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A Review on Solar Desalination System

Swaraj V. Sakharkar[1], Amol D. Pitale[2]

[1]Student, M.Tech. Heat Power Engineering, G. H. Raisoni College of Engineering, Nagpur, India- 440016

[2]Professor, Department of Mechanical Engineering Department, G. H. Raisoni College of Engineering, Nagpur, India- 440016

Abstract: ***Desalination is a most promising method to produce potable water. Due to unavailability of fresh water & depletion of fossil fuels, human being move towards renewable sources of energy. In addition, the pollutants released from burning fossil fuels may harm the environment as well as human being. Therefore, instead of conventional desalination system, which uses fuel as a thermal source, solar desalination is the best way to generate potable water. Researchers works on the commercial use of solar desalination system due to limitations of unavailability of solar radiation consistently. Desalination system runs on solar may generate more potable water at low cost. This review presents the various types of solar desalination.***

Keywords: Desalination, potable water, solar collector, solar pond, photovoltaic (PV)

1. Introduction

The trend of using renewable energy sources in power generation plants carried out in the world for reducing greenhouse gases emission from fossil fuels. Tidal wave, geothermal power, biomass, wind and solar are renewable energy sources which are presently used for power generation. It is extremely expected that quick development of renewable energy sources will result cheaper worth of energy value within the close to future.

Presently world energy sources are highly dependent on fossil fuel such as coal, natural gas and oil that contribute 59.26% as compared to other sources. Other sources are nuclear which contribute 1.95%, renewable energy source contribute 12.91% of overall energy sources. The highest contributor of renewable energy sources as shown in figure 1a is hydropower, which contribute 16.52%.

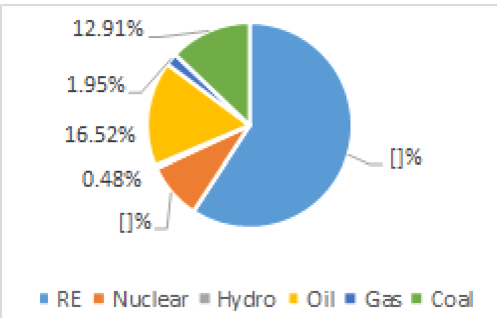

Figure 1: Scenario of Energy Sources in World

The most necessary component in life on globe for development is water. According to the World Health Organization (WHO), at least one billion people unable to get clean and fresh water, and about 41% of Earth's population live in the semi-drought areas, and this population may rise up to 3.5 billion by the year 2025[1,2]. India receives about 100-125 cm of rain per annum, which is unevenly distributed. Due to increase in population and continuously change in climate leads to rise in demand of fresh water. One solution to these problems is desalination which is known to remove excess salt and minerals from sea water. Desalination is carried out by different types of processes i.e. multi-stage flash, multi-effect and membrane based on reverse osmosis desalination which is now using commercially[2]. Following figure shows the operation of desalination cycle which is divided into different parts as shown in figure 2.

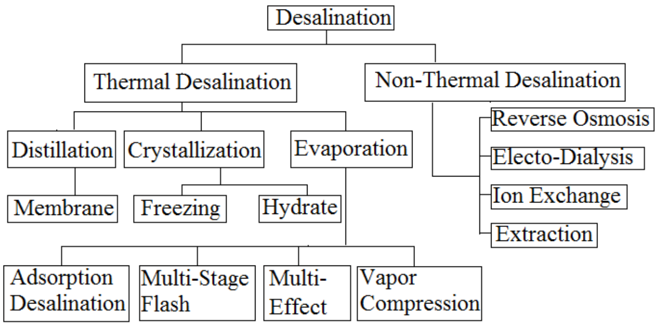

Figure 2: Classification of desalination

2. Solar-Based Driven System

2.1 Solar driven MSF

MSF is the second most popular desalination technique after RO system which is used where large amount of water has to convert into potable water. It requires power from external source which consume more energy as well as require large thermal energy. Fig shows the multi stage flash system with power source and solar collector. Salt water is fed through condensing tubes which is preheated as well as condenses the steam which is flashed in the flash chamber. The brine which is heated by renewable source of energy enters the flash chamber. Some part is flash due to higher temperature of brine than temperature at vacuum pressure of flash chamber. Due to the danger of scaling the top saline solution temperature is constrained to around 110^0C[3].

