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A Review of Solar Desalination Methods for Remote Areas

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ABSTRACT

The inadequacy in supply and the shortage of clean potable water has taken centre stage in recent times. The first half of the year 2016 is already witnessing huge water scarcity in many part of the country. High growth of population coupled with rapid industrial developments in Indian subcontinent resulted in shortage of clean drinking water for people living in rural areas and remote villages especially in desert. In urban and rural areas surface or ground water is polluted due to industrial waste or rampant use of chemicals in agriculture (e.g. insecticides, pesticide and chemical fertilizers). Other dimension to the problem is acute shortage of power supply for running traditional water cleaning systems such as reverse osmosis. One of the prominent economical methods of converting the saline water to potable water is solar desalination. It distils the saline water by evaporation and condensation the way nature makes rain. Here in this paper, the goal is to provide an overview of conventional as well as solar desalination technologies available at present.

Keywords: *Solar Desalination; Still; Clean Water; Humidification.*

1.0 Introduction

Abundant amount of water is available on the earth but modern time is witnessing scarcity of fresh potable water throughout the world and situation is grimmer in the desert areas and Indian subcontinent. The percentages water distribution of sea water and fresh water on the earth are 96.54% and 2.53%, respectively [1], but the mankind has access to only 0.36% of 2.53% fresh water [2]. Rapid industrialisation, deforestation and increased used of chemicals in agriculture has polluted the source of freshwater such as river, ponds and groundwater. In the Gulf region and at the other places, high grade energy is used in multi effect evaporators and reverse osmosis plants to desalinate the sea water. Both the methods are fossil fuel burning methods causing environmental concerns by the way of CO, emissions. Also there is scarcity of energy in rural and remote areas of Indian subcontinent.

Therefore, in this context, the development of desalination technologies operated with renewable energies is a promising and futuristic prospect. Among the sources of renewable energy, the use of solar energy seems to be most attractive, as the regions with greater water shortages have abundant solar radiation throughout the year.

Various desalination methods are available as of now but selection of most appropriate desalination technique depends on chemical composition of feed raw water. Economy of desalination determined with amount of energy needed for desalination, is directly proportional to degree of salinity of feed water. High degree of salinity is found in sea water and brackish water has lower degree of salinity [3]. Desalination systems can be broadly classified into thermal distillation or membrane separation [4]. In thermal system solar energy is used to heat and cool the brackish water to provide clean water by the process of distillation. Membrane separation systems based on solar energy provides electricity to drive reverse osmosis plants or creates electric fields for electrolysis process.

2.0 Solar Energy, Its Importance and Availability in India

In India the electrical energy demand for the period 2016–17 is anticipated to be 1392 TWh, and

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the electrical energy demand for the period 2021–22 is anticipated to grow to be at least 1915 TWh [5-6]. India has an installed capacity of 207.85 GW as on September 2012. Captive power plant generates further 31.5 GW.This indicates huge shortfall in demand and supply. To fulfil this gap many renewable source of energy are being explored and one such source which comes to mind is solar energy. Sun is the source of life on the earth, out of its energy output of 3.8 ×1020 MW, only a small fraction, 1.8 × 1011kW, is intercepted by the earth [7]. Further, it is estimated that, 30 minutes of solar energy is enough for the world energy demand for one whole year [8].Thus, in principle, solar energy can supply all present & future energy needs of world on continuing basis. Solar energy is omnipresent, environment friendly and freely available in contrast with electric power which is rarely available and costly [9].

Most parts of India have 300 – 330 sunny days annually, which are estimated to produce at least 5000 trillion kWh per year – enough to power India's total energy consumption for a year [10]. The India Energy Portal estimates that using 10% of the land for harnessing solar energy, the country can produce 8,000GW, which is fifty times the current total installed power capacity.

3.0 Conventional Desalination Technologies

Desalination is defined as a process of recovering the pure water from saline water and removing salts and minerals using different forms of energy. As the saline water is not fit for consumption by human and other animals living on earth's crust, it becomes essential to remove the salinity of the water. Ever Increasing groundwater extraction coupled with rapid industrialization has resulted in increasing salinity of water in wells and aquifers. This led to a large interest in the development of economically viable and environment friendly desalination technologies [11]. A number of desalination methods for distillation of saline water have been developed as reviewed here.

3.1 Thermal desalination

Thermal desalination processes use thermal energy to heat saline water to form steam and then steam is condensed to produce pure water which can be utilised for industrial or domestic usage. The leading thermal desalination processes are multi-stage flash desalination (MSF), multiple-effect distillation (MED), and mechanical vapor compression (MVC).

3.1.1 Multi stage flash (MSF)

In this method seawater is converted to pure drinking water by boiling and condensing through many stages in a closed vessel under low pressure. Water is boiled at a temperature below its boiling point and the phenomenon is known as "flashing effect" [12].MSF unit can have up to 40 stages for heating water and condensing [13].

