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Solar Energy Based Purification of Sea Water – A Detailed Review

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Abstract - ***The availability of drinking water is essential for the survival all of mankind. Adequate amount of water resources are available on our planet but very few of them can be used for the purpose of drinking. A number of water purification methods have been put forth by researchers to purify brackish water and sea water. As water purification processes require some sort of energy source, and with the advent of renewable sources of energy utilization in various fields, a thorough review of solar powered purification setups is essential. An effort has been made to review all the available research and technology for water distillation using solar energy in this research paper. It is found from the literature survey that, a number of research setups and devices are available but are currently not being used due to high initial setup costs and limited technological awareness in the society.***

Key Words: *Humidification dehumidification (HDH), Solar Stills, Reverse Osmosis (RO)*

1. Introduction

Solar water purification is a relatively simple treatment of brackish (i.e. contain dissolved salts) water or sea water in to fresh water. Distillation is one of many processes that can be used for water purification and can use any type of thermal energy. Concentrated solar energy can be used to provide this thermal energy, in a sustainable and environmentally friendly option. In this process, water is evaporated; using the energy of the sun then the vapor condenses as pure water leaving behind the dissolved salts and dirt sediments. They are classified in two groups; (1) phase-change processes and (2) membrane process. Phase change processes can be further classified into multi-stage flash (MSF) distillation, multiple effect distillation (MED), vapor compression (VC), and membrane processes are further classified into reverse osmosis (RO), electro dialysis (ED). A review of research in the fields of Humidification dehumidification technology, Solar Still Setups and Reverse Osmosis plants has been undertaken in this paper, with a further goal to provide assistance in creation of new projects related to above topics, for production of low cost drinkable water especially in remote areas and regions with high poverty. Only a sustained effort by researchers can help in providing for an environmentally sound solution, to this rapidly growing need of providing of basic necessities to an ever growing population on this planet.

2. REVIEW

2.1 Humidification dehumidification (HDH) desalination technology

Nature uses solar energy to remove dissolved salts from ocean water by means of the rain cycle. In the rain cycle, sea water gets vaporized (by solar thermal energy) and humidifies the air. Then the humidified air rises and forms clouds. Eventually, the clouds condense this water vapor as rain. The man-made version of this rain cycle is called the humidification dehumidification desalination (HDH) cycle. The main drawback of the solar still is that the various practical processes (solar absorption, evaporation, condensation, and heat recovery) all occur within a single container. By separating these functions into distinct processes, thermal inefficiencies may be lowered and overall performance drastically improves. This separation of processes is the crucial characteristic of the HDH system. For example, the recovery of the latent heat of condensation, in the HDH process, is affected in a separate heat exchanger (the dehumidifier) in which the seawater, can be preheated. The unit for solar collection can be optimized almost autonomously of the humidification or condensation process. The HDH process, thus, promises higher efficiency due to the separation of the basic processes.

Hefei Zhang et al [1] present a hybrid solar desalination process of the multi-effect humidification dehumidification and the basin-type unit. The solar evacuated tube collector is employed in the desalination system, multi-effect humidification dehumidification desalination (HDD) process is calculated, and then the water excluded from the multi-effect HDD process is reused to desalinate in a basin-type unit further ahead. The research proves that the multi-effect HDD has much room to be enriched.

Guangping Cheng et al [2] proposed a solar desalination process using air humidification and dehumidification. In order to increase the output of freshwater, the double-pass solar air heater and tubular solar collector are used to heat the air and seawater respectively. The air is humidified by bubbling in the seawater pool, and dehumidified in the inorganic heat pipe condenser. The heat transfer performance of the solar air heater with double vacuum glass-covers and double air passes is studied, and the theoretical model of its heat transfer and the calculation methods are given.

M. Amidpour et al [3] experimentally evaluate and optimize the humidification–dehumidification desalination process for production of fresh water from brackish water. Experimental results show that two-stage HD desalination unit can increase thermal recovery in condensers and hence, reduce thermal energy consumption and investment cost of the unit. Productivity can also be increased by 20% compared with the single-stage unit.

M. Abd Elkader [4] experimented on a three stage multi-effect humidification (MEH)-dehumidification process with energy storage system which was designed, manufactured, installed and outdoor tested in the Faculty of Engineering, Suez Canal University, Port Said, Egypt. The thermal collection part of the system (three flat plate collectors) has been designed to provide hot water to the desalination chambers. The investigational test results showed that, the increase of seawater mass flow rate through the setup from 0.1 liters to 0.13 liters increases the efficiency of the system by 10 %. It can be seen from the results also, that the use of energy storage increases the output by 13.5%.

