Experimental Investigation of Solar water Desalination with Phase Change Material and TiO₂

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Abstract: This paper investigates the conversation of wastewater into pure water by desalination effect. The solar energy is a primary source of this method. Three types of investigation carryout for the setup: (1) Only Wastewater poured into the chamber, (2) Black stones placed over the bottom of the plate, (3) Using the Paraffin wax used as a phase change material. The Temperature and water production quantity measured respective methods. For these methods, data compared and analyzed. The mixture of titanium oxide and paraffin wax was poured into the copper tube and placed over the surface plate. Solar energy stored large quantity in day period lesser in night time by the paraffin wax liberates its stored heat. The absorbed heat energy cannot escape in the chamber. Because the double glass solar still fully insulated by Polyurethane Foam. In this experiment gives the water production rate at different session of a year. There is a three objective of this investigation: (1) Desalinating Backrush water into pure water with help of solar energy. (2) Achieve Water Output 2 litres pure water per day from 10 litres Wastewater. (3) Complete the project with economically and easily maintainable.

KEY WORDS: Double glass solar still (DGSS), Phase Change Material (PCM), Titanium oxide (TiO₂), Black Stone, Copper Tubes, Digital Thermocouple Indicator (DTI)

1. Introduction

The pure water availability was decrease rapidly by usage of water for human living purpose. The growth of industries also mainly depends on water. The world was surrounding by 70% of salt water. However, human cannot use that salt water directly. That is why world research for alternative method for produces pure water. There is a lot of purification process. However, some processes need the external energy like electrical and Thermal energy. The best way of produce water is desalination method from salt water or waste industries water like die company, chemical company etc. In solar water desalination, the production rate of water quantity depends on climate and intensity of temperature level. Therefore, the demand of desalination technologies is increasing. The development of Small size with effective desalination units are needed to establish an independent water supply in urban areas.

This is the motivation for research on alternative desalination processes. [1] M.T. Chaichan, H.A. Kazem, et al. use the concentrating solar heater for desalination process with paraffin wax as phase change material. In addition, it was stored heat energy in two different insulation materials. The desalination setup gives four conclusions from end of the investigation. They are Using water as a thermal energy storage material with and without solar tracker device. From the usage of solar tracker system working time was increased 5hours. The system productivity and concentrating efficiency increased in 307.54% and 64.07%.The system has also working time was increased 3 hours by using of PCM. [2] Ravi Gugulothu, Naga Sarada Somanchi et al. include the different energy absorbing materials in single basin solar still system. This desalination system is thermodynamically attractive and economically good technology. Sensible heat storing method increases the temperature storage medium. This work is discussed the Magnesium Sulphate Hepta Hydrate (MgSO₄ 7H2O), sodium acetate (CH3COONa) and potassium dichromate (K2Cr2O7) PCMs are used to energy
The increase of surfactant concentration greater than 400 ppm leads to decreases the daily water production. [10]

