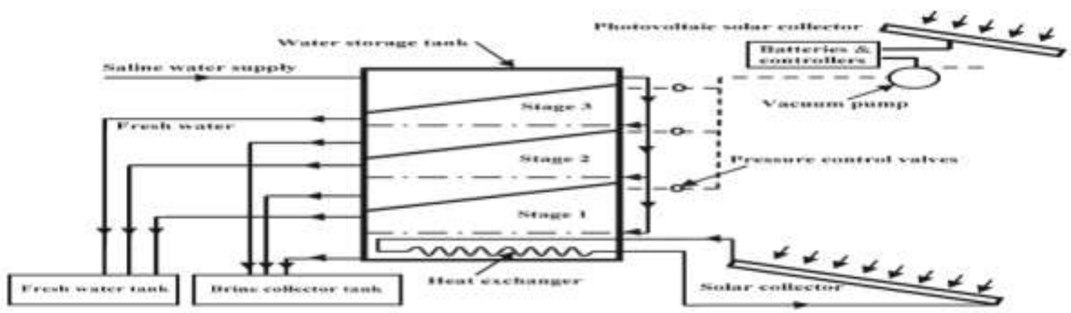


Fig.32. Schematic diagram of the evacuated triple-stage solar still [2].

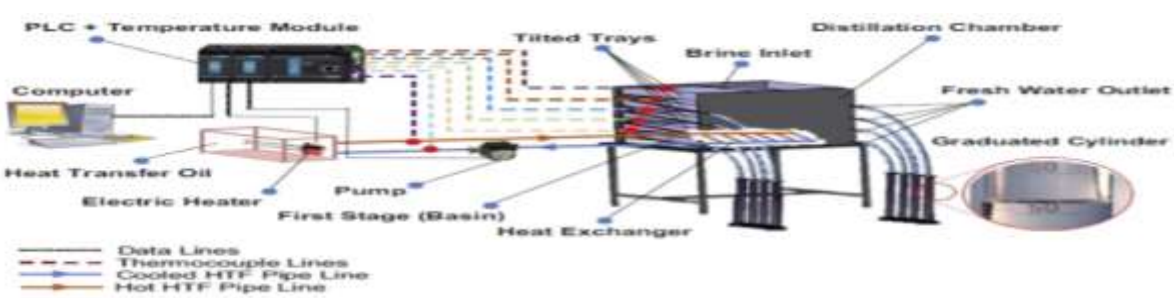


Fig.33. Four-effect active solar still [2].

Latent heat of condensation of water vapor which increase the temperature of glass cover can be used for preheating the saline water and based on this concept multi effect solar still is formulated, a study has been done on double basin solar still connecting with the vacuum tubes in lower basin achieved 56% higher distillate compared to the conventional double basin solar still, another study has been done but manufacture double basin solar still from black granite gravel it was reported that 67% more distillate with 30 mm size black granite gravel, A single and multi-effect solar still manufactured by glass as basin material The result showed that the insulated double basin solar still increase the distillate by 17.38% higher compared to single solar still, during year Highest daily yield ofv31.6 kg on summer and of 27.83 kg in winter. While triple basin solar still with a parabolic concentrator, cover cooling on solar still and energy storage materials in fins has been tested, it showed that Maximum distilled water daily yield of16.94 kg/m2 for triple basin solar still with above modifications and 6.49 kg/m2 for conversional triple basin solar still a maximum daily water production from multi-stage solar still was about 8.1 kg/m2 at 2 cm depth of water. An experimental study on triple effect corrugated basin solar still with vacuum tube connected to lower basin has been reported a maximum daily fresh water yield of 43 kg [10].

3.3.2. 4. Finned and stepped solar stills

A stepped solar still with using internal and external (top and bottom) reflectors .The absorber plate is made of five steps (each of size 10 cm × 200 cm) with tray depth 0.5 cm and width 12 cm, so that the absorber and water area are equal to 1.16 m2. The mirrors are added on the vertical sides of the steps as internal reflectors of stepped still. The top external reflectors are inclined backward. The results showed that the daily productivity of the modified stepped solar still increases by about 125% over conventional still. New type of solar desalination technique finned and stepped solar stills are connected in parallel with a mini-solar pond. It is concluded that by adding sand and sponge to the finned solar still, the productivity increases by about 96%. The productivity increases by about 100% by adding fins, pebble and sponge to the stepped solar still [2].

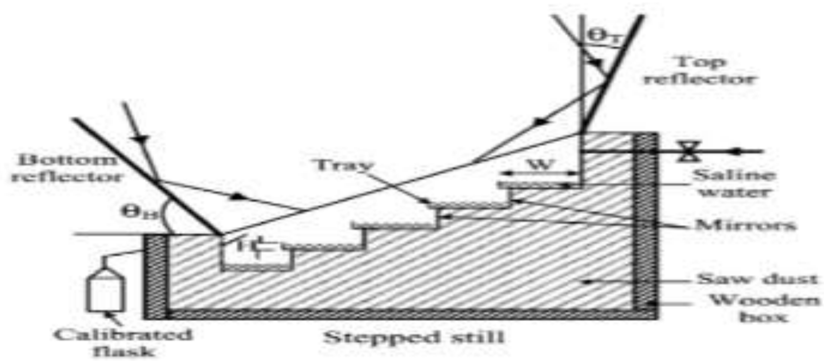


Fig.34. Stepped solar still with internal and external reflectors [2]

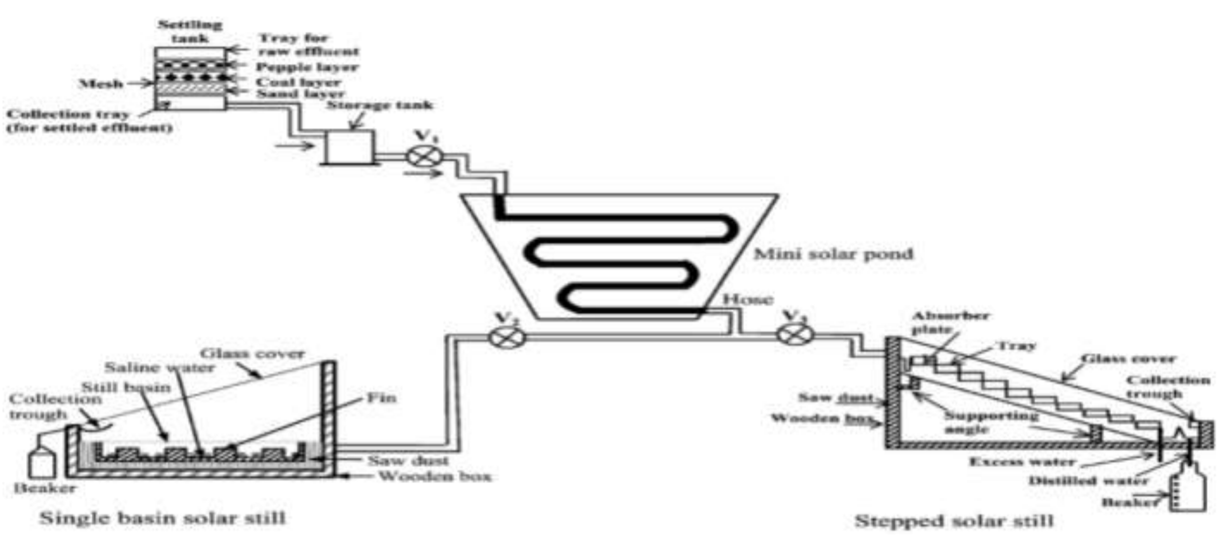


Fig.35. Finned and stepped solar still in parallel with mini-solar pond [2]

3.3.2. 5. Solar stills with thermoelectric cooling

Thermoelectric coolers are used to increase the temperature difference between the evaporation and condensation surface which lead to enhanced distilled water output[10],portable Solar still with small scale, with thermoelectric cooling to increase the condensation rate, All walls of the still are made of Plexiglas to make it lightweight, unbreakable, easily mounted and corrosion proof. The thermoelectric cooling systems consist of P-type and N-type blocks of semiconductor materials. When electrons pass through P-type to N-type semiconductors, cooling effect occurs. The portable solar still included two main zones; evaporating and condensing zones. The results showed that the maximum efficiency of the novel system is 13% and the distillated water is suitable for drinking [2]. A study was done using thermoelectric cooler that increased the temperature difference. A portable asymmetrical solar still using three thermoelectric cooler to reduce the condensing cover temperature the resulted has observed that the production rate has improved by 3.2 times compared to conventional one [10].

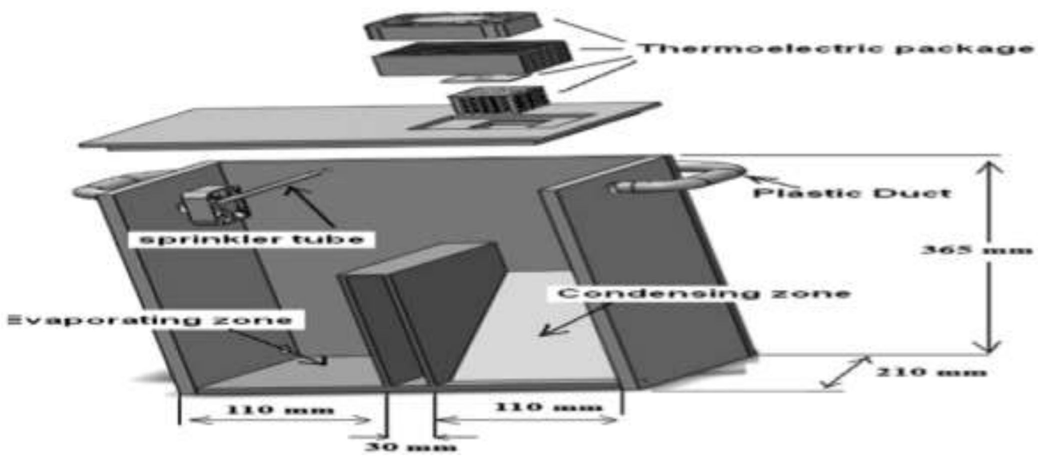


Fig.36. Portable active solar still with thermoelectric cooling [10].