Julian Blanco et al [5] have analyzed about the AQUASOL Project whose objective is the development of a lesser expensive and more energy efficient seawater desalination technology based on Multi-Effect Distillation process with zero brine discharge. Specific proposed technological developments (new design of CPC collector and absorption heat pump, hybridization with natural gas and recovering of salt) are expected to both increase the energy efficiency of the process and process economy. The expected result would be an improved MED technology with market potentials and suitable to be applied in the Mediterranean area and similar locations around the world

2.2 Solar stills

Solar still is an apparatus to desalinate impure water like brackish or saline water. It is a simple device to get fresh distilled water from impure water, using solar energy as fuel, for its various applications in domestic and industrial sectors. The basic concept of using solar energy to obtain drinkable fresh water from salty, brackish or contaminated water is quite straight forward. Water left in an open container in an open area will evaporate into the air. The purpose of a solar still is to capture this evaporated (or distilled) water by condensing it onto a cool surface. Increasing water temperature and the area of water in contact with the air can increase the rate of evaporation. A wide, shallow black painted pan makes an ideal vessel for containing the water. The pan is painted or coated black (or some other dark color) to maximize the amount of solar energy absorbed. It should also be wide and shallow to increase the surface area, assuming the availability of a material with good thermal energy absorbing properties and resilience in heated salt water. To confine and condense the evaporated water, we need some kind of surface close to the heated salt water, which is, quite a few degrees cooler than the water. The evaporating pan is usually covered by a sheet of clear glass or transparent plastic (to allow sunlight to reach the water) which is slanted at a slight angle to let the fresh water that condenses on its underside, to drip down to a collecting trough. The glass creates a cavity and also holds the heat inside.

Mayruresh et al. [6] fabricated a setup of Solar Water Purifier according to theoretical design as shown in Fig. 1, and a sample of purified water from the setup was sent to water testing laboratory and from the results obtained it was found that the sample was free from particulate matter and disease causing pathogens and hence the water was fit for drinking. Temperature from the setup easily rose up to 70°C in 2 hours and thereby killing the pathogens through the process of Water Pasteurization. Also, comparison was made between the existing filters like which were dependent on electricity like R.O filter, U.V. filter and it was found that the Solar Water Purifier had many advantages over the conventional filters in terms of manufacturing and maintenance cost and also it can be successfully implemented in rural and slum areas where there is lack of electricity but abundance of solar energy.

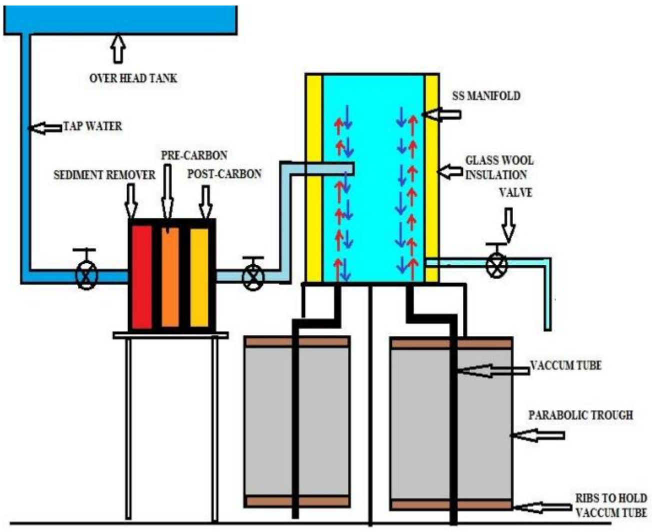

Fig -1: Layout of Solar Water Purifier [6]

Bassam A/K et al. [7] have investigated numerically the effect of water film cooling of the glass cover on the efficiency of a single-basin still. The authors have proposed that correct use of the film-cooling parameters may augment the still efficiency by up to 20%. And simultaneously, a poor combination tends to significantly reduce the efficiency of the still. The presence of the cooling film also neutralizes the effect of wind speed on still efficiency.

Kobayashi S. et al. [8] have analyzed a specific problem associated with the feeding system of a roof type solar still. A laboratory setup of two effects having 500 × 500 mm heat penetrating area was designed and made mainly from polyethylene film. The upper surface was illuminated by infrared lamps in the intensity range between 240 and 650 W/m^2. The experimental test operation using salt water proved to steadily produce fresh water. The materials for constructing solar stills were also discussed and a concept was proposed to replace a panel of photoelectric cell for the heat receiving plate.

Sando M. et al. [9] have presented a simulation model for multi effect thermal diffusion stills, obtained by formulating the rate equations and the heat and mass balance equations with respect to the process variables. The results derived by the simulation showed acceptable results with the experimental data taken from the laboratory test plant having five stages and one m^2 frame area. Calculation with the model showed the effect of design and operation parameters such as solar intensity, heat transfer coefficient through the partition and feed rate of brine to each stage on the distillate productivity. The results showed that the distillate productivity is independent of overall heat transfer coefficient through the partition if its value becomes greater than 230 W/m^2.K. Correlation to obtain the feed rate at each stage required to maximize the efficiency of distillate was obtained as a function of the solar intensity and ratio of brine feed between two successive stages.