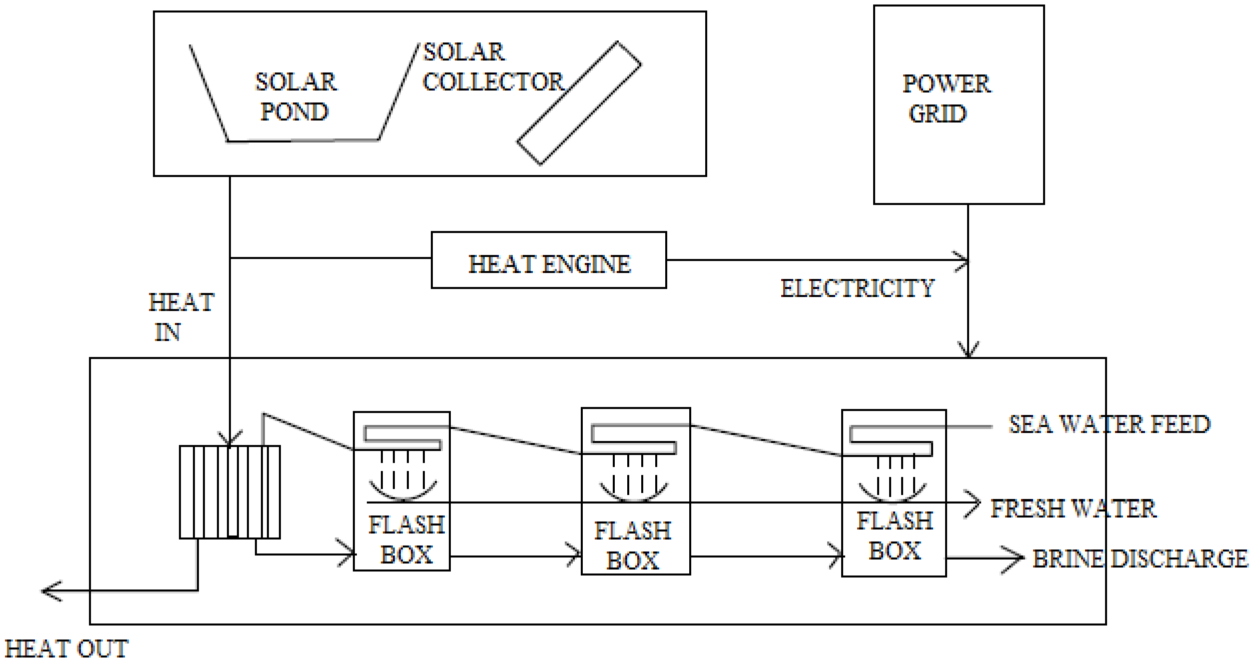

Figure 3: Solar MSF System

2.2. Solar driven HDH System

The phenomenon of rainfall is very much alike to HDH process. HDH desalination process is a flexible, reliable, cost-effective as well as free from environmental pollutants. Figure shows a diagram of HDH desalination system consists of humidifier, dehumidifier & solar collector placed between humidifier and dehumidifier to heat the air. Air at ambient temperature enters the humidifier in which it mixes directly with water.

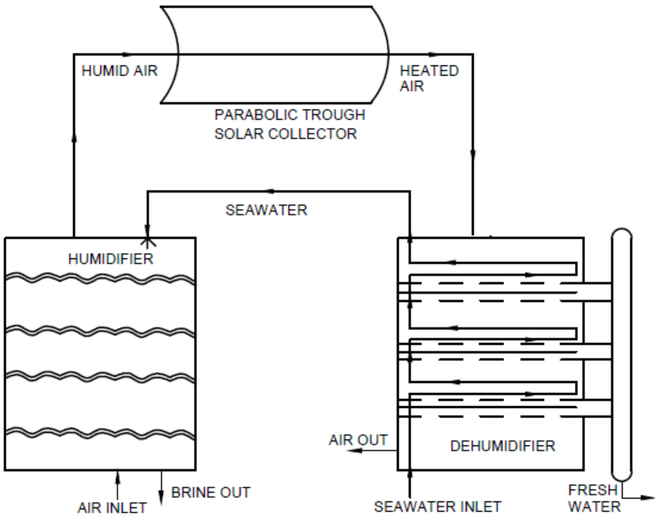

Figure 4: Solar HDH System

Humid air then moves through solar collector resulting in hot humid air. This hot humid air is allowed to dehumidifier for good condensation due to temperature difference between salt (sea) water and hot moist air. Hot water comes out from dehumidifier recovers heat from hot air and heats up the cold air in humidifier[4].

