International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 6, Nov-Dec-2021, ISSN (Online): 2395-566X

A Review on Design & Development of a Solar Pond and CFD Modeling

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Abstract- Evaporation condensation process for converting saline water to fresh water is the widespread and the oldest technology used for desalination. In this process, the saline water is heated using a heat source to the evaporating point (here the solar pond) and thus this steam that is evaporated leaves behind the salt content present in the saline water. The evaporated fresh steam is then collected and then condensed to give us the fresh water. This fresh water is then again distilled to lose the remaining ppm thus making it drinkable. This technology is cheaper than the others since it doesn't have any other energy costing elements other than the heat source and condenser. Thus, by using a solar pond as the heat source we are reducing the cost of the desalination process. Accordingly, a review on design & development of a solar pond and CFD modeling has been done.

Keywords- Solar pond, evaporation, condensation, desalination.

I. INTRODUCTION

A solar pond is indeed a solar energy collector which resembles a pond and is often rather large in size. A form of solar energy collector are using a huge, saline lake as a flat plate collector, absorbing and stores solar energy in the pond's warm, bottom layers. Those pond images are fascinating. Solar ponds can be natural or man-made, although most of the ones in use today are artificial. [2]

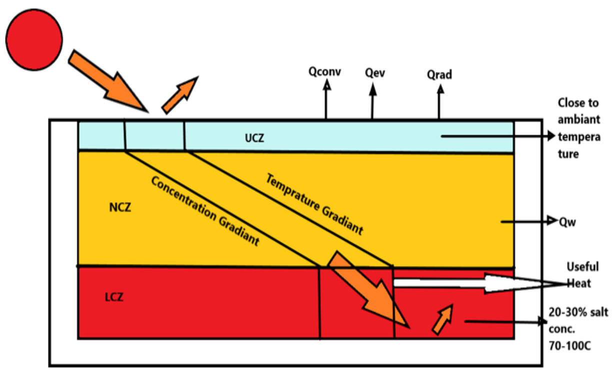
A salt-concentration gradient in the water is indeed a critical feature of solar ponds that allows them to function efficiently as solar energy collectors. This gradient causes intensely salivated water to concentrate at the pond's bottom, the concentration diminishing as it approaches the surface, resulting in cold, fresh water there at pond's top. The bottom of both the lake has a collection of saline water known as that of the "The freshwater top layer was defined as the "surface zone," whereas the storage zone is recognized as the "storage zone."

The "storage zone" is many meters deep in the overall pond "with a depth of one or two meters. While sunlight could indeed reach to the pond's bottom if indeed the water is murky, these ponds should be clean in order to function properly. "As sunlight falls on these ponds, the majority of the incoming light reaches the bottom," heating up the "storage zone."

"This newly heated water, on the other hand, cannot ascend, preventing heat loss upwards. Since saline water was heavier than that of the fresh water on the surface of the pond, this can rise, and thus the upper layer prevents convection currents from developing. As a result, the pond's top layer works as just an insulating blanket, preventing the major heat loss process from of the storage zone. The bottom of the pond is heated to extraordinarily high temperatures - about 90°C - while losing any heat. This temperature is high enough just to start and run an organic Rank in cycle engine if the pond is now being utilized to generate electricity."

II. SALINITY GRADIENT SOLAR PONDS

"A SGSP is a big saltwater pool that absorbs and stores solar thermal energy. The pond is divided into three sections: the upper convective zone (UCZ), the lower convective zone (LCZ), as well as the non-convective zone (NCZ) (NCZ). Fresh or low-salinity water generally floats on top of the NCZ in the UCZ.



"Figure1: Zones of the SGSP - the UCZ, which loses heat from the surface by convection, evaporation and radiation; the NCZ, with concentration and temperature gradients, and no convection currents; and the LCZ, the hottest layer with the highest salt concentration"

The salt solutions in the NCZ grow in concentration (and hence density) as you go deeper. There is no convection in this layer because the concentration stratification prevents convection. The NCZ floats atop the third layer, the LCZ (or storage zone), which has the greatest salt content (near saturation) and traps and stores solar energy. A schematic of the SGSP is illustrated in Figure1."

"Figure 1 shows that when the solar radiation falls on the surface of the pond, some of this radiation will be reflected and some will penetrate inside the pond. When fresh water is heated, it becomes less dense than the cooler water above it, and convection begins." Because the SGSP's NCZ prohibits convection reaching spreading throughout the whole pond, "convection occurs independently in the UCZ and the LCZ.