2.3 Reverse Osmosis (RO)

Reverse osmosis is a pressure driven process where a pressure difference larger than the osmotic pressure is applied across an appropriate semi permeable membrane. Fresh water passes from the concentrated salt solution to the dilute one. In practice, the saline feed water is pumped into a sealed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the salt content of the remaining feed water rises. Simultaneously, a portion of this feed water is discharged without passing through the membrane. The quantity of the feed water discharged to waste in the brine stream varies from 20 to 70% of the feed flow, depending on the salt content of the feed water, pressure, and type of membrane. A usual salvaged value for a seawater RO system is only 40%. An RO desalination plant basically comprises of four major systems (1) Pretreatment (2) High-pressure pump (3) Membrane assembly (4) Post-treatment. To prolong membrane lifespan, extensive pre-treatment is typically required to condition the feed seawater. Therefore, suspended solids must be extracted and the water pre-treated so that salt precipitation or microbial development does not ensue on the membranes. Usually, the pre-treatment involves, fine filtration and the addition of acid or other chemicals to prevent precipitation and the growth of microorganisms. The high-pressure pump provides the pressure required to allow the water to pass through the membrane and have the salts discharged. Pressurizing the saline water accounts for the greatest energy consumption by the RO. Subsequently the osmotic pressure, and hence the pressure essential to achieve the separation is directly linked to the salt concentration, RO is regularly chosen as the method for purification of brackish water, where only small to intermediate pressures are necessary. The operating pressure varies from 15 to 25 bar (225 to 375 psi) for brackish water and from 54 to 80 bar (800 to

1,180 psi) for sea water using an osmotic pressure of 25 bar. Energy recovery from the high-pressure brine exiting an RO plant forms an essential part in decreasing the overall energy consumption for desalination, specifically in large-scale RO plants for seawater desalination.

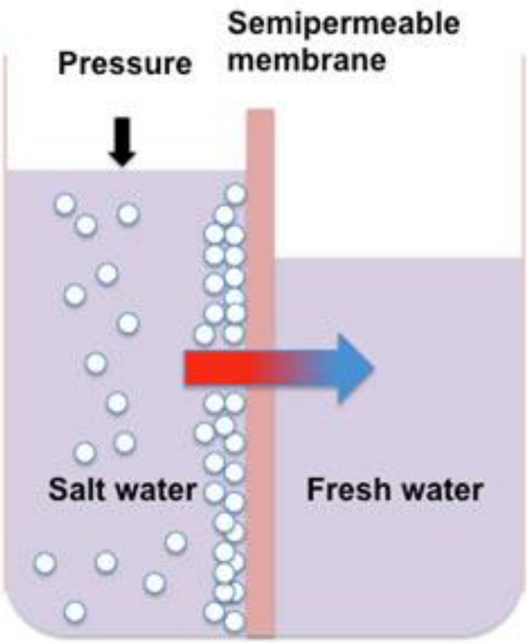

Fig -2: Reverse Osmosis Process [10]

Schafer A. et al. [11] described the design and field-testing of a photovoltaic (PV)-powered desalination system. The system defined was proposed for use in isolated areas of the Australian outback, where fresh water is particularly inadequate and it is often essential to drink high salinity bore water. The system based on a hybrid membrane configuration was implemented, with an ultra-filtration module for eliminating particulates, bacteria and viruses and a Nano-filtration or RO membrane for removing dissolved salts. The setup created pure drinking water from a diversity of feed waters, as well as high salinity (3500 mg/L) bore water. The specific energy consumption varied from 2 to 8 kW h/m^3 of disinfected and desalinated drinking water, reliant on the salinity of the feed water and the experimental setup working conditions.

Neskakis A. et al. [12] reported on the feasibility of a small Photovoltaic driven RO desalination plant, with a normal daily production of drinking water with discharge of 0.8-3 m^3/day. They examined the effect of feed pressure on produced water quality, on plant productivity and on total energy consumption. At the feed water pressure of 48 bars, the specific energy consumption of the project was 16.3 kWh/m^3. Productivity of the project was 124 L/h using permeate concentration of 450 ppm. When the feed pressure was raised to 63 bar, the specific energy consumption fell to 15 kWh/m^3, and productivity improved to 155 L/h with permeate concentration of 330 ppm.

Schmid J. et al. [13] presented a feasibility study of water desalination in Egyptian deserts and rural areas, where there is a shortage of fresh water in spite of the presence of large sources of brackish water areas, using photovoltaic energy as the primary source of energy. They also proposed an economic design of a PV powered small scale reverse osmosis water desalination system. It was estimated that the cost of producing 1 m^3 of fresh water from the PV-RO system is approximately $3.73. . If the system capacity and the daily range of operation are raised, the cost of generating fresh water will be diminished in these areas. The authors also mentioned that using different systems fueled by renewable sources of energy would be beneficial in keeping the environment clean for the people living in these remote areas.

3. CONCLUSIONS

From this exhaustive literature review, it is found that various methods are developed for distillation of water. These methods are subject to the demand of fresh water, quality of water source and the involved expense. Conventional Reverse Osmosis systems are currently prevalent domestically but at the cost of plenty of waste water. Non-conventional water purifiers like solar stills have unlimited potential but their usage is inadequate due to lesser output rate. Humidification dehumidification process is the most appropriate option for fresh water production and combined system for simultaneously hot water production. The multi-effect distillation method can be used for mass production of fresh water. The detailed review reveals that there is a need to develop a hybrid system of water purification which can overcome the limitations of all existing water purification systems.

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