2.3 Solar driven RO system

Reverse Osmosis process drives on pressure in which pressure difference is more than osmotic pressure is apply oneself to semi-permeable membrane. The main parts of RO system are

1) Pre-treatment
2) High pressure pump
3) Membrane Assembly
4) Post-treatment

Pre-treatment section contains filter for filtration of particulate, chemical addition etc. Membrane section contains semipermeable membrane through which saline or brackish water is permit to pass under high pressure with the help of high power pump. Post treatment consists of correcting the pH of water as well as chlorinate the water for removing the impurities.

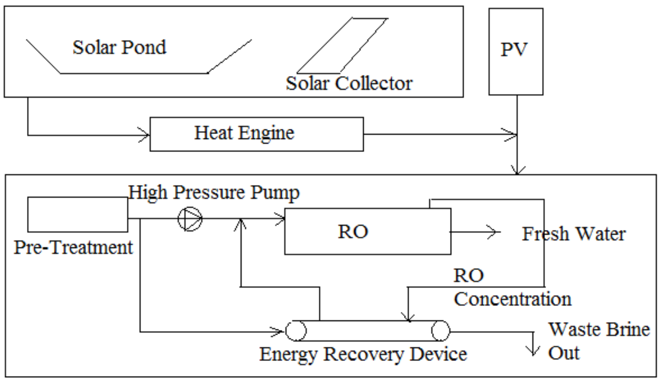

Figure 5: Solar Reverse Osmosis System

RO is the most favourable system in terms of capacity. Energy consumption total depends on salinity of water. PV panels are used for requirement of electricity or solar collector or solar pond for mechanical energy to run the system. The requirement of an RO system is that the osmotic pressure should be greater than 25 bar[5].

2.4 Solar still

Solar still is the easiest and simplest method to produce purified water for a daily need. It consists of a basin with a cover at its top of material such as glass. The basin is blacken so that maximum quantity of solar energy be absorbed. Saline water is feed onto the blackened basin which evaporates after transport of solar energy from the top cover to the basin water.

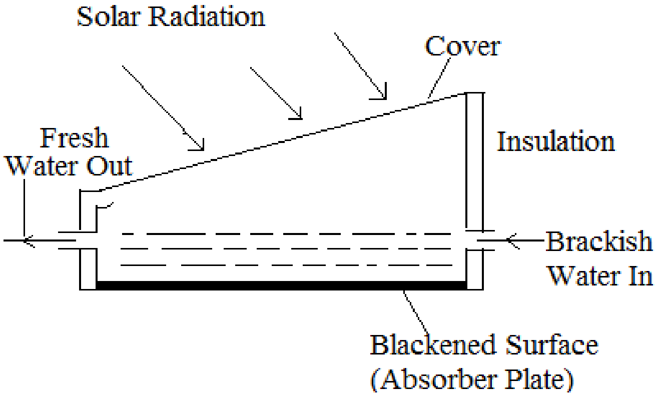

Figure 6: Solar Still

This condensate glides in the lower end of the cover under gravity. After which this distilled water is use for further use. The output of solar still is influence by many factors such as ambient temperature, slope of cover, material selection, salt concentration, temperature of water. Normally the production of fresh water is lowered due to loss of heat which is found to be 4-5 L/m^2/day[6].

2.5 Solar driven MED

Thermal energy from source is use to heat up the seawater in the initial stage and the resulting vapour is used to heat up the water in next stage because further stages are at low temperature and pressure. Seawater or brine is use to cool the vapour. The energy use for MED of seawater is 6.5-11 kWh/m^3[5]. MED has various configurations namely: forward feed, backward feed and parallel feed.