MSF is able to handle higher contaminant loading (heavy metals, suspended solids, oil, grease etc.) as a feed sea water. MSF is very much capable of producing good quality water which may be used for process industries, power plants, and many other applications. The major challenges associated with MSF are scale deposition and corrosion [14-15]. Both alkaline and non-alkaline scale depositions are observed.

3.1.2 Multi-effect distillation (MED)

In MED method, the water is first boiled and then converted to hot steam in boiler. Multi effects are produced by successive heating of saline water by this steam in evaporators. The hot steam moves from first evaporator to the second and then the third one and heating the saline water in each stage. In the fourth stage saline water acts as condensing media for the hot steam. Latent heat due to phase change during vapour condensation in each stage is used and then it is released to the atmosphere. Evaporator is termed here as stage [16-17]. Scaling and corrosion are the main challenges with this system.

3.1.3 Vapour compression distillation

In this system energy needed to heat the incoming saline water is not taken from thermal source as in MED and MCF but heat is produced by vapour compressor which is a mechanical source [18].It is a proven reliable and robust desalination technology that is noticeable because of its capacity to treat quantities of water with different percentage of salt concentrations. The major drawback with this technique is higher operating and installation cost in comparison with other desalination technologies such as MSF and MES [19]. Vapour Compression (VC) distillation process is essentially the most thermodynamically effective process out of single-purpose thermal desalination plants [20]. The "heat pump" work and the energy required for liquid pumping is the only power consumed by the process.

3.2 Membrane based desalination

Membrane processes has drawn attention for their strong separation abilities and exhibiting a huge potential for the treatment of water worldwide. Important Membrane processes are reverse osmosis (RO), Nano-filtration (NF), and electro-dialysis (ED). RO membrane technology is currently the leading technology worldwide for desalination installations and has found application for brackish as well as seawater applications. The major drawback with these membrane separation processes is formation of polarization films and residue which may produce bacteria and causes fouling [21].

3.2.1 Reverse osmosis (RO)

RO desalination processes are based on the osmosis phenomenon, that is, the osmotic pressure difference between the saline water and the pure water is used to remove the impurities from water. [22]

It is a pressure driven process in which a feed stream runs under pressure through a semi permeable membrane that separates two aqueous streams, one high concentration of salt and other low concentration of salt. As the applied pressure is greater than osmotic pressure water will pass through the membrane but salt is retained. This gives us pure water which can be utilized for domestic as well as industrial purpose [22].

3.2.2 Nano filtration (NF)

The Nano filtration (NF) membrane is a pressure-driven membrane process having properties central to reverse osmosis (RO) and ultra filtration (UF) membranes.

Its main advantages are high flux, low operating pressure, comparatively low investment with low operation and maintenance costs. These advantages have increased the applications of NF worldwide [23]. NF process has become economically more attractive that traditionally used high pressure RO system.

3.2.3 Electro-dialysis (ED)

Electro-Dialysis process is based on the principle of electrochemical separation in which ions are transferred through ion exchange membranes by using direct current (DC) voltage. A driving force is used to transfer ions from the source water through cathode and anode to a stream of concentrate wastewater, creating an extra diluted stream between anode and cathode. ED removes dissolved solids, as per their electrical charge, by transferring the saline water ions through an electrically charged semi permeable ion exchange membrane [24].

4.0 Solar Distillation

As can be seen in the above paragraphs, the cost of running various desalination processes is on the higher side due to high energy cost of the evaporation process. Solar distillation process uses the solar energy which is free and renewable and that looks very attractive. Solar Desalination systems can be broadly classified as Solar Stills and Humidification dehumidification (HDH) desalination.

4.1 Solar stills

It is probable one of the oldest method of water desalination. Solar Still is a simple device which works on the principle of greenhouse effect. It is made of an airtight insulted sink covered with tilted glass sheet. Solar radiation is made to pass through the glass and is absorbed by the saline water. On heating water starts evaporating and it condenses on glass sheet. This condensed water flows downward due to gravity and collected in a trough [25].

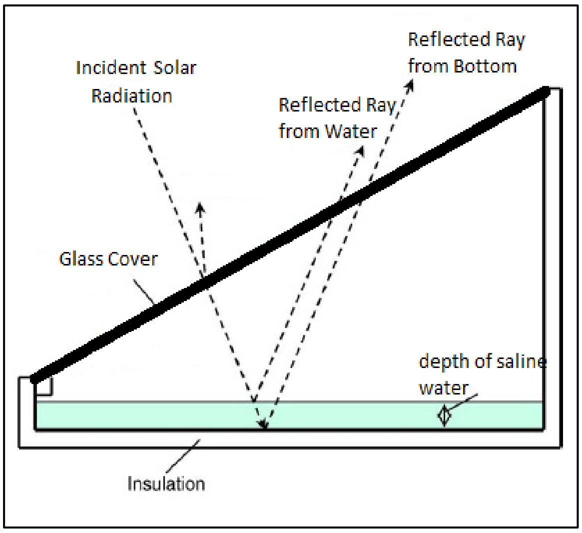
Fig-1 shows a simple schematic diagram of solar still. This is a very basic design of the solar still.