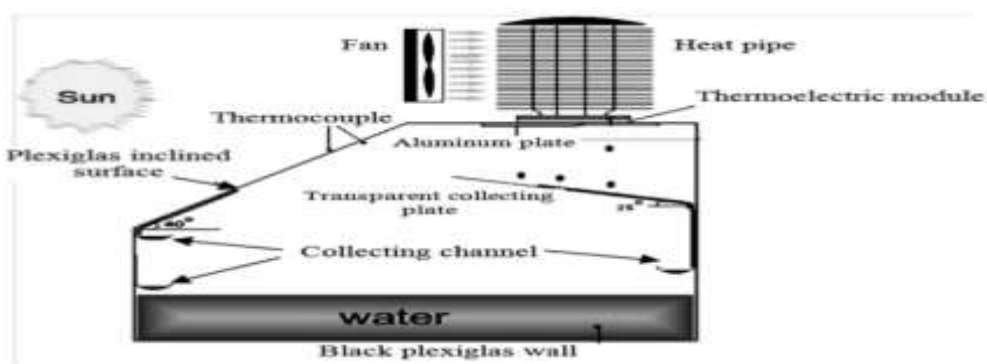


Fig.37. Solar still with thermoelectric cooler [2].

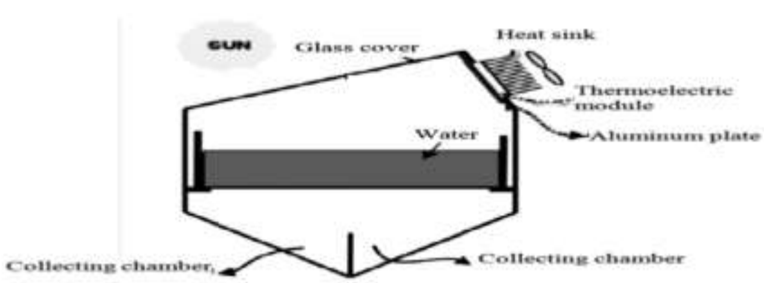


Fig.38. Asymmetrical solar still with thermoelectric cooler [2].

An experimental study has been conducted that by varying the height between the saline water surface and glass cover, which mean by reduction in height from 23 cm to 9 cm improves the distillation rate up to 26% [10]. Finally, solar still is the oldest method of solar desalination, so many papers have studied, the following table (Table 4) describes many methods that related to solar still.

Table 4: Different method of Solar Still desalination process.

Type of process	Method of working	Reference
Effect fin configuration parameter in Solar Still	To improve efficiency and productivity of solar still it must be integrated with different parameters, in this paper study the effect fin configuration parameter. Integrating fins in the basin of a flat plate solar still decreases the preheating time for evaporating water in the still's basin, which lead to the still's productivity increases. This paper also includes modeling equation for energy balance in inner surface of glass cover, water basin and shadow area of the fins	[76]
Modeling of Corrugated wick type of solar still	This paper explain the most recommended strategies to enhance the productivity of wick solar still, Description of the proposed corrugated wick type and simple basin type solar stills. Corrugated wick is the porous material that partially immersed and wetted by the water in the basin by capillary effect in order to increase the rate of evaporation. And also includes modeling equation and its assumption. Modeling equations for the energy balances for the glass cover, porous material and water basin, modeling of the simple basin solar still.	[77]
Effect of using Nano-fluids and providing vacuum on the yield of corrugated wick solar still	The previous paper was explained Corrugated wick type of solar still, but this paper discussed effect of Nano-fluids in corrugated wick solar still. The combined effect of both the different parameters of the liner corrugated, double layer wick material, using internal reflecting mirrors and induced vacuum and the application of Nano-fluid on the basin solar still performance. Two types of Nano-particles are used the cuprous and aluminum oxides nanoparticles. The results are compared to the conventional still and showed that external condenser and using the cuprous oxide nanoparticles reached nearly 285% over the conventional still while using the aluminum oxide nanoparticles reached approximately 255% over the conventional still.	[78]
Modified single-basin single-slope solar still with pin fins absorber and condenser	This paper is modified solar still as integrated system with a pin fins absorber plate, absorber of the solar still is manufactured by plywood painted black in order to improve absorbability. The study of this paper is theoretically without modeling equations. A cumulative water production was 41.95%, 23.39% and 11% implying a hourly solar still efficiency was of 12.9%, 9.7% and 3.1% are recorded for the still with an external condenser and with pin fins absorber coupled	[79]
Effect of Nano-fluids on passive double slope Solar Still	This paper also discussed Nano-fluid in solar still, but in passive double slope solar still, with three different type of Nano-fluid which are different Al_2O_3, TiO_2, and CuO nanoparticles, with thermal modeling contains heat balance of different component. The result showed that maximum temperature difference increases to 0.25% concentration of nanoparticles and then it starts decreasing beyond it and Al_2O_3 nanoparticles in the base fluid water has higher value of maximum temperature difference as compared to TiO_2, and CuO base fluid water	[80]

Improvement techniques of solar still efficiency	This paper explain theoretically without modeling equations the efficiency of solar still and ways to improve performance of solar still. It was showed that using absorber material as black rubber mat, black ink, and black dye enhanced productivity by 38%, 45% and 60% respectively, adding 10 kg of sand as sensible heat storage medium increasing the daily productivity and efficiency by 1.153 kg/m2/day and 10.8%, when applying the vacuum productivity of solar still is increased gives 2.5 kg/m2/day more yield compared to the conventional solar still, The sun tracking system is more effective than fixed one and increasing the productivity of the still increasing the productivity and overall efficiency by 22% and 2% respectively.	[81]
Flow of water from an air cooler on the cover to a single basin solar still	New idea of solar still is obtained in this paper, which is solar still coupled to a desert cooler to make water flow through this cooler, water flow over the glass cover to decrease the temperature of glass cover, the initial water temperature flowing over the glass cover is assumed to be either the ambient temperature or a temperature higher than the wet bulb temperature. Energy balance is explained on with and without water film, water in basin, bottom of basin and glass cover. When water flow at wet bulb temperature from cooler, there is a slight increase in mass flow rate of fresh water and the yield tends to saturate at a mass flow rate of 0.075 kg/s, when two solar still coupled with a desert cooler the cost of additional water produced is the least (Rs.0.60/l) for Jodhpur and the highest (0.78/l) for Chennai.	[82]
Solar still connected to an external solar collector and incorporating PCM	This paper study solar still connected to an external solar collector and incorporating Sodium Thiosulfate Pentahydrate as PCM, it was observed that PCM supply energy during night without any change in thermal behavior, it becomes more effective at lower level of water in the basin also it was observed that Changing the level from 10 to 5 cm doubled the productivity.	[83]
Improvement technology of solar still efficiency	This paper mainly explain solar still as ways to improve performance of solar still (storage energy material, effect of vacuum technology, wick materials, external reflector and sun tracking system) and also explain some type of solar desalination HDH, MED & MSF. It was showed that a good absorber medium (Charcoal particle) produces 15% more yield, the mixture of paraffin (wax and oil) used as a special phase change material increases the productivity to the maximum value of 851ml/m2h, the productivity is increased by 38%, 45% and 60% respectively when absorbing materials like black rubber mat, black ink, and black dye are used, the productivity of solar still increased when vacuum was applied. The atmospheric pressure and gravity were used to create vacuum distillation which gives 2.5 kg/m2/day more yield compared to the conventional one.	[84]
Brine desalination with solar still	This paper discuss more details of solar still as Installing reflectors (internal and external one), integrated solar still with solar collector, effect of increasing surface area and recover latent heat, effects of climate and operating condition and modeling for mass and heat transfer	[102]

3.4. Membrane Distillation (MD)

The membrane distillation is the thermal separation process which depends on membrane that transports water vapor across a micro porous hydrophobic membrane [16], is a thermally driven process in which a microporous membrane acts as a physical support separating a warm solution from a cooler chamber, which contains a liquid or a gas, investigated worldwide as a low cost and energy saving alternative to conventional, but can't use for large scale [20]. The MD process can reach approximately 100% rejection of non-volatile electrolytes and also has several advantages such as hydraulic pressure than conventional thermal processes, lower requirement of operating temperature, lower effect of salinity on the permeate flux, and lack of the corrosion thanks to the characteristics of polymer membrane materials. There are four types of MD processes: sweeping gas membrane distillation (SGMD) The permeating vapor is removed by using an inert gas stream which passes on the permeate side of the membrane. Condensation is done and with large volumes of the sweep gas and vapor stream [20], direct contact membrane distillation (DCMD) is the oldest and most used process, having liquid phases in direct contact with both sides of the membrane [20]., air gap membrane distillation (AGMD) additional air gap between the membrane and the condensation surface. This gives rise to higher heat and mass transfer resistances. Although heat loss by conduction is reduced [20], and vacuum membrane distillation (VMD) vapor is withdrawn by a vacuum on the permeate side. The permeate-side pressure is less than the saturation pressure of the evaporating species and the condensation of the permeate takes place outside the module [20]. It is preferred to use the DCMD process due to its simple configuration in which the condensation of water vapor occurs at the permeate side, and also its potentially high permeate flux [16]. There are three steps of transport mechanism: Evaporation of water at the warm feed side of the membrane, transfer of water vapor through the non-wetted pores, Condensation of water vapor transported at the permeate side of the membrane [20].