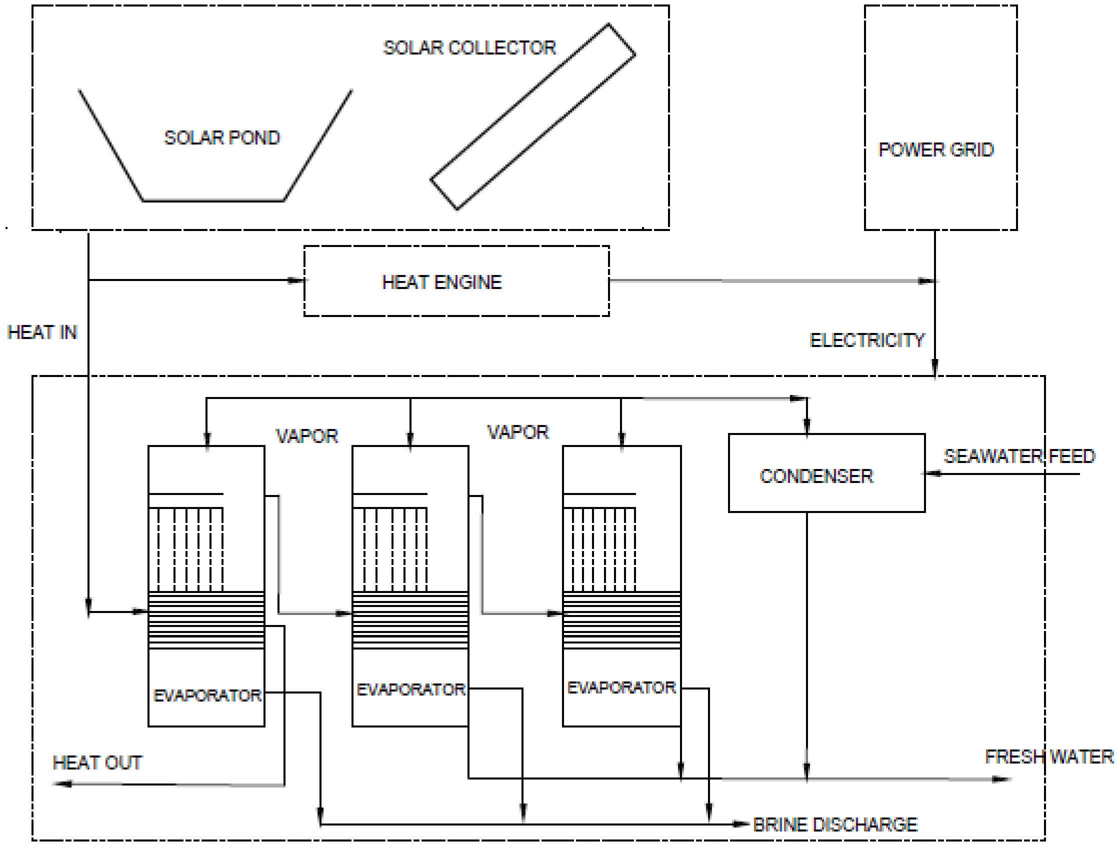

Figure 7: Solar MED System

2.6 Solar driven electro-dialysis

It works by passing a flood of salty water between two cathodes with inverse charges. The anodes haul the broke down salt particles out of the water, leaving freshwater at the central position of the stream. At that point, a progression of films isolates the freshwater stream from the salty one. This procedure is considerably more productive than procedures like invert osmosis. Moreover, very little vitality, all of which can be from sun powered boards, is required for this procedure, making it earth manageable.

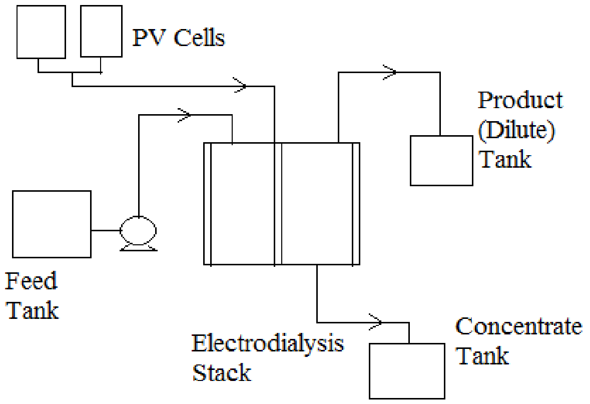

Figure 8: Solar Electro-dialysis System

This is especially valuable in nations that do not have consistent access to framework control sources. Necessity of energy of system is proportional to water salinity, so the feed water salinity should not be more than 6000 parts per million of salts. Salinity of feed water less than 400 parts per million is not appropriate due to lower conductivity[7].