The parametric analysis successfully conducted on the mathematical model and simulation performed. The system can produce 3.5 kg/d distilled water at 5.4 kg/d distilled water at summer days. This rage was suitable for domestic usage. [5] J. Blanco Galvez et al. deals with MEDESOL (Seawater Desalination by Innovative solar Powered Membrane Distillation System) sponsored by European commission. The multi stage membrane distillation (MD) concept used here to develop the water production rate at high and cost effectively for standalone desalination. Solar distillation is best-developed technologies of non-conventional energy driven desalination. Membrane distillation systems classified into five different configurations: air-gap MD (AGDM), direct contact MD (DCMD), liquid-gap MD (LGMD or LMD), vacuum MD (VMD) sweeping gas MD (SGMD), and osmotic MD (OMD), three of which, DCMD, AGMD and VMD, are the best suited for desalination applications. From the analysis VMD, low pressure is applied on the permeate side and the steam condensation takes place outside the membrane module. [6] B. Feng et al. present GOF suspension for seawater desalination through vacuum filtration by graphene oxide framework (GOF) membrane. Here 4-phenylene diisocyanate (PDI) was chose as cross-linking for covalent modification of GO Nano sheets to prepared 3D GOF. The PDI-modified α-Al2O3 tube prepared micron thickness level. The developed GOF membrane was tested for seawater desalination by Pre-evaporation. The three-dimensional structure reduces the resistance of the mass transferring through GOF membrane and water flux was increased slightly. The thick of 18 µm GOF membrane at 90 °C, produce 11.4 kg·m-2·h-1 Water flux with 99.9% of ion rejection for 3.5 wt.% seawater desalination. [7] M. Reali et al. reported to solar innovative barometric distillation technology for seawater desalination had lot of attractive features like, i) simple construction with effective solar vacuum collector. ii) Quesi-Steady state operation happens at sub atmospheric pressure. For 100m 3/day production, consume 2kWh/m3 electric power supply. A simple barometric layout Desalination method which achieves an efficient exploitation of solar energy for desalinate seawater. [8] M. Reali et al. discuss the barometric layout of solar barometric distillation technology for seawater desalting (SW–SBD). There is two kinds of plants are analysed in SW-SBD process. The first plant use single distillation heat exchanger with single stage distillation process at ~50°C operating condensation temperature. The second plant had two-distillation heat exchanger with two-stage distillation process connected in serious. This plant operates at ~40 and ~60°C condensation temperature. Vacuum solar collector, Glass or Polymer blends used to construct the SW-SBD plants. The plants regulated by means of a custom-designed control system. [9] A.S. Nafey et al present the heat transfer of boiling water by desalination process. The sodium lauryl sulfate (SLS) used to increases the effect of concentration of solar water desalination process. The small amount of surfactant additive makes higher top brine temperature with fresh water product. The system productivity increases with 0.7%, 2.5%, 4.7% and 7% at additive concentration equal to 50, 100, 200 and 300 ppm respectively. From the analysis increasing the surfactant concentration greater than 300 ppm does not affect the daily water production. The increase of surfactant concentration greater than 400 ppm leads to decreases the daily water production. [10]
M.R. Qtaishat, F. Banat et al. discuss the hybrid membrane evaporative desalination process. It needs two types of energy source like low temperature heat and electricity. In this membrane process, (MD) process coupled to mature technologies like solar collector and PV panels. The small SPMD units help to provide sufficient water to urban areas peoples. The MD desalination process cheapest technology compare than commercial PV-RO process. This low temperature type MD process reduces the chemical interaction between process solution and membrane. It was reduce vapour spaces compared to conventional distillation. [11] Kuwen Zhao et al. discuss the characteristic of solar energy and tidal energy with multi effect solar desalination unit. The cost of the system is reduced by means of tidal energy is used to supply power for drainage and water supply to system as well as maintaining vacuum of the inside chamber. The system operates under condition of vacuum based on multi effect evaporation condensation processes. So, that low grade soar heat used for getting higher thermal efficiency. This system operated by vacuum extraction mechanism. The unit needs periodic vacuum extraction or non-consumable gases will accumulate to a degree of destroying the vacuum. Hydrodynamic analysis carried out for the vacuum extraction processes utilizing tidal energy. From the analysis unit can operate 2m larger range in tidal area. [12] R.B. Saffarini et al. evaluate Solar-powered membrane distillation (SP-MD) desalination systems in strong solar radiation with off-grid areas. This work provides assessment of established SP-MD system and identifies construction features. This system was reviewed in terms of operating conditions and their