Natural convection will indeed be inhibited in the NCZ due to the salinity gradient." The salinity of the NCZ rises because it progresses from top to bottom. Whenever a layer is heated, the density of that layer decreases significantly. This would, however, stay heavier than the one above it. Convection, which really is frequent in fresh water, will be prevented by this operation. The NCZ serves as a slab in this scenario.

"The NCZ lowers heat loss from the LCZ greatly, and heat only travels upward through conduction. As just a result, the temperature of the LCZ rises to 100 °C or even higher, whereas the UCZ remains at a lower temperature, near to ambient. The heat stored inside the LCZ can then be retrieved and used for a variety of purposes."

In areas with little rainfall and poor runoff, evaporation suppression is just a huge undertaking that contributes significantly to water conservation. Evaporation is influenced by a number of elements, including the body of water's surface area, ambient temperature, wind speed, and relative humidity. Evaporation leads inside the loss of both heat and mass, so eliminating it is important and will improve the solar pond's effectiveness.

The temperatures of any and all three layers are significantly affected by the thickness of both the SGSP layers. The UCZ must be maintained as thin as feasible, whereas the NCZ should be no more than 1-2 m thick. The ideal LCZ thickness is determined by the pond's purpose and operating temperature.

The SGSP faces a number of challenges, including the NCZ's instability and significant amounts of surface evaporation. "This research has looked at these issues, notably successfully experimenting with a thin layer of paraffin on the pond's surface to prevent evaporation. Because solar gel ponds were proposed as a solution to problems, their viability has just been investigated and compared to SGSPs in just this study. A gel layer was utilised to replace the NCZ in the gel pond."

Salt dispersion from of the LCZ to the UCZ has been virtually eliminated. However, it appears that now the present implementation will be limited to trials in labs and tiny pilot plants because just like the high cost of chemicals and building challenges.

II. CLASSIFICATION OF SOLAR PONDS

Solar ponds may be divided into two categories: convective and non-convective solar ponds. To illustrate the types of solar ponds, a simple schematic (Figure 1.2) might be made.

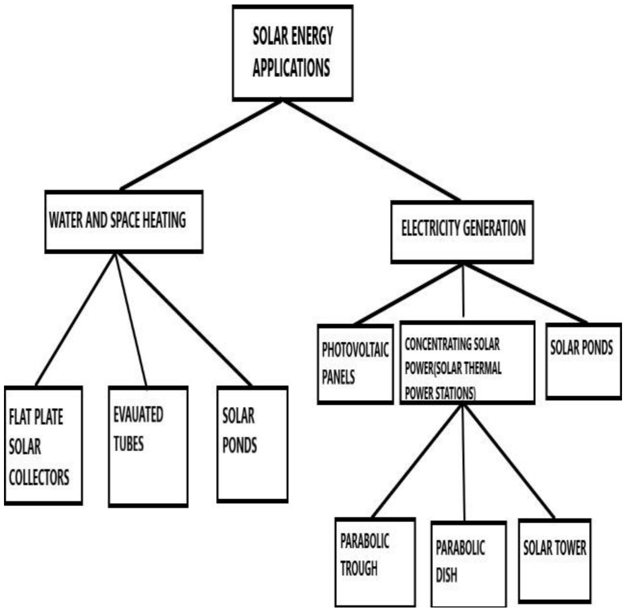


Fig 2. Diagram showing the different types of solar ponds.

"Convection is widespread in this sort of pond by necessity, because they're often shallow. A salt-free pond is indeed a modest solar pond. Shallow ponds have the benefit of being able to be placed on rooftops if indeed the building construction is sturdy enough. The technique is thought of as a batch process, with just a warming operation every day and a storing activity at night.

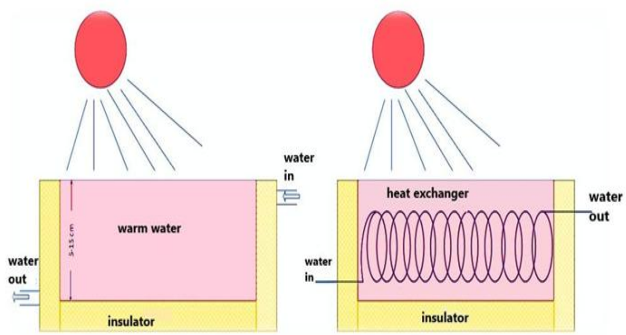


Fig 3. Two schematic diagrams of the Shallow pond, (a) a simple shallow pond (batch process), (b) a shallow pond has a heat exchanger to circulate water for the heat extraction (closed process)".