The main consideration of the DCMD process is to reduce the energy consumption resulting from a higher conductive heat loss; the aim of many researchers is to reduce the specific thermal energy consumption. Firstly, heat recovery systems have been applied in MD processes to reuse the residual thermal energy from the brine and permeate streams. The heat recovery has a great effect on the reduction of the energy consumption of the MD system. The heat energy is recovered from the retentive via heat exchanger; reduced inlet feed sea water by using preheating energy. Secondly, the membrane has been designed to reduce conductive heat loss and to increase permeate flux. The composite configuration is one of several commercial membranes used to reduce conductive heat loss and improve the permeate flux. Composite membranes consist of an active layer of hydrophobic polymer casted on a thicker supporting layer of a hydrophilic or hydrophobic polymer. The support layer is thicker than the active layer to prevent heat loss via conduction. In addition, the thinner active layer can reduce the mass transfer resistance. Thirdly, thermal energy supply, which has low cost, is required for economic operation of the MD process. Alternative energy sources have been studied as free energy suppliers for MD processes [16].

Numerous experimental and theoretical studies on solar-assisted or-powered MD desalination systems presented a theoretical analysis of DCMD desalination system using a solar energy and auxiliary heater, which consists of a temperature modulating scheme and a heat recovery scheme. A shell-and-tube-type PVDF hollow fiber membrane module was employed, and the results showed that the overall permeate production capacity is 31 m3/day. The SMDCMD system featured in this study which includes an energy recovery scheme and a dynamic operating system has been suggested to increase monthly average daily water production and thermal efficiency. The monthly average daily water production and thermal efficiency have been compared both with and without the dynamic operating system each month at a tank volume of 28.8 m3and a collector area of 550 m2 [16].

MD is known for more than 50 years and first patent on the process, advantages of this process is production of high-purity water, the potential to exploit waste grade heat, nearly concentration-independent operational performance, compactness with respect to the conventional thermal processes and less stringent mechanical strength requirements for membranes applied. In study of Banat et al reported the economic analysis of a small-scale solar MD unit. The cost was a strong function of plant life and membrane was equal to $ 15/m3. Solar thermal collectors have been used for heating the feed water but electricity is supplied by PV. A very good quality of distillate has been claimed at expense of 200–300 kW h/m3 of specific energy consumption [17]. Most of solar driven MD processes are based on vacuum membrane distillation (VMD) systems and air gap MD can offer the advantage of high flux even at low feed temperatures. In another study have analyzed the use of salinity gradient solar collectors and solar ponds for MD for two configurations: heating of feed water before entering into the modules and submerging the module inside salinity gradient solar ponds or insertion of solar collector inside the module. The application of solar collector was the most promising option with water flux as high as 142 L/m2 h [17].

The concept of multi-stage distillation was applied in designing of the modules in order to improve thermal efficiency of the modules. The latent energy was recovered on condensing side that can be used to heat the feed water is suitable for coupling with solar energy, however, the wetting resistance of the membrane and thermal efficiency of the process performance needs to be more improved to make the technology suitable for commercial applications. The maximum thermal energy observed was 79% that corresponds to specific energy demand of 810 kW h/m3 [17].

3.4.1. Solar-powered multi-stage DCMD system

The SMDCMD system consists of the solar-thermal and multi-stage DCMD systems. The solar-thermal system is consist of two circuits: the primary solar circuit for collecting solar energy and the secondary one for supplying hot seawater to the eight-stage DCMD modules through the four seawater storage tanks, that are constructed in a top to-bottom arrangement to fulfill thermal stratification and achieve thermal demand in terms of hot seawater supply. These two circuits are thermally linked to each other through the plate heat exchanger (HX1). In the present work, the solar collector area is in the range of 350 m2–550 m2 and the seawater storage tank volume is in a range of 16 m3–28.8m3 [16].

The operation procedure of the SMDCMD system is as follows: The makeup seawater via the HX2 that recovers the residual heat of the brine discharged from the multi-stage DCMD system flows into the HX1 as soon as hot seawater is supplied from the storage tank-4 to the multistage DCMD system. This ensures that the seawater storage tanks are always fully filled. During the mid-day hours, the makeup seawater preheated by the HX2 is continuously heated up by the HX1 in the solar-thermal system that collects the solar energy through the evacuated tube collectors (ETC) array, and supplied dynamically to the storage tanks based on the temperature by controlling valve operation. Here, it is sent back to the tank with temperature closest to but less than the makeup seawater, which assures that the storage tank-4 temperature is the highest [16].

When the top temperature of seawater storage tank-4 meets the operative feed temperature (set-point 1), the feed seawater drawn from the seawater storage tank-4 is delivered to the multi-stage DCMD system by controlling valve operation (CV) in the control system. The multi-stage DCMD system with a dynamic operating system then operates to produce the fresh water and the number of modules used is dynamically controlled based on the inlet feed temperature of each successive module. If the outlet feed temperature of each successive module is lower than set-point 2, the subsequent-stage module is not operated and the brine flows to the HX2 to recover its remaining heat to the makeup seawater. On the other hand, the normal operation of the SMDCMD system without a dynamic operating system features that although the set-point 1 is applied all eight-stage DCMD modules operate, regardless of the set-point 2. As in a dynamic operation, however, the low-temperature makeup seawater is supplied to the HX2 and partially recovers the thermal energy of the discharged brine. Meanwhile, the produced fresh water flows into a pure water tank, and a portion of it is cooled down to monthly average daily seawater temperature through the HX3 and then recycled to the bulk permeate of the multi-stage DCMD module [16].

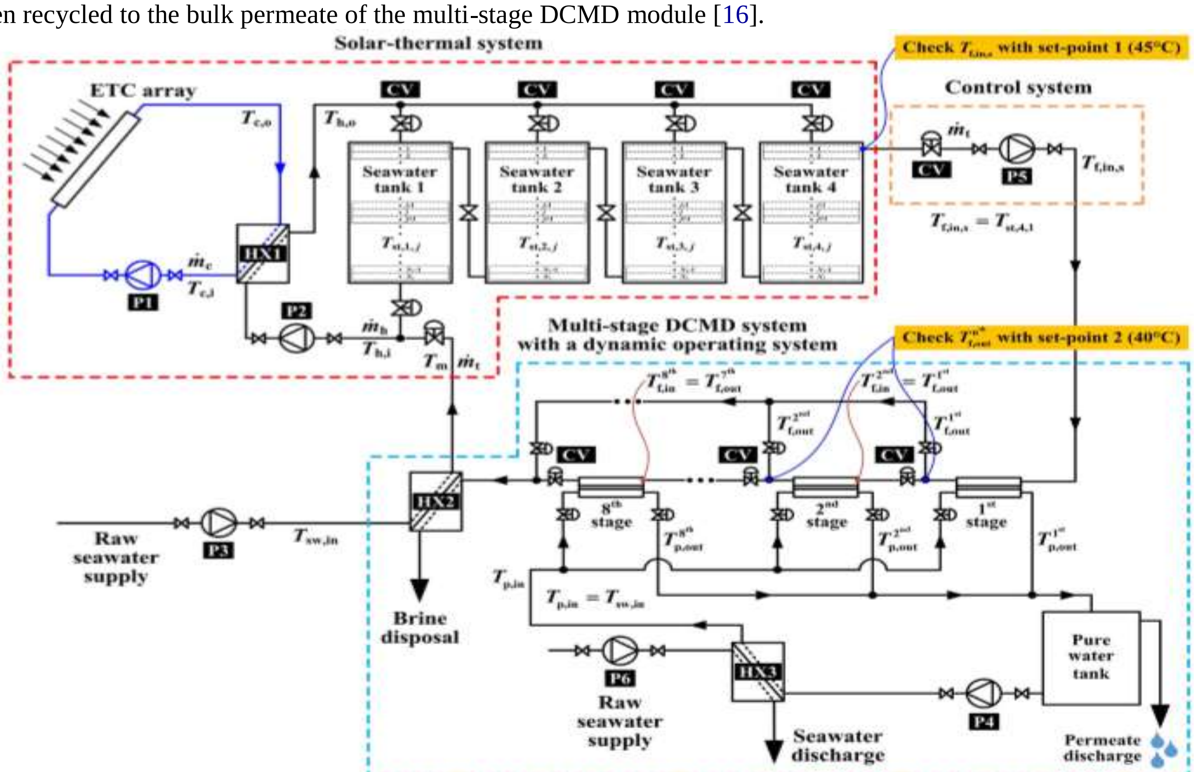


Fig.39: Schematic diagram of the SMDCMD desalination system [16].

The effects of temperature difference on the thermal efficiency and permeate flux of a single module with dimensions (50 cm ×60 cm× 0.3 cm) with respect to temperature difference between the inlet feed and permeate temperatures at the inlet permeate flow rates of 20 l/min and an inlet permeate temperature of 20 °C. In this study, the thermal efficiency and minimum permeate flux required in the SMDCMD are set to be 54% and 10 kg/m2 h, respectively; thus, the temperatures of set-point 1 and 2 are determined to be 45 °C and 40 °C, respectively [16].

3.4.2. DCMD process using a composite membrane

The composite membrane is one of several commercial membranes used to improve the permeate flux and reduce conductive heat loss. Composite membranes consist of an active layer of hydrophobic polymer casted on a thicker supporting layer of a hydrophilic or hydrophobic polymer. The support layer is thicker than the active layer to prevent heat loss via conduction. In addition, the thinner active layer can reduce the mass transfer resistance [16].