2.7 Solar adsorption desalination system

Working principle of solar adsorption desalination system are as follows. When the saline water is fed into the evaporator, it flashes the water into vapour at very low pressure by applying the vacuum to the system. The vapour then travels through the adsorber bed where moisture of water vapour adsorb by the silica gel present in adsorber bed.

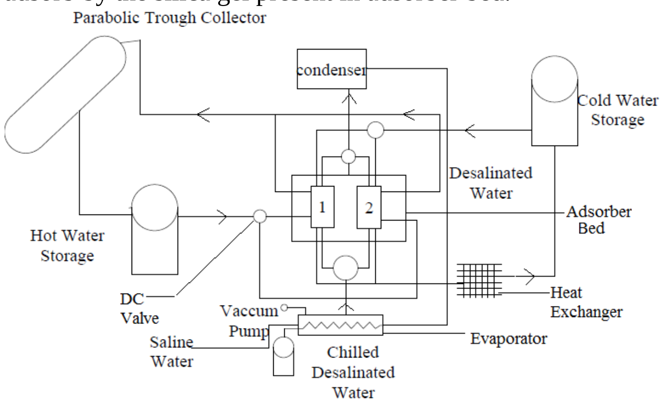

Figure 9: Solar Adsorption Desalination System

The heat extracted during adsorption will diminish by the cold water distributed from water jacket of adsorber bed. The moisture adsorb by adsorbent will release from it when the hot water distributed through the water jacket. The vapour will then pass across the condenser where they condensed and the fresh water will produce. Number of bed increases for reducing the period span of system[1].

3. Literature Review

3.1 Solar collector

G. Jims John Wessley[8] et al., performs experiment on flat plate solar with two pass flow arrangement. They studied the effect of velocity of atmospheric air and atmospheric temperature on water temperature. The gain in temperature found in noon around 64°C which is maximum while the solar radiation is recorded as 932.651W/m^2 with an overall efficiency of 43.7%. Above results obtained when ambient temperature becomes maximum as well as wind velocity becomes minimum because of the lesser heat loss.

Abbas Hakim Sima[9] et al., experimentally performs a desalination system by conglomerate with twin glass vacuum tube, heat pipe and parabolic trough collector. They studies the system performance by using various heat transfer fluids in between the twin glass vacuum tube and heat pipe. Heat pipe is located inside the twin glass vacuum tube collector. On adding water, oil and aluminium foil between the area of twin glass vacuum tube collector and heat pipe they found that,

a) When there is no water i.e. aluminium foil between twin glass vacuum tube collector and heat pipe, then the rate of heat transfer becomes low due to air voidage and unconstrained contact.
b) When water is used then the rate of heat transfer increases but it is constrained due to low boiling point. In addition, vapour generation along the contact surface restricts the heat transfer.
c) When oil is used the degree of heat transfer significantly increases due to the oil properties. In addition, vapour is not generated between the channels.

Riffat[10] et al., carried out the experimentation on V-trough solar collector. They construct the V shape concentrator by combining two parabolas and focal line to the base. They come with the result that the efficiency of this new collector is 38%, which is higher than other when water is heated up to 373K.

3.2. Desalination Technology

3.2.1. HDH desalination system

Fahad A. Al Sulaiman[4] et al., develops a mathematical model of open water, open air HDH desalination system for different arrangements and the gained output ratio. One of the arrangement is that the solar collector used as an air heater fixed halfway in evaporator and condenser which gives the gained output ratio of 4.7 which indicates better execution and higher efficiency whereas in other arrangement air heater is fixed ahead of evaporator which gives a gained output ratio of 1.5.

A. A. Sabaneh[11] investigate an HDH desalination system using tilted solar heater. In this work two fold pass solar air heater with double glass cover of evacuated type, which is tilted to reduce the loss of heat, heats ambient air. Two fold pass is used to heat the ambient air two times. Due to this arrangement they found 7% increase in productivity than double fold pass solar air heater and 39% than flat plate double fold pass solar air heater.

3.2.2 Multi-stage flash desalination system

Edward K. Summers[12] et al., investigates a cycle performance of multi-stage flash using membrane distillation based on vacuum. They replace the flash chambers with membrane distillation. By using membrane distillation, vapour can be preheated in the condenser by lowering the pressure in the successive stages.