Incoming solar radiation is very important input variable for solar stills [26] . Solar radiation consists of beam and diffuse constituents and both have different optical properties while falling on a surface [27]. While beam radiation travels in straight line to the earth, the diffuse radiation comes from the whole sky dome.

The azimuth angle and altitude of the sun influence the amount of solar radiation reaching the surface in case of beam radiation but in case of diffusion the surface's exposure to the sky determines the incident solar energy [28-29].

Solar Stills are classified into two types as active or passive. Active stills use an additional external thermal energy source such as waste heat or solar panel a boiler to aid heat addition to the salty or brackish water [30]. In passive still only solar energy is utilised to heat the saline water inside the silt box [31]. The efficiency of the active system is reported higher than that of a passive still but the value is controlled by system configuration and does not depend much on meteorological conditions [32].

Fig 1: Schematic Diagram of Solar Still



The solar stills can have various designs largely due to variation in shapes. Solar stills as reported in the literature can by of different types such as conventional Solar Stills, Conical Solar Still, Vertical Solar Still, Inverted Absorber Solar Still, Single-slope Solar Still with Passive Condenser, Double Condensing Chamber Solar Still, Multiple Effect Solar Still and Multi-Wick Solar Still [32, 33, 34].A classification of solar still by Shankar and Kumar, 2012 is shown in figure-2 [35].

Solar still system can be modelled by energy and mass balance equations. These energy and mass equations are time dependent as solar energy depends on the time of the day [36]. Efficiency and performance of solar stills can be measure like other thermal systems.

Efficiency can be defined as the ratio of the evaporative rate of heat transfer from water surface to glass cover to the solar radiation intensity. Solar still system performance is defined as the ratio of desired output to the required input. Desired output here is identified as distilled water and input is solar energy collected by solar still [37].

4.1.1 Summary comments on solar stills

A review of the work of a number of previous researchers shows that the performance of the solar still depends on design and operating parameters. The performance of the solar still can be improved by number of methods such as by increasing the amount of thermal energy input by the use of reflecting concentrating mirrors or with the help of external heat source. The performance of the solar still can also be improved by increasing the evaporative surface area by using the wicks or sponge cubes of charcoal. Beside this low depth of saline water and low ambient temperature also increases the production of distilled water from the solar still.

4.2 Humidification dehumidification (HDH)

Humidification-dehumidification (HDH) desalination is a relatively new desalination technique based on heat and mass-transfer methods. This method consists of first evaporating the saline water into dry air in a humidifier. These water vapours are then converted to fresh clean water by the process of condensation in a dehumidifier.

As this system operates on a lower operating temperature than the solar still it becomes a suitable method to be used with solar energy [38]. Advantages of running with solar energy coupled with low operating temperature makes it a suitable candidate for desalination in remote rural area or desert areas [39].

Modern HDH systems are optimized by waste heat recovery from condensing water for preheating the incoming water source.

A new hybrid solar desalination system is also in use which is combination of HDH and single stage flashing evaporation unit [40].A large number of studies theoretical as well as experimental had been conducted on the HDH desalination systems.

Many methods are used to classify the HDH systems such as based on cycle configuration as closed air open water, closed water or open air open water systems. HDH systems are also classified on the basis of type of energy used such as thermal, geothermal, solar or hybrid systems. HDH systems are classified into air heated or water heated systems depending on the stream being heated [41].

4.2.1 Summary comments on humidification dehumidification desalination

The humidification- dehumidification desalination process HDH is a method of choice for far flung and desert areas where demand is decentralized. Water desalination capacity of HDH is in between conventional and solar still but it can be operated solely on solar energy. The operation and maintenance of HDH desalination plant is economical and simple.

The complicated effects of water and air on the performance can be studied and they will be useful for design and optimization of future HDH desalination plants.

5.0 Conclusions

Solar desalination is future to fulfil the ever increasing thirst of mankind with rapid increase in population and industrialisation. It is attractive as it uses renewable source of energy and it is environment friendly. Solar desalination systems can be used for small to large desalination requirements. This review has considered conventional methods of desalination as well as solar desalination. Special attention is given solar desalination. In solar desalination solar still is low efficiency technology and but well established. HDH desalination system powered by solar energy is under lot of investigation by researchers as it is more efficient and simple to operate. HDH systems are more useful for remote areas where demand for clean water is decentralised. It is evident that, in the coming decade solar powered desalination methods will be more and more popular due to their low operating cost and environment friendliness.

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