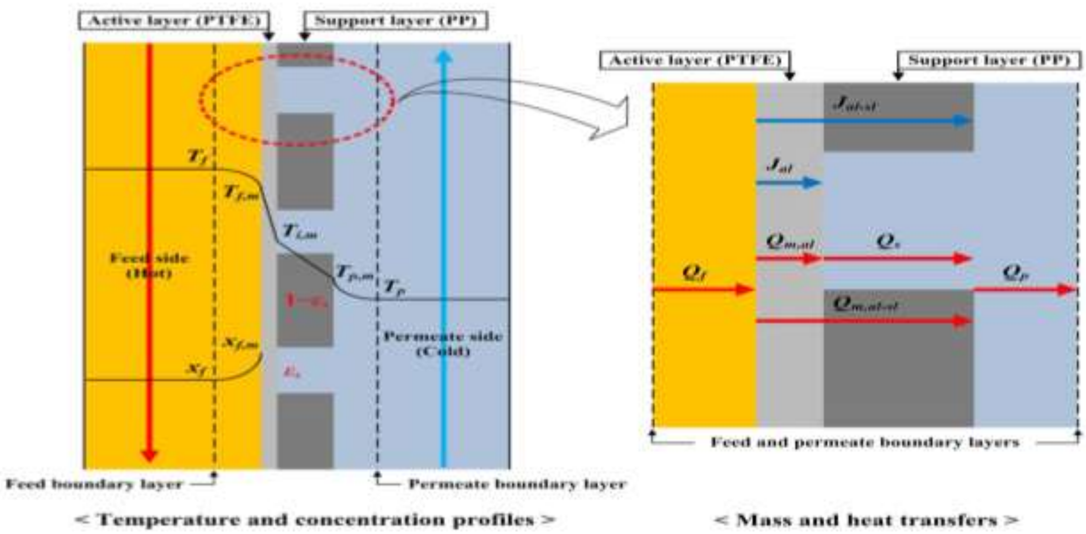


Fig.40: Schematic diagram of the DCMD using composite membrane [16].

This process consists of two parts a composite membrane and flat sheet type DCMD, a composite membrane which consists of the PP as a support layer and the PTFE as an active layer, the flat sheet type DCMD module consists of a flat sheet membrane and the two rectangular channels (feed and permeate sides). The water vapor is generated at the liquid-vapor interface on the feed side of the membrane by the partial vapor pressure difference between the feed and permeate sides, and the generated water vapor moves through the hydrophobic membrane pores [16]. Another papers that study Membrane Distillation is mentioned at the following table (Table 5).

Table 5: Different method of Membrane Distillation desalination process.

Type of process	Method of working	Reference
Better understanding of membrane distillation	This paper discussed in full details (theoretically) Membrane distillation, as areas at which MD is applied, modeling in MD, variables that are affecting on MD (feed temperature, inlet concentration, stirring rate, temperature difference and vapor pressure difference), parameters that effect on membrane (membrane thickness, membrane porosity and membrane porous size and membrane surface chemistry), membrane fouling and energy and maintenance cost. For better understanding of MD process was presented in this paper, showing the sequences of the different step that should be followed.	[85]
Modeling of direct contact membrane distillation	This paper is focused on one type of MD which is direct contact membrane distillation, study of DCMD depends on modeling equation which contains membrane flux (heat and mass transfer), transport models of feed and permeate sides(feed side in tube, permeate feed side in shell) and simulation techniques. The study showed that both permeate flux and thermal efficiency reduce along the fiber length when the feed gets cooled down, Although the permeate flux and thermal efficiency increase with the increase of the temperature	[86]

	and the flow rate of the hot feed, there is a trade-off between thermal efficiency and the permeate flux with the increase of the cold water flow rate and the decrease of cold water temperature.	
Thermal efficiency and cost estimation of membrane distillation	This paper also focused on direct contact membrane distillation but in modeling only mass and heat transfer of DCMD, and also thermal efficiency and cost estimation. It was observed that As a thermal process, MD suffers the disadvantage of a more intensive energy requirement with respect to reverse osmosis. , even the comparison with traditional thermal desalination systems, such as MED and MSF, seem sun favorable because of the additional resistance to mass transport and of the reduced thermal efficiency (due to heat conductivity loss) offered by the membrane. On the other hand, as an evaporative process not limited by concentration polarization, MD can operate where RO fails, showing the interesting potential to increase the water recovery factor.	[87]
Modeling of AGMD	The main point of this paper is modeling of one type of MD which is air gap membrane distillation, firstly set of assumption that build modeling then equation of modeling in case of co-current or counter-current flow for flat sheet module. It was observed that the thermal efficiency of the process increases as the membrane surface area increases which causes the AGMD process to operate at low temperature difference across the membrane, leading to lower water vapor flux.	[88]
Low-cost and economics for using geothermal heat for freshwater production	This study focus on source (low cost) energy required for membrane distillation, this paper discuss theoretically Low-cost emerging sources of low enthalpy geothermal heat, from economics point of view, solar thermal energy and Membrane distillation an emerging technology. It was observed that better technical and economic performance with geothermal heat than used with solar heat due to constant heat source and so prevents expensive and complicated adaption of technologies and heat storage	[89]

3.5. Multi-stage flash (MSF)

MSF has the second largest desalination capacity after the RO processes. This large-scale process, due to low-quality of steam rejected from power cycles as the heat source some researchers showed that it is preferred to use indirect solar desalination for large desalination projects. Most of the energy consumption of MSF is the thermal energy used to distill water, while electricity is needed also for pumping. MSF could be connected with a power grid and solar thermal heat source at the same time; or providing heat and electricity at the same time be connecting with a solar thermal system through a heating engine. In MSF process, saline water moves through a sequence of vacuumed reactors called stages which are work at lower pressures, saline water is preheated before enter stage. External heat is used to heat the preheated saline water more than its saturation temperature. Then Saline water is passed from one stage to another in which a small amount of water flashes to steam in each stage and the remaining brine flows to the following stage for more flashing. The flashed steam is condensed and collected as fresh water after removing the latent heat of condensation to preheat the entering seawater at each stage.

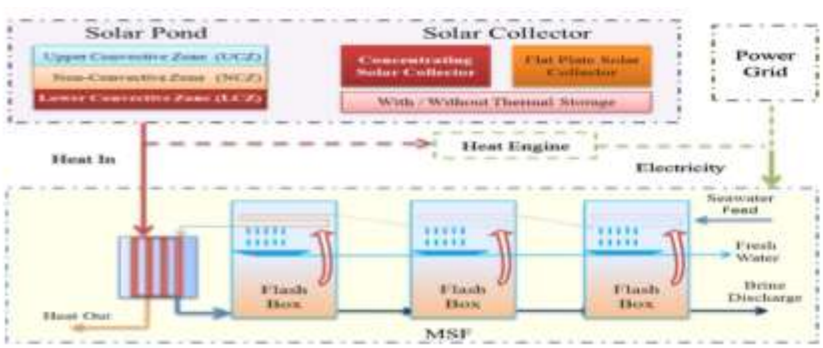


Fig.41. Schematic of solar assisted Multi-Stage Flash Desalination Process

3.5.1. Solar pond driven MSF

A solar pond is a type of solar thermal, since the produced salt could be used in the pond itself. Solar pond is a solar collector and storage in same time, which is table pool of salt water in which the water salinity increases in the middle layer from its top to the bottom with a gradient that prevents convective mixing on absorbing solar radiation and the resulting increase in temperature. Heat is passively collected and stored in the lower convective zone (LCZ) because the middle layer is a non-convective zone (NCZ).However, the solar pond has to be oversized in case of winter conditions, necessitating some of the surplus summer heat to be wasted On the other hand; waste heat from other sources such as gas turbine may be used during periods of low solar radiation. These kinds of hybrid solar pond systems could store excess waste heat, like gas turbine exhaust during peak times in order to lower the cost of water production and the size of solar pond. From advantages of solar pond, low cost of the collector per unit area, low storage capacity and capability of utilizing reject brine which considered as a waste product for other processes, solar pond surface could be used for cooling water due to its lower temperature during summer, but solar pond need sunny conditions, large flat land and also has environmental impact as soil contamination by pond brine leakage [15]. Most commercial MSF units operate with top brine heated by steam at temperature of 90–110oC while the solar pond operates in the range of 30–95oC.Therefore, in solar pond assisted MSF systems, the first stage of the MSF heat exchanger is changed to a liquid–liquid heat exchanger instead of steam–liquid heat exchanger [15].

3.5.2. Solar collector driven MSF

Solar collector field provide thermal energy for the desalination process, so it is connected with a conventional distillation plant. Solar collectors can be divided into two types concentrating and non-concentrating one. Solar collectors are chosen depend on the desired process temperature. In order to enhance the performance of MSF, a wide working temperature range of MSF is needed, and gain higher gained output ratio (abbreviated as GOR, and defined as the number of kilograms of desalinated water produced per kilogram of steam consumed), it is preferred to discharge the brine at the last stage [15]. It was found that controlling the flash evaporation pressure is important, i.e., by reducing the flash evaporation pressure from 0.014 MPa to 0.010 MPa, the desalination rate could increase almost 5 times in some direct solar thermal desalination systems. In general, MSF series connected stages require temperature and pressure control and some transient time is needed to establish the normal running operation of the plant. MSF uses the seawater feed as the coolant which means that MSF uses sensible heat to recover the latent heat from the distilled water. Therefore, MSF requires large amounts of seawater re- circulating within the system and consumes more electricity than a MED process [15].