Shaobo Hou[13] et al., optimize multi-stage flash desalinating for performance using pinch technology. Pinch technology is an method which identifies the energy efficiency graphically. They simulate three different conditions,

a. ejection of fresh water not in middle stage
b. ejection of fresh water in every stage
c. ejection of fresh water in every 5 stages

By keeping temperature difference of stage and pinch same i.e. 2K, the gain output ratio of first situation is around 17.5 while the gain output ratio of second and third situation comes around 9. They also found that the gain output ratio depends on the combine effect of temperature difference of pinch point and stage as well as the working temperature of multi-stage flash system.

Jims John Wessley[14] et al., experimentally investigate the performance of small scale flash evaporation desalination system with respect to input parameters such as evaporator pressure, brine inlet temperature, feed water flow rate. They found that with an evaporator pressure of 800 pa system is able to generate 4 l/h of potable water. Potable water rise by 30-50% with decline in evaporator pressure and an rise in 20-35% when the intake brine water temperature is raised. Also 10% rise in output is obtained by raising the feed water flow rate.

Chung Hanshik[15] et al., performs the theoretical computation which compares the specific energy consumption by elevating the top brine temperature, increases the consumable water generation and reduces specific energy consumption i.e. temperature rise by $10^{\circ}C$ increases the water generation rate by 15.8% as well as 6.4% reduction in specific energy consumption.

3.2.3 Reverse osmosis desalination system

Clark C. K. Liu[16] et al., design a RO desalination system runs on windmill. This system comprises of windmill system, which is taken as multi-vane windmill, which provides high torque at start up, flow/pressure stabilizer to stabilize the flow according to pressure requirement, RO unit. The requirement of low pressure can be achieved and delivered at a wind speed of 4.5 to 9.0 m/s. At 5m/s wind speed the feed water can be kept at 13 l/min flow rate, which is efficient. The recovery ratio and rejection rate comes around 20% and 97% respectively.

Murray Thomson[17] et al., design an reverse osmosis system driven by photovoltaic without batteries. They do not use batteries because batteries containing lead acid degrade rapidly which costs high for maintenance and removal. Instead of battery, they used the array of photovoltaic of 2.4 kWp with a tracking based on single axis, which increases yearly production of water, by 33%. The overall algorithm is developed by CREST. They also found that cost of producing fresh water comes around £2/m^3.

3.2.4 Solar Still

Mohammed Farid[18] et al., evaluate the performance of solar still which contain single basin. They carried out the performance in terms of production and efficiency of still. They found that,

a) Fall in water depth increases the efficiency
b) Increase in velocity of wind decreases the productivity of still with a greater value.
c) The efficiency of solar still is independent of incident solar radiation. It increases with decrease in diffused radiation.
d) Productivity increases with increase in ambient temperature.

Hitesh N. Panchal[19] et al., carried out the performance of solar still having double basin. Three conditions are used to estimate the performance,

a. solar still containing double basin
b. vacuum tube couple to solar still containing double basin
c. solar still containing double basin with black granite pebble

They found that, on using black granite pebble in solar still increases the fresh water output to 9% while using vacuum tubes with black granite pebble in solar still increases the output of distillate to 65%. In addition, on using vacuum tube output of distillate increases to 56%.

3.2.5 Adsorption desalination system

Wu[20] et al., develops a model for adsorption desalination system. They found that the water generation rate is a component of period span. Water generation per period reduces over the few initial period before going up against a relentless esteem. This reduction is because of inadequate desorption of water from silica gel. The period span which water generation by adjusting number of period along with level of recuperation from adsorbent. The ideal period span obtained by number of period as to restrict high usage of silica gel.

S. Mitra[1] et al., creates a lumped model by utilizing preservation of energy. These equations are solved for evaporator, condenser and adsorber bed. They found that temperature swing and exchanging time is fundamentally quicker than that amid adsorption and desorption forms. It ought to be noticed that sensible heat exchange to the bed is undesirable from COP viewpoint does not commitment to adsorption/desorption prepare. In this manner a proficient adsorber configuration ought to have least warmth mass. Also bed pressure at the preheat process end during exchange time is same as the operating pressure of condenser which is 12.5 kpa.