International Journal of Scientific Research & Engineering Trends
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"Figure 3 shows that the make- up of a shallow pond is not complicated, and the essential parameter it needs to function is the sunlight. Solar energy is absorbed and transformed to thermal energy through heating the water with in pond during day, as shown in Figure 1.4(a).

The hot water is moved to an insulated storage tank at night and when the absorption rate is near zero. The use of a coil heat exchanger in Figure 1.4 (b) shows how thermal heat is transferred."

III. PAST STUDIES

Panchal et al. (2020) [1] "the experimental investigation of a single-basin solar always with porous fins attached to the absorber plate was given. Experiments were carried out on a single-basin solar still with and without the addition of porous fins. Fins are commonly employed in solar stills to shorten water preheating time and achieve positive water and inner glass cover temperatures during the morning hours, resulting in increased distillate yield. As during week of May 2017, a series of tests were carried out in the Government Engineering College Patan during daylight hours. Standard instruments were used to monitor temperatures such as that of water, the inner glass cover, and solar insolations. According to the results of the trial, the distillate yield after fin attachment was 3.8 L, whereas the traditional solar still produced 2.67 L. Using porous fins in such a solar still resulted in a 42.3 percent increase in efficiency.

Adhikari et al. (2020) [2] discussed several pond design ideas and advises the adoption of a Pond-In-Pond (PIP) strategy to reuse purposes, wherein PIP is the combination of two types of ponds—anaerobic and aerobic. The findings of recent studies that used Computational Fluid Dynamics (CFD) to analyse a flow-diversion mechanism, as well as performance data from current PIP systems, demonstrate that now the PIP is a viable idea for wastewater reuse systems. The PIP system under investigation produced an annual effluent BOD of around 40 mg/L on average. The design of hydrodynamics in large-scale RPRs, according to Moreira, must be thoroughly addressed in order to decrease power consumption and improving mixing performance."

Anagnostopoulos et al. (2020) [3] provided In just this study, a CFD simulation setup was constructed in order to generate a fully adaptable model that can be used to any actual circumstance. A comparison of the findings obtained using an existing one-dimensional MATLAB model and the two- & three-dimensional CFD models generated from this study was also conducted in order to assess the improvement in accuracy and processing resources required. The two- and three-dimensional models are far more accurate than the one-dimensional model. These are therefore discovered to correctly assess heat loss to the environment; irradiance absorbed either by solar pond, and also the pond's thermal performance throughout the year. Two different geographical places have already been assessed: Bafgh (Iran) and Kuwait City.

Sogukpinar et al. (2020) [4] "A numerical examination of the temperature distribution of solar ponds in Turkey were performed and the results were compared to experimental data for a particular district. For this, a prototype salinity-gradient solar pond with square cross- section with insulated wall and with seven layers was modeled by considering previously conducted experimental studies, and then, numerical method was conducted by using Finite Element Method with commercial software COMSOL. The data for temperature & sun radiation came from the General Directorate of Meteorology, where they've been measured since 1927.

Using yearly average values of temperature and sun radiation data, a numerical computation was done. The model contains all options for estimating temperature distributions in the upper convective zone, non-convective zone, and heat storage zone, taking into account radiative, conductive, and evaporative heat losses. The highest temperature was computed at the conclusion of 600 hours of entire simulation and afterwards temperature stayed constant, according to numerical data. Because the pond's side walls and base are insulated by rock wool, a significant amount of heat loss was mimicked just at pond's top surface. Just one sun pond temperature stayed below 300 K in Edirne, solar pond temperatures in five provinces remained below 310 K, and solar pond temperatures throughout 31 provinces was calculated greater than 320 K, per the numerical analysis."

Panchal et al. (2020) [5] suggested the need for an SP to increase the production of a solar still (SS) by supplying hot water via the heat energy stored inside of it. This also demonstrates how shallow and small SPs may be used with SS to increase yield. This report also includes a list of future research projects on SS utilizing SPs. According to the present review report, the SP boosts the yield of both the SS.

Abu-Hamdeh et al. (2020) [6] provided a numerical simulation of the improved spiral pipe system used in solar ponds, along with experimental validation. The much more essential component of both the solar ponds because affects its effectiveness would be its piping system, that hasn't been adequately examined thus far. Grooving the spiral piping system's wall to enhance this field (which is considered to be placed at the lower convective zone (LCZ))" was adopted as an improvement mechanism. It is indeed worth noting that grooves are formed in an annular shape on the spiral pipe's wall at varying spacing in the revolutionary modification process.