3.6. Solar assisted multiple effect distillation (MED)

The solar assisted MED process needs both thermal energy and mechanical energy similar to the solar assisted MSF process. Solar assisted parallel feed MED, in which seawater is passed to a sequence of successively low-pressure vessels called effects. The external heat is supplied to the first effect and the generated vapor of the previous effect supplies its latent heat of condensation to the next effect. MED systems reuse latent heat vaporizes the seawater that is not similar to MSF which recovers latent heat of the vapor by the sensible heating of the seawater. The specific heat capacity of water is 4kJ/kg/K while the latent heat of vaporization is 2300kJ/kg, therefore MED systems normally have 2–14 effects but MSF systems have more than 20stages. To reach high heat transfer efficiency MED systems use falling film horizontal tube evaporator/condensers. Operate with a relatively low top brine temperature approximately lowerthan75 oC to reduce scale formation and corrosion and also to improve the overall efficiency the system is combined with heat pumps [15].

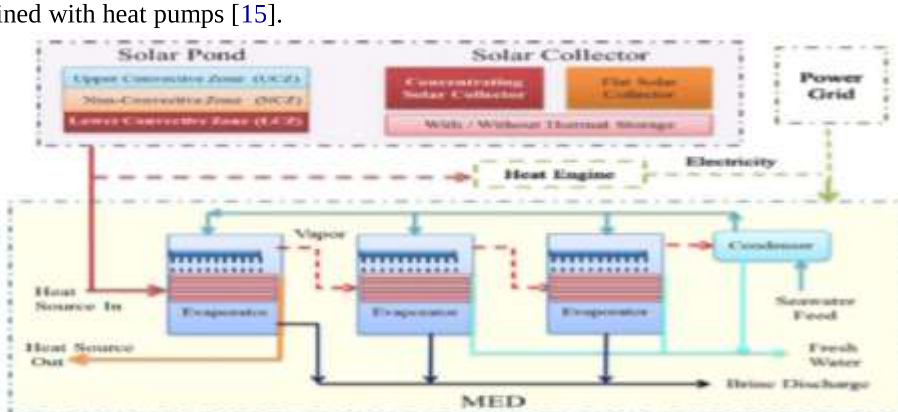


Fig.42. Schematic of solar assisted Multi-effect distillation desalination Process [15].

3.6.1. Solar pond assisted MED

This system is also similar to Solar pond assisted MSF but MED need lower temperature Which make the solar pond operation relatively easier, A large ratio of solar pond surface area with MED heat transfer area leads to continuous increase in pond temperature, the optimum thicknesses for upper convective zone (UCZ), non-convective zone (NCZ) and lower convective zone (LCZ) were reported as 30 c.m, 110 c.m and 400 c.m, respectively, by mathematical modeling it was found that intermediate steam supply temperatures range of 80–90 oC are more efficient for the operation of solar-assisted MED systems because higher steam supply temperatures decrease the solar improvement [15].

3.6.2. Solar collector assisted MED

Some solar MED systems were combined with heat pumps to improve their performance optimize the operating parameters so as to maximize the evaporator distillate production for every month of the year. Some plant maintenance was needed for example; dusted position could cause the water production to drop to 40% of the clean collector production [15]. The combination of low energy consumption and economic costs, together with the inhere under ability of the low temperature, MED and RO plants avoid the necessity of comprehensive seawater pretreatment and make the MED process one of the best candidates for safe and durable large capacity desalination [15].

3.7. Adsorption desorption solar desalination

The hybrid system consists of evacuated tube solar collector, two storage water tanks, hybrid adsorption desalination cooling system, thermostat and three delivery pumps thermostat this system has three main cycles, the first cycle called solar cycle, evacuated tube solar collector collected solar heating energy during daylight hours. The pump1 circulated hot water to maintain

homogenous hot water temperature in Tank. This Pump depends on the collector outlet hot water temperature, the pump flow rate in the first water cycle is 0.3 kg/s when the collector is gaining energy from the sun water temperature reach above 85ºC. In the secondary cycle hot water in Tank1is passed to Tank2 by pump2, function of this pump is to transfer the thermal energy from Tank1 to Tank2 with same flow rate of pump1. The importance of second cycle is to produce more stability in the inlet hot water temperature to the hybrid adsorption desalination cooling system and to reduce the instability in temperature of driving hot water. This due to system with hot water storage tank has less fluctuating potable water product and cooling energy production compared to the system without storage tank and generates higher cooling capacity. In the third water cycle, hot water from Tank2 is delivered to the hybrid adsorption desalination cooling system using pump3.This pump delivers hot water from Tank2 to the hybrid adsorption desalination cooling system cycle with a flow rate lower than in pump1, pump2 equal to 0.2 kg/s. This flow rate is selected to gives best performance at constant hot water inlet temperature. The flow rate in first and second cycle is worked at operating flow rate for solar collector and to be higher than the flow rate in third cycle for speed recycling the hot water in solar collector and tanks before entering hybrid adsorption desalination cooling system [9]. The adsorbent material is Silica gel. The adsorption unit consists of two identical adsorption units called Bed1 and Bed2, condenser, and an evaporator.

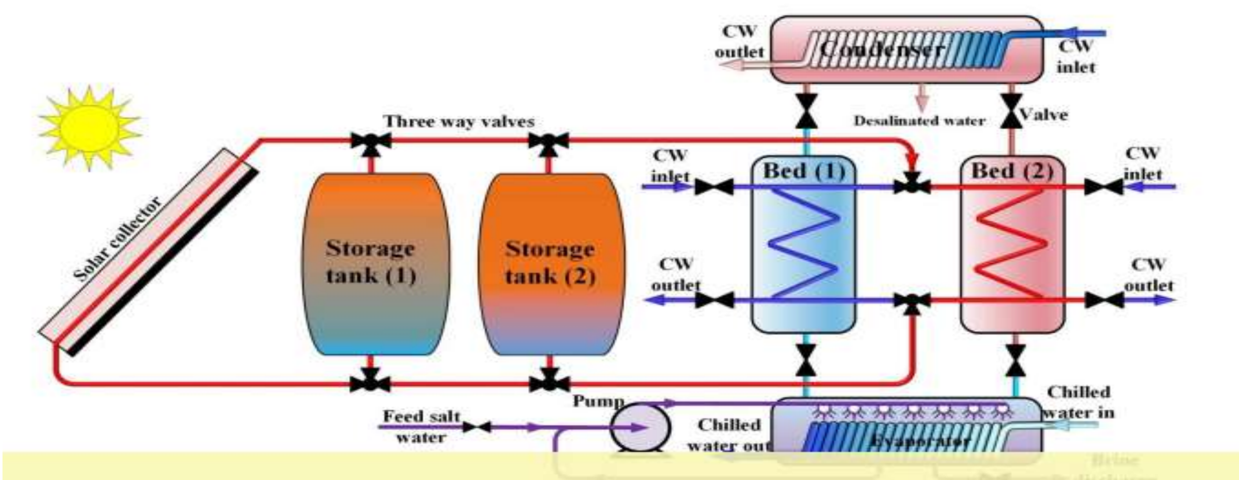


Fig.43: Schematic two beds hybrid ADCS [9].

The adsorbed/desorbed which are Bed1/Bed2 respectively are connected to solar thermal system to heating the bed during isosteric pre-heating and isobaric desorption condensation processes (processes 1→2→3) and to the cold water to cooling the bed during isobaric pre-cooling and isobaric adsorption-evaporation processes (processes 3→4→1). Maximum specific daily water production is approximately 10 m3/ton of silica gel. While, maximum coefficient of performance and specific cooling power of the system are about 0.5 and 134 W/kg respectively [9]. In another study using Concentrating Photo Voltaic Thermal collectors operate at temperatures greater than 100 °C (can applied in steam production, refrigeration and desalination process). Solar collector area per unit chiller capacity varied from about 3–5 m2/kW cooling cost range from 0.09 to 1.01 €/kWh. CPVT collectors have gained more importance by the scientific community and manufacturers. As CPVT systems show great affect into modern power generation technologies from these technologies SHC systems, CPVT collectors can easily guarantee the operating temperatures necessary to drive single stage absorption chillers at temperature range from 75–90 °C, adsorption chillers operate at low temperatures at range of 45–65 °C with respect than those required by the absorption ones. adsorption chillers, for example of adsorption chillers adopting zeolite-water and silica gel-water as working pair could increase the applications range of solar cooling systems. In this study devices of double stage absorption chillers can be fed, but in case of low ratios between beam and total solar radiation, CPVT systems suffer from their lower power density this circumstance and their complex maintenance are the main drawbacks for their market uptake, so to solve this problem and increase their system economic profitability, the combination of CPVT devices with low temperature thermally-driven refrigeration devices, as adsorption chillers [8].

3.7.1. Graphene oxide used for desalination

Graphene oxide has been used as absorber in solar desalination and as filtration film in desalination. Graphene oxide film have porous structure, high chemical stability, high absorption, hydrophilicity, and excellent anti-fouling properties. Graphene oxide absorb sunlight and converting it into thermal energy through optically excited electron-electron scattering, thus heating and evaporating water. The Graphene oxide films with nanochannels is that it provides a path for water supply and vapor escape, the d-spacing of nanochannels is nearly 0.76 nm, while water is 0.275 nm, nanochannels is larger than water molecules so as to enable the permeation of water. Desalination is occurred by the phase-changing process, with the non-volatile ions left. Finally, fresh water is collected by condensation. The features about this technology are it exhibits high water flux; it requires electricity power to drive and it requires relatively high capital investment. [101]. Table 6 describes many other ways for Adsorption desorption solar desalination process.

Table 6: Different type of Adsorption desorption solar desalination process .