physical properties. From the evaluation several performance are noted like performance ratio, gained output ratio (GOR), energy recovery scheme applied and membrane flux achieved. Four types of principal involved in this configuration: Air Gap (AGMD), Sweeping Gas (SGMD), Direct Contact (DCMD) and Vacuum (VMD). SP-MD systems give low GOR values and very high specific thermal energy consumption. Out of all four system configuration the VMEMD has a highest recovery ratio of water. [13] R. Gemma Raluy et al. explains solar desalination is ideal solution of isolated areas which receive greater solar irradiation per day. At low temperature the MD process operates and suitable for thermal solar system and waste water heat recovery units. In this work presents last 5 years’ experience and analysis of MD data. The first year 20 m3/day of water get from optimize MD and system technology. [14] Rada Zarasvand Asadi discussed purifying oil field waste water from gas refinery plants. This system also worked based on prevapouration. The saline oily effluent treatment used in this processes and evaluated. Here, 40 m2 surface areas installed with one pilot scale membrane desalination system. The transparent plastic cover foil placed on the ground for UV resistant. The period of spring 2005 is 1.3 L/(d.m2) water can achieved from the plant. The performance of purification (purified water versus contaminated) of the Sarkhon Gas Refinery plant wastewaters total dissolved solids (TDS) from 1991 reduced to 91 mg/L, conductivity from 3342 reduced to 150 μS/cm, chloride from 1565 reduced to 6.6 mg/L and Oil and Grease from 31 reduced to 1.12 mg/L. [15] R.B. Saffarini et al. explain economic evaluation of water production in solar powered membrane distillation (SP-MD) systems. The system analysis three SP-MD systems like Direct Contact (DCMD), Vacuum (VMD) and Air Gap (AGMD). A parametric study conducted for AGMD with SP-MD configuration. The results shows whenever the feed inlet temperature increases the water production cost will increased significantly. The membrane length and lower air gap and feed channel depth reduces the cost of water with effectively. [16] R. Schwantes et al. motivate the research on alternative desalination process for small scale autonomous and robust desalination units to improve the independent water supply in rural areas. This work demonstrates parallel multi MD-module setup with experimental studies. Three plants are takeout to analysis and different types of approaches are carried with respect to energy supply, hydraulic lay out or MD module configuration. [17] H. Ben Bacha et al. presents the investigation study of dynamic functioning of a solar desalination based on Humidification and dehumidification process. This work creates and established mathematical model for the system uses of real meteorological data. The developed models help to predicting the various meteorological conditions behaviour. The prototype consists of a humidifier, an evaporation tower, a condensation tower
solar air collector and a flat plate solar water collector. The output of water attended maximum in July. Decreases of solar radiation leads top increases the inlet air relative humidity of the humidifier. The increase of air flow rate decreases the outlet relative humidity of humidifier. [18] H.C. Duong et al. explain technique of brine recycling during direct contact membrane distillation (DCMD) for seawater. The hot brine return to the feed tank the system water recovery increases and sensible heat of the hot brine was recovered to improve the thermal efficiency. From the brine recycling the specific thermal energy consumption of the desalination processes was reduced half. The sea water recovery range achieved up to 70% in 24 h by DCMD process without any scale formation on the membrane surface area. Increases of feed temperature help to reduce the negative effect of salinity on water flux at a high water recovery. [19] M. Asbik et al. analysis the exergy of solar still combined with heat storage system in meteorological conditions taken on 15th of June 2011 at Errachidia city (Latitude: 31°58’N, Longitude: 4°20’W, Morocco) to find out exergy losses during the heat storage and discharge. Paraffin wax is used as phase change material (PCM) to store and liberate the heat. The destruction of exergy (entropy generation) are the thickness of the PCM medium, the ambient air velocity and the brackish water depth are discussed. During sunshine period the amount of destroyed exergy is crucial. The night period PCM generates the highest and lowest exergy destroyed respectively to brackish water. The instantaneous exergy efficiency is lower than 5% at day time for some time it exceeds 80% at night period on the solar still. [20] Abu El Nasr’ M et al demonstrate humidification and dehumidification principal in water desalination system using solar power. This system consists of non-packing bed type humidifier with sprayer, Water pump, an air blower, a copper coiled Dehumidifier, a flat plate solar water heater, a water flow meter, three thermocouples and four gate water valves. The made of Poly Vinyl Chloride (PVC) pipes used to connect the pipes; which makes light weight of the system. Inlet water temperature is directly proportional to water productivity.