Kyaw Thu[21] et al., introduce an execution of an adsorption desalination plant with different number of beds. The tried results are computed as far as key execution parameters. They found that highest possible usable water generation per tonne of silica gel is around 10 m^3 although analogous performance ratio is 0.61. To attain accomplish most extreme water generation at lower heat source temperature, more extreme period span is required.

P. G. Yousef[22] et al., numerically researches the impact of evaporator and condenser temperatures on the performance of adsorption period for the generation of consumable water and cooling impact. They found that water generation and specific cooling capacity increases with decline in condenser temperature and increase in intake evaporator temperature. Experimentally they achieved consumable water generation of 10 m^3/tonne silica gel/day and SCC of 77 Rton/tonne of silica gel.

Bidyut Baran Saha[21] et al., develops and performs an advance adsorption desalination cycle in which the energy rejected by condenser used in evaporator for saline water. Experimentally they found that greater water generation rate attained at both lower cooling temperatures as well as increasing cooling flow rates. Also at 70°C hot water intake temperature, SDWP of 9.34 m^3 and PR of 0.77 is achieved as well as at 50°C SDWP of 5.5 is achieved. The best period span of existing system computed to be lesser as compared to other cycles.

3.2.6. Multi-effect distillation system

Young Deuk Kim[23] et al., simulate a model mathematically for transient behaviour of multi-effect distillation system driven by solar. Solar system comprised of collectors of evacuated type. This system contains storage tank of capacity 280 m^3, heater, collector of evacuated type of 849 m^2 and condenser of six effects. They found that yearly efficiency of collector drops from 57.3 to 54.8% and solar fraction drops from 49.4 to 36.7% resp. with temperature of heating water from 80 to 90°C. Due to this, the PR increases from 4.11 to 4.13 while generation rate of water increases from 0.18 to 0.21 kg/s and GOR comes about 3.4.

Jimmy Leblanc[24] et al., design a solar MEE desalination system runs on solar pond using model. They design the system using model to compute the technical and economical consideration. They found that the MEE powered by solar pond with 3 effects, still have a low cost as compared to reverse osmosis with PV as well as reverse osmosis powered windmill. The present system with 3 effect requires 900 kj to generate a litre of potable water which convert 56% of saline water into potable water has a capacity of 2300 l/day of potable water.

3.2.7 Electro dialysis desalination system

O. Kuroda[25] et al., proposed a system which uses small battery to use the current directly from PV to run electro dialysis system. For this a storage system is proposed which is known as partially desalinated water which is used when the power source supplies varying current. When PV supplies large amount of power to system. Saltwater is converted to partially desalinated water and when get small amount it get converted into potable water.

3.3 Cost Economics

Fiorenza[26] et al., studied cost economics of desalination system driven by solar and photovoltaic between capacities of plants from 500 to 5000m^3/day which they compared with conventional desalination system. They also studied various factors influence on cost of various parameters of plants. After study they found that cost of solar desalination plant i.e. solar thermal multi-effect evaporation or photovoltaic reverse osmosis of 5000m^3/day capacity comes about 2US$/$m^3$. It is greater than conventional system but solar based system compensate the impact on environment by conventional.

P. G. Yousef[27] et al., carried out the analysis of various desalination technologies and compares it in terms of energy requirement, impact on environment and cost incurred in various component of plant. They found that adsorption desalination emits low CO_2 i.e. 0.6 kg/m^3. The total cost incurred in adsorption desalination is about 0.2 $/$m^3$ even with salinity of feed water around 67000ppm which generates water of low salinity of 10ppm. In addition the requirement of energy for adsorption desalination is also low i.e. 1.38 kWh/m^3.

4. Conclusion

In this paper, a review of various desalination systems runs on solar energy is presented. The water requirement in world is increasing day by day so the solar energy is continuously gaining more attention due to its consistent supply of energy without any impact on environment. Cost of water is determined by the energy cost which is the most essential element when the water is formed from desalination system. From literature it was concluded that reverse osmosis and multi-stage flash desalination system is the favorable system in terms of large scale production but as we increases the salinity then the membrane periodically changes and also cost increases. However, adsorption desalination system can generate potable water of less than 10 parts per million with a less environmental impact of 0.6 kg/m^3 and overall costs around 0.2 $/$m^3$ with salinity of 60,000 ppm. In addition, the V- trough solar collector is more efficient in comparison with flat plate collector and compound parabolic collector at an working temperature of around 120°C.

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