Type of process	Method of working	Reference
Absorption and Adsorption Solar Desalination System	This book discussed Solar Absorption Desalination System, in case of Single-Effect and Multiple-Effect Solar Absorption Desalination System and Practical Test and Evaluation of a Multiple-Effect Solar Absorption Seawater Desalination. Salt solutions which have strong adsorption behavior on water vapor are LiBr, LiCl, LiI, LiNO3, CaCl2, ZnCl2, and KNO3. This book includes parameters at which modeling equations are designed (mass balance equation, relationships between saturation concentration and temperature, mass of secondary steam, energy balance equation and mass balance and salt balance between the imported seawater and exported brine)	[90]
Solar-powered absorption chiller	This paper includes Solar cooling system, relation between Solar cooling and absorption chiller, literature in Solar-powered absorption chiller, from the literature review it was reported that most of solar absorption chillers installed around the world are based on single-effect chillers and low-temperature solar thermal collectors	[91]
Adsorption ice making and water desalination	This paper contain a new idea about adsorption technology as using water or saline water as refrigerant in the production of freeze desalination applications, ice or ice slurry. Vacuum-direct freezing of single bed adsorption system to produce four useful outputs; cooling, ice, ice slurry and distilled water using both tap and sea water as refrigerants with CPO-27Ni Metal Organic Framework adsorbent material. It was concluded fresh and	[92]

	sea water can be used in adsorption systems as refrigerant to achieve low evaporation temperature less than 0 o C.	
CO2 adsorption hybrid for cooling and desalination	This paper include description of Description of hybrid compression-adsorption cooling and desalination system and Thermodynamic framework of hybrid cooling and desalination system as Carbon dioxide cooling cycle (Evaporator, Compressor & Gas cooler), heat recovery system (generator, preheater), Dual-evaporator adsorption cooling and desalination system (Evaporators, Adsorption beds), overall heat transfer coefficient and performance parameters. It was concluded that the overall coefficient of performance is improved about 61% as compared with the CO2 cycle by the second configuration.	[93]
Adsorption using Silica gel in desalination	This paper discuss adsorption assisted cooling and desalination adsorbents materials are zeolites and silica gel and adsorbate is water for useful cooling effects at the evaporator and the desalination effects at the condenser. Since the conventional adsorption cooling system works at low evaporator pressure, also includes Thermodynamic model (Evaporator, Sorption reactor, Condenser) and Parameters used for simulating the proposed adsorption cooling and desalination system are presented in this paper.	[94]
Adsorption desalination cycle	This paper presented Adsorption desalination pilot plant but in theoretical way without modeling or simulation. Adsorption desalination process can produce fresh water and cooling power by using waste heat or renewable energy sources as solar or geothermal energy, it is also inexpensive and has a low operational cost when compared to conventional desalination technologies as reverse osmosis or multi-stage flash.	[95]
Thermally modeling of Adsorption Cooling and Desalination	This paper presented desalination system comprising four adsorption beds and two evaporators, produces fresh water in the condenser and chilled water at two different temperature, as mentioned before in another paper silica gel used as adsorbent and water used as adsorbate, the paper contains thermodynamic Model of Adsorption Cooling and Desalination. It was concluded that the amount of water vapor per adsorption-desorption cycle is 2.5 times higher than the conventional one.	[96]
Using phase change materials in solar absorption refrigeration	This paper discussed a new combination between solar absorption and Using phase change materials, Solar absorption refrigeration system requires a continuous operation so use phase change materials to continue the supply of energy, this paper explain idea theoretically without any modeling equations. It was concluded that three basic factors influencing the selection of PCM are Melting temperature, latent heat of fusion and PCM thermos physical, PCM saves energy but increases the initial cost.	[97]
Combined open-cycle absorption heat pump and thermal desalination system	This paper depends on idea of combination of an open-cycle absorption heat pump (OAHP) and a low-temperature multi-effect evaporation (LT-MEE) water desalination process, System configuration and Mathematical modeling is obtained, for Mathematical modeling discuss thermodynamic performance criteria, Model validation. The main idea is using both the sensible heat and latent heat of high-humidity gas to produce fresh water from saline water	[98]

Absorption refrigeration and pre-desalination system for marine engine exhaust gas heat recovery	This paper explain theoretical and experimental investigations of an absorption refrigeration and freezing pre-desalination based marine engine exhaust gas heat recovery system. The paper build Basic assumptions at which Mathematical model is build (mass balance equations and energy balance equations for the system, coefficient of performance and refrigeration of evaporator). From this system it was concluded that the concentration of the ammonia–water rich solution at 0.28kg/kg and the generation temperature increasing from 125°C to 145°C, total refrigeration output varied from 6.1kW to 9.9kW and the cooling capacity of the cold storage sub-branch was increased from 1.2kW to 5.2kW.	[99]
literature review of hybrid adsorption desalination–cooling systems	The main idea of this paper explains the current literature review on the dual effect (cooling and desalination) adsorption desalination system, firstly discuss Adsorbents, then Hybrid adsorption desalination with cooling system, many figures of adsorption desalination is found to be more explained but doesn't include any modeling equations. This paper achieves knowledge for the impact of operational and design parameters of such as adsorption desalination heating, cooling temperatures and cycle times.	[100]

3.8. Types of Solar Collector

The aim of solar collector devices is to collect solar radiation and then transfer the heat to the absorber fluid to increase internal energy to be used domestic application [18]. The thermal efficiency of solar collectors between 60% and 75% [6]. Classification of solar collector according to the temperature level achieved by the thermal fluid in the collectors Low temperature collectors are those operating less than 80 °C, and used in heat source for membrane distillation process, but medium temperature collectors are those operating in between 80 to 250 °C, used to provide heat for thermal desalination processes by indirect heating with a heat exchanger [20]. All solar systems need low maintenance cost and operation but large installation areas and high initial investment. But they remain the best solution for remote areas and small communities in arid or semi-arid regions where there is lack of water from other sources [106]. There are two types of solar collector Concentrating type, and Non-concentrating type.

3.8.1. Concentrating type

This type consists of a concentrator and a receiver, and a rotatory element to allow the sun's rays to be always focused on the absorber tube. This type can collect the highest solar radiation, so has high temperature can reach 400 o C, temperature of absorber fluid rise from 0 to 150 o C [18].

3.8.1.1. Examples of concentrating solar collector

The parabolic trough, parabolic shape with a highly reflective material is used to concentrate incident light onto the receiver tube along the focal line. The receiver tube is made of an absorbent material and is covered with a glass tube to reduce heat loss. The fluid inside the receiver tube is heated by the focused radiation thus converting solar radiation into heat. The temperature of the absorber tube can reach up to 350–400°C, which is higher than of flat plate or evacuated tube [6].

3.8.2. Non-Concentrating type

This type has no optical concentration, so has lower temperature than concentrating one, applied when temperature requirement is of the range 40–100 °C. From its properties are, ease of maintenance no moving part requirements, and low operating cost. From its applications are in domestic water heating, building heating, crop drying and industrial processing [18].

3.8.2.1. Flat plate solar collector

It consists of a dark flat surface, to absorb solar radiation and transfers the heat to fluid in the tubes. In order to minimize heat loss thermal insulation and transparent screens are used [6].

3.8.3. Nano fluids used as absorber fluid

Nano fluid consists of a mixture of a base fluid always liquid as oil, ethylene glycol and water and nanoparticle 1-100 nm as oxides, metals, carbides, or carbon nanotubes. Reasons for choose Nano fluid as absorber fluids in solar collector: thermal conductivity is increased when using Nano fluid, Nano fluid increases Thermal diffusivity which lead to increasing heat transfer rate, increases heat transfer between the base fluid and solid particle due to large surface area to volume ratio, using Nano fluid in solar collector reduces CO2 emission and saves annual electricity and fuels. But from difficulties and challenges of using Nano fluids are Nano fluid is not stable for the long time, limitation in using Nano fluid due to high cost of Nano particle and time-consuming, it has a toxic nature, continuous and long-time use of Nano fluid cause erosion of walls [18].

3.8.4. Evacuated tube solar collector assisted heat pump

The Evacuated tube collectors produce temperatures of up to 200 °C and thus can be used as an energy source for thermal desalination processes [20]. An evacuated tube collector, which consists of tubes made of a vacuum layer between borosilicate glass layers. The inner tube is coated with a black coating which is responsible for absorbs solar energy and transfers it to the liquid inside. The function of vacuum layer minimizes heat loss from the tube [6]. The Evacuated tube solar collectors have been used in the domestic water heating, due to the Evacuated tube solar collectors vacuum reduces convection and conduction losses, which leads to the efficiency of Evacuated tube solar collector is higher than the Flat plate collector [19]. Example of using Evacuated tube solar collectors is agricultural greenhouse, the agricultural greenhouse is used at night or even at daytime hours in case of low solar radiation. The heating system consisted of evacuated tube solar collector and electric heat pump. Two heating conditions were applied, the first condition, at higher solar radiation the Evacuated tube solar collectors was used to heat the water and the hot water circulated and stored to be used at night while, the heat pump was switched off, while in second condition the electric heat pump used for heating water to be stored in the hot water storage tank and then circulated in a polypropylene pipes , temperature of hot water in hot water storage tank is 55 o C, When the temperature of water in the hot water storage tank exceeded 55 ºC the electric heat pump switched off, the operating mode of the hot water circulation pump at a temperature set point for heating of 14 ºC, the hot water circulation is stopped when the internal air temperature exceeded 14 ºC, During the heating condition (higher solar radiation) closed valves 1, 2, 5 and 6 while, in second condition opened circulation pump and valves 3 and 4 to heat the water in the hot water storage tank, during the heating period at night when the greenhouse internal temperature be less than 14 °C, the hot water from the hot water storage tank will be circulated by the first circulation hot water pump along the horizontal tube to heat up the greenhouse air. Thereby, opened valves 1 and 2 and closed valves 3 and 4 and the circulated water will be between the water tank and greenhouse only then the cold water at the outlet of horizontal tube will be return back to the hot water storage tank to be heated again by either heat pump or the solar collector [19].