2. Methodology

An open atmosphere takes it to experimental conducting area. The Banna Amman Institute of Technology, Sathyamangalam, Erode, at (11.4960° N, 77.2770° E) location setup placed. The following figure 1 and 2 elaborates the configuration of system.

![Figure 1 Schematic diagram of experimental set up](image)


2.1 Description of Experimental Setup

i. The wooden plates and mild steel plates used to form a chamber setup. The Mild steel plate (1100 mm * 95 mm * 5 mm) placed in the bottom and covered by wooden plate. For increasing heat absorption purpose, setup fully painted in Black color.

ii. Double glass solar still was close the chamber. Bottom of the glass had small projection provided to drain the condensate water to storage tank.

iii. Polyurethane Foam form as an insulated material used to cover the setup and product from heat losses of chamber.

iv. The mixture of Titanium Oxide and Paraffin wax packed in copper tube. Packed copper tube placed over the Bottom of the plate. Small size Black stones are included for increase the sensible heat storage rate.
v. The digital Thermocouples staked in different places for measuring the Temperature.

T-1 = Water Thermocouple  
T-2 = Inside Glass Thermocouple  
T-3 = Outside Glass Thermocouple  
T-4 = Inside Chamber Thermocouple  
T-5 = Atmospheric Thermocouple

vi. The small tubes connected to draining area for collect the compensated water from Projection. The tubes connected to Storage tank.

3. Experimental Investigation:

The experiment conducted at month of February on 2017 by three different configurationally.

(1) Salt water with PCM  
(2) Salt water with Black stone  
(3) Salt water only

From these, data are collected and best three days data used for comparison purpose. The comparison conducted for Temperature levels versus definite interval period. The Following Graph figures 4, 6, 8 are explains Water production for particular method.

3.1 Salt water only: (Method - I)

The figure 3 explains Different places temperature at definite time. The salt water only poured in the set up and Data are consecutively measured. From the graph Water, temperature (T-1) gradually increases up to 2PM from morning 9AM. The peak temperature Reaches on 60°C to 68°C. This time inside glass temperature (T-4) and Inside Glass Temperature also increases gradually. After 3PM, water temperature falls rapidly. However, Inside Chamber temperature maintain under 55°C to 62°C because of Insulation.

3.2 Salt water with Black stone: (Method - II)

In this Method-II set up 5 Kg Black stone was placed over the mild steel base plate. This black stone acts like sensible heat storage medium for the system. The Graph figure 5 explains the temperatures of system at different places. Using Black stone with Saltwater, time to heat absorption rate was more than other two methods. Because of previous Method-I salt water only poured in the chamber. But, this method had black stone for help to increase the Heat storage rate and Dissipate when the surrounding temperature comes down. Figure 5 explains, during 9AM to 11AM water temperature varies from 31.3°C to 54.9°C. The time 12AM to 5PM averagely water temperature maintained in 60°C to 70°C.

3.3 Salt water with PCM: (Method - III)
4. Water Production Level

The actual Quantity of water chamber is 125.4 liters. For effective condensation purpose, only 12 liters of salt water poured day. The pure water Production range varying by following methodology.

Method – I = 1195 ml/day
Method – II = 1365 ml/day
Method – III = 1635 ml/day

From the figure 8 Compares the Method of Set up and Production Rate. These analyses help to find the better performance methodology. The method – III is gives more production of pure water compares to other three methods. The period 11AM to 2 PM water production range gradually increases up to 350ml at Method – III. The method – II production range reach up to 305ml at 2PM. From these methods shows sensible heat storage mediums gives good result for water production.

5. Conclusions

The following results obtained from these experimental investigations:

1. The results visualized that the presence Phase Change Material (PCM) and titanium oxide (TiO$_2$) make the production of pure water is 1.635 liters/day from 12 liters of saltwater.
2. Using of Black stone as a sensible heat storage medium also improving production rate without any cost.
3. The water production rate is high in 1:30PM to 2PM in sathyamangalam zone.

6. References