3.8.5. The solar chimney

The solar chimney is used to generate a hot airflow, it composed of a tower fixed to a translucent cover or collector, opened at the edges, the incident solar radiation heats the ground under a collector, in order to heats the air inside the solar chimney. The hot air accelerates towards the center of the device to run wind turbines, which in turn produce electrical power, but solar chimneys convert only a small proportion of the solar heat collected into electricity and the efficiency increase with the tower height. When height of 194.6m and a diameter of 10m, the produced electricity is 50-kW for turbine. This type of solar collector (solar chimney) haven't used in desalination yet [104].

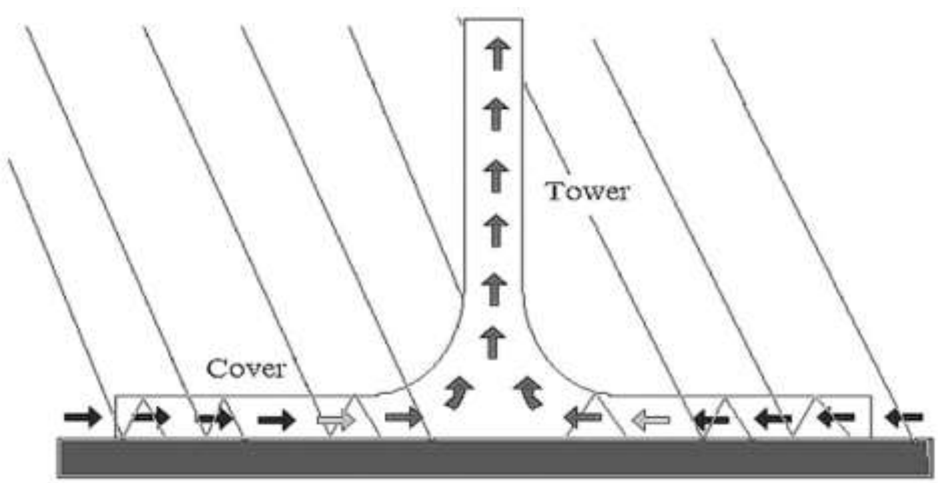


Fig.44: Principle of solar chimney [104].

3.9. Types of Photo Voltaic

Photo Voltaic cell convert solar irradiation into electricity through the transfer of electrons in PV cell the current produce is Direct Current, so using converter to convert Direct Current into Alternating Current, Solar cells work best at low temperatures, the PV cell photo current is proportional to the solar intensity, as the operating temperature rises then all cell materials lose efficiency, the conversion efficiency degrades by nearly 0.4–0.5% per degree rise in temperature, to increase the PV power generation the tracking flat PV system is used [20]. There are three generations of PV cells: 1st generation is crystalline silicon (c-Si) technologies, the conversion efficiency of crystalline silicon ranges between 15% and 18%, 2nd generation is amorphous silicon thin-film (TF) technologies, thin film (TF) PV technologies are the lowest-cost to manufacture. The production cost of cadmium telluride (CdTe) thin film module is currently the least; $0.76/Wp and 3rd generation is Nano-PV technologies [20].

3.9.1. Photovoltaic-thermal technology (PV-T))

This technology is used in order to reducing the operating temperature of PV cells, improving the overall energy efficiency of the system and also minimizing the space requirement and system cost. It was observed that PV modules converts only 10–17% of the solar radiation into electric energy while 40–50% of the radiation is converted into heat which can cause serious damage to the PV systems, that lead to using thermal technology in PV cells [21].

3.9.2. Method of working PV-T

The surface temperature of the PV cell can reach ° 80 C in absence of thermal management, PV/T remove the excess heat through various thermal management techniques by using PCMs, air, liquids, and heat pipes [21].

3.9.2.1. Air based PV/T system

Air is used as a heat transfer fluid for thermal regulation, the mass flow rate of air has important role in improving the overall energy efficiency of the system and in reducing the cell temperature, overall efficiency was found to increase with glazing (above PV) and an absorber plate, while electrical and thermal efficiency in configuration (I) being 10.66% and 0% , in configuration (II) are 10.73% and 21.19%, in configuration (III) are 10.33% and 41% and in configuration (IV) are10.65% & 44.4%. The formation of fins in the lower channel of the PV-T based air heater is observed to increase the thermal and electrical efficiency by 15.5% & 10.5% while reducing the cell temperature by 30° C. when increasing mass flow rate from 0.03kg/s to 0.15kg/s lead to increases the electrical efficiency to 20% [21].

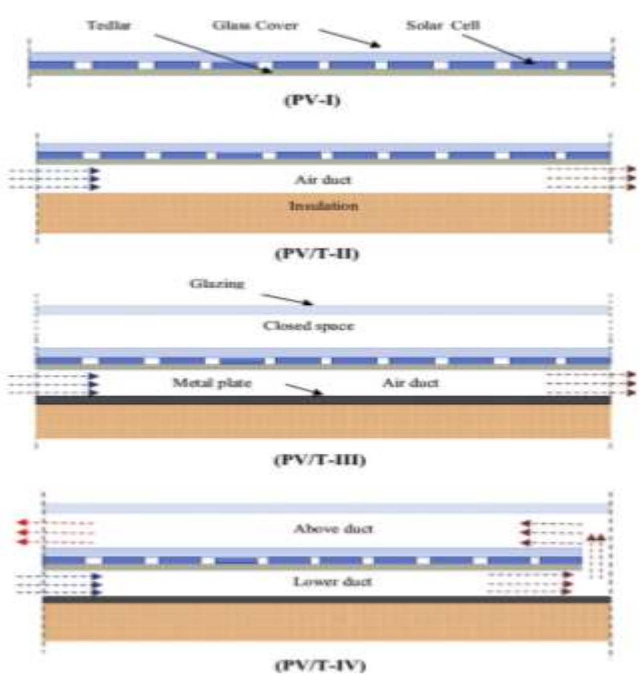


Fig.45: Four different type of PV/T configurations [21].

3.9.2.2. Liquid based PV/T system

This type of PV/T system depend on uses both air and water for heat transfer in a single system called bi-fluid based PV/T system. Performance improvement in collectors when set of fins in placed in collector in direction of air flow, the temperature of PV cell was 49.22 ° C when the water flow rate was 0.0017kg/s at air flow rate of 0.0262kg/s as compared to 57.79 ° C when operating under single water mode at same flow rate. Similarly, when water flow rate is fixed at 0.0066kg/s under bi fluid mode of operation the mean PV cell temperature was observed to be 51.42 ° C at lowest air flow rate of 0.0074kg/s as compared to 62.77°C when operating under single air mode at same lowest flowrate [21].

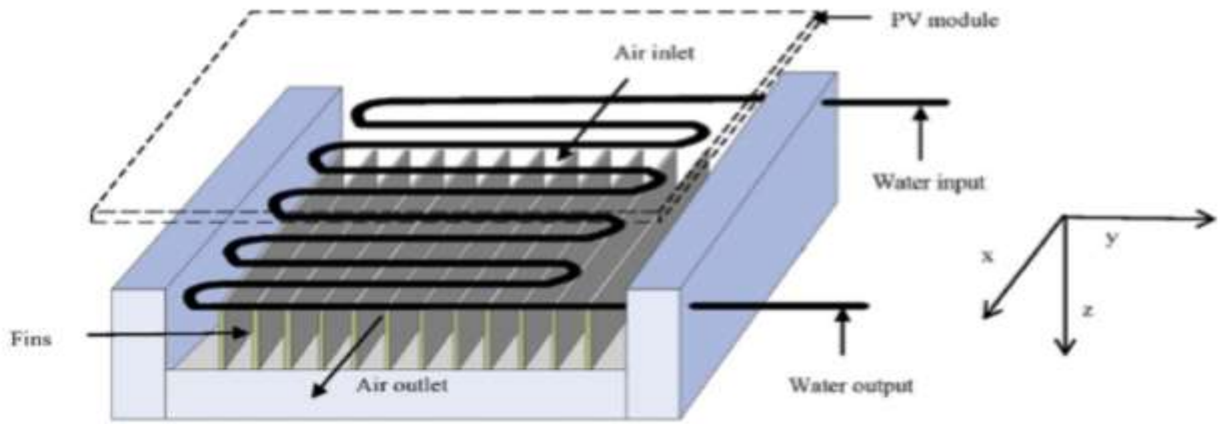


Fig.46. Sectional view of bi-fluid based PV/T collector [21].

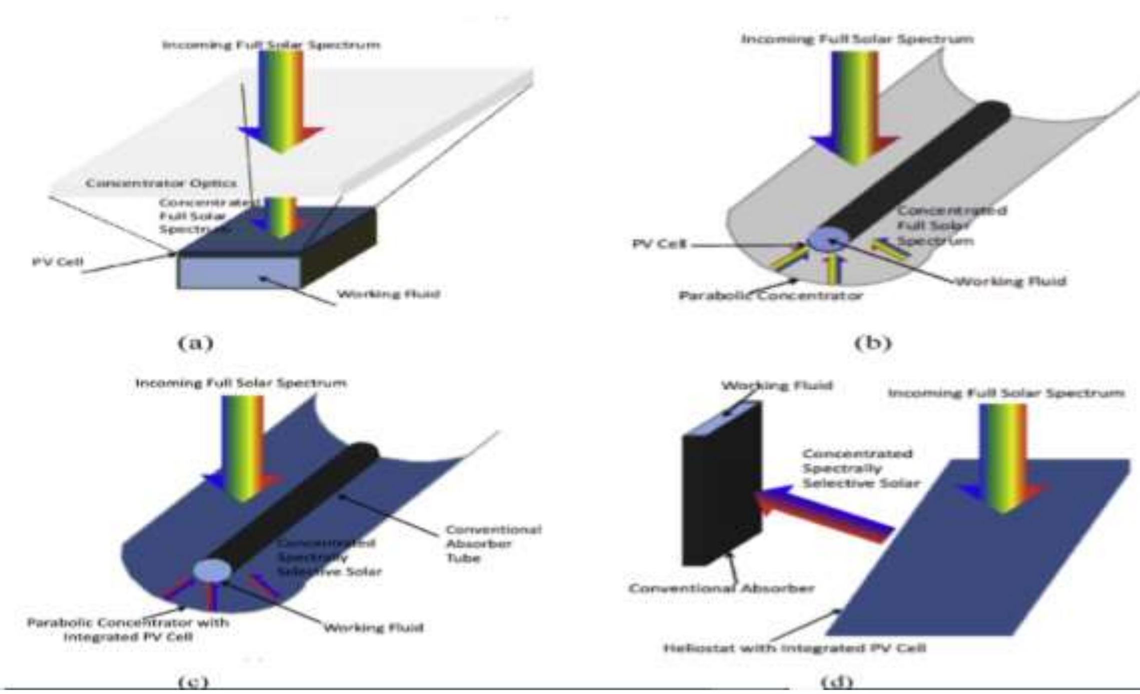


Fig.47: (a) Fresnel lens based thermally coupled C-PV/T system (b) parabolic trough based thermally coupled C-PV/T system (c) parabolic trough based thermally decoupled C-PV/T system (d) heliostat based thermally decoupled C-PV/T system [21].

4 Summery

This section summarizes the important comparison between each type of solar desalination. A review on the performance of HDH, Reverse Osmosis, and Solar still, Membrane distillation, Multi-stage effect and Multiple-effect distillation are carried out and the important finding are reported here. HDH process consist of humidifier and dehumidifier, the best type of humidifier is Bubble column humidifier due to direct mixing air with water for long period. Packed bed humidifier has considerable impact on the humidifier performance as improving extraction of gas from humidifier. While dehumidifier at plate fin tube dehumidifier doesn't affect by corrosion as it is manufactured from CuNi alloys which have a higher corrosion resistance can reach high velocity of saline water up to 2.5m/sec without fouling. While at bubble column dehumidifier increasing velocity led to increasing in the heat flux and decreasing in the effectiveness which lead to low production. The high productivity in packed bed Humidifier Dehumidifier was achieved by wooden slates is5.4 l/h and inverses to about 5.8 l/h using forced circulation for air and inlet water temperature and capacity of storage tank is 100 L. Packed bed Humidifier Dehumidifier desalination from advantage of this process good thermal insulation to prevent heat loss, leak proof and using packed bed material increase mass transfer coefficient between supplied air and saline water in the humidifier. But it needs a high source of electricity for pump to circulate the heated water through the unit. Storage tank with built in heat exchanger for heating saline water before enter humidifier and electric fans in the condenser all of this may increase cost of distilled water. In order to reducing cost packed bed material must be available in local market. HDH bubble column from its advantages dried air and water are in counter current flow which increase heat transfer coefficient but variation is very small which can't apply in industrial scale and uncertainly measured of temperature, increase pressure lead to increase in heat transfer rate from cost point view it increase the cost as increase pressure need more electricity, but it increase the performance and efficiency. Humidification–dehumidification desalination process by photovoltaic thermal energy recovery this is very good process as it is known PV produced electric energy only but, in this process, not only PV produced electric energy but also thermal energy. instead of loss heat in PV using air flow inside PV in order to heating air but this method decrease efficiency of electric energy produced maximum production in summer is 0.528 L/m2 • d. While packed bed Humidifier Dehumidifier production is 5.8L/h (139.2L/d). Table 7 discusses many types of Humidification-De Humidification process.

Table 7 : Comparison between types of Humidification-De Humidification process.

Type of HDH	Process	Reference
Packed bed Humidifier Dehumidifier	Three packing materials, different in material type, have been used in humidifier. The mass and heat transfer coefficients in the humidifier and condenser have been obtained experimentally. When equilibrium is reached (steady state conditions); measure all parameters flow rates, air and water temperatures at inlet and exit of each tower, relative humidity of air at the inlet and exit of each tower, and the unit productivity. The following procedure has been followed to obtain the heat transfer coefficient. The energy gained by water and lost by air is obtained by measuring flow rate and temperature change for each fluid.	[11]
HDH bubble column	In Bubble columns water diffuses into air bubbles and the outlet air gets humidified. The outcome of bubble column humidifier depends on the bubble velocity, gas hold-up, bubble diameter, air and water temperatures and also the mass and heat transfer coefficients. Bubble columns is used in HDH systems as humidifiers, dehumidifiers, or in some cause use both of them, they have advantages as reducing the size required for humidification or dehumidification process due to the large contact area and the low thermal resistances. The air flow rate reach up to 14 kg/h, water temperature of 50–90 oC, and water height in the bubble column of 20–60 cm. It was concluded that both the fresh water production and the humidifier efficiency increase with the air flow rate and water temperature, while the water height slightly	[10] & [12]

	affected in the bubble column.	
HDH driven by photovoltaic thermal energy recovery	The design simulation was depended on a PV panel with surface area of 1 m2. The mass and heat balances for the stages in the system, were used to describe the units in the system. Mass flows and heat balances were considered as conserved across each of the units in the system for example PV panel, humidifier, and dehumidifier. The PV panel and the supplied air used to recover thermal energy resulting from the solar radiation on the PV unit, in humidifier the mass flow rates of saline water and dry air were 3.6 and 4 kg/h · m2, respectively. Adiabatic evaporative cooling was applied for the humidified air out of the humidifier. The outlet air from the humidifier is saturated with vapor which mean RH=100%. As a result of the transport of vapor from the saline feed water to the air in the humidifier, The water production was defined in this study as the quantity of water produced per square meter of PV panel per day but the thermal energy consumed is the thermal energy required to produce a unit amount of water	[14]
HDH with solar collector	Humidification–dehumidification system integrating with external reflector (inexpensive external reflector is used to increase the distillate productivity of single-effect stills) and water heaters has been manufactured and tested at various weather conditions, To save excess heat in HDH system, a black painted absorber has been used at the bottom of the humidification chamber. In this process operates on the basic principle of evaporation inside the chamber air gap and condensation through the attached condenser. By using different Wick materials, black cotton cloth helps to achieve maximum productivity of 4.21 L/day. The addition of permeable materials and energy absorbing materials also enhance the distillate output to 4.27 L/day.	[1]

The highest world water desalination capacity is Reverse-Osmosis (RO) desalination processes as it provides nearly 65%. This high percent is due to non-corrosive equipment, less energy consumption nearly 10-fold less than thermal techniques and relatively safe operation. RO would be the key technology to reduce the overall carbon footprint of desalination as it doesn't require any fossil fuel only needs electricity from PV and batteries. But RO desalination has high cost; this high cost is due to PV cells. In order to store electricity lead acid batteries are used, this battery require charging and its efficiency decrease by the time all of this lead to increase cost of RO desalination. Some researchers saving energy until 60% by using the feed water for cooling the PV arrays and heating the feed water. This method may lead to decrease in RO desalination cost.

Solar still or direct desalination is from the oldest ways of solar desalination. Many researchers had developed this desalination process to improve its capacity of fresh water production. From advantages of solar still, it's a very simple device so easy to maintenance and easily collected fresh water, the daily efficiency of the still is approximately 37% and 42%. but using a flat plate solar collectors and condenser the performance increased by 141% in case of sprayed hot water and 132% in case of a jet hot water in active circulation mode. Which mean efficiency nearly increase three times. But using evacuated solar collector the productivity increases by about 215%but require heating brackish water continuously. It's preferred to use evacuated solar collector rather than flat plat solar collector. As evacuated solar collector increases by approximately 1.5 times compared to flat plat collector. During night time solar energy is absented to solve this problem PCM is used the most famous one is paraffin wax, which increase production rate by 40%, from defect of solar still it's applied only on small scale.

Membrane distillation depend on phase change process in its operation. Which mean needing of great source of heating energy, to improve MD process it's preferred to prevent heat loss. So, reduction of the energy consumption of the MD system is affected by the heat recovery. This lead many researches to play on heat recovery, and also the design of membrane has ability to reduce conductive heat loss and to increase permeate flux. While using Composite membranes have been prevented heat loss via conduction, and the thinner active layer can reduce the mass transfer resistance. All of these are advantages of MD but it has low distillation capacities

MSF and MED are nearly the same process but there are some different between them as Some researchers showed that MSF isn't thermally efficient like MED, while others see some disadvantages in the Thermodynamics of the MED process over the MSF process other than the thermal losses that are higher in the MSF than in the MED due to its higher operating temperature, Compared to MED, MSF has high overall efficiency, high heat transfer co-efficient, relative independent stages and less water recycling. However, in order to lower the energy consumption, MED needs large surface area of evaporators to reduce the temperature difference of adjacent stages; and, some research has shown that when operating with high-pressure steam, MED consumed more energy than MSF.

In Adsorption desorption solar desalination there are two ways of solar collector. evacuated solar collector or concentrating photo voltaic thermal collector, in case of evacuated solar collector temperature of hot water reach to 85 0 C, although temperature is lower but, in this process, has stability of water temperature. While concentrating photo voltaic thermal collector temperature is higher than 100 0 C and also can used for steam production, refrigeration process.

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