Although the modifications enhance the amount of heat extracted from the pond, they also improve irreversibility to a somewhat level. As a result, numerous critical factors such as groove spacing, groove depth, flow rate, fluid type, and input temperature (Pr) was investigated to see how they contributed to entropy creation. Furthermore, the influence of those characteristics was assessed using multi-criteria conceptual designs such as ηW−S and NH to determine whether of Nu (or Q) or S'gen outweighs of another.

At different inlet temperatures (283 K, 303 K, and 323 K), 3 distinct working fluids, comprising water, ethylene-glycol, and therminol-55, were employed to cover a Pr range of 3.35–744. The results reveal that increasing the flow velocity and the depth of grooves, as well as reducing the pitch of grooves, enhances the creation of entropy. Whenever the depth of grooves is really the greatest and the pitch of grooves is the smallest, the maximum increase in NH is roughly 26%. When the inlet temperature rises, therminol-55 and ethylene-glycol were indicated, according to the findings. So when total performance of solar pond is at its greatest, it's a major competitive advantage as ηW−S=0.125.

S El-Sebaeya et al. (2020) [7] "presented multi-phase, three-dimensional CFD model, which predicts the performance of the solar still without using any experimental measurements, Dependent here on CFD model of solar radiation. Simulated water and glass cover temperatures, but also fresh water output, are compared to experimental values in Sheben El-Kom, Egypt (latitude 30.5° N and longitude 31.01° E). The simulation findings are found to be in good agreement with the measured data in the experiments. The daily simulated and experimental cumulative productivities of the single-slope solar still at a water level of 2 cm were determined to be 1.982 and 1.785 L/m2, respectively. Furthermore, at the measured water depth, the simulated and experimental daily efficiency are about 16.79 percent and 15.5 percent, respectively.

Yousafet al. (2019) [8] presented Diffuser design for evolution of solar pond and detailed research to overcome the effect of buoyancy in the stratified region and extend the range of plume emanated from the diffuser. Over the last few decades, diffusers of various designs and forms, including diffusers with round and rectangular outputs, have been used in solar ponds." Despite the fact that experts had found that semi-circular diffusers with rectangular slots are much more efficient, only limited study has been done using Computational Fluid Dynamics to corroborate those findings.

The focus of the study is on diffuser designs and comparisons, as well as computer examination of the influence on the originating flow. Various CFD modelling techniques from the Reynolds-Averaged Navier Stokes (RANS) family, including the semi empirical k-E model basis, have been examined in this study. Based on the finding, the best diffuser design enabling stratification in a salinity gradient solar pond was determined using the CFD approach that had only been explored on a small scale previously. This is what has aided in the development of a gradient creation and maintenance mechanism that is more efficient.

El Kadiet al. (2019) [9] "given the important criteria for achieving maximum efficiency levels are well-established salinity and temperature gradients. In the work, a high-fidelity model based on computational fluid dynamics (CFD) is constructed to predict the behaviour of the SGSP in hot climate regions. The model can mimic the double convective effect by concurrently solving the Navier-Stokes and energy equations. Brines of various salinities (i.e. 10%, 15%, and 25%) were employed to examine their impact on the formed salinity/temperature gradients. The simulation findings reveal that the three zones (upper convective, non-convective, and lower convective) were successfully established with generally constant salinity & temperature gradients. Nevertheless, pumping 10% saline brine into the lower convective zone (or storage zone) preserves the greatest storage temperature of roughly 79.2°C after a six-hour flow period.

Rabhy et al. (2019) [10] revealed a novel entirely transparent solar distiller that is meant to be incorporated into in the roof of an agricultural greenhouse to create desalinated water for plant irrigation using surplus solar radiation. To analyse the distiller's performance, a numerical approach is suggested. This method combines lumped models for various components of both the distiller depending on transient mass and energy balance equations with such a computational fluid dynamics (CFD) model to simulate the flow, heat transfer, and phase change of humid water and air with such a free surface within the distiller.

The predicted temperature variations of the glass and basin by the lumped model are used as boundary conditions for the CFD model to improve the accuracy of the water production estimations. The results of the lumped model and the coupled lumped–CFD model are compared with the experimental data from a transparent distiller test performed at Alexandria, Egypt.

The same average daily efficiency of 12.4% for both the experimental measurements and the coupled lumped–CFD model is shown." According to the verified numerical model, improving basin insulation could increase daily yield by about 22%. In August, the highest yield is expected to be 618.2 mL/day. Integrating transparent distillers onto a greenhouse roof may deliver 37.5 percent of irrigation water while also lowering greenhouse cooling system power consumption by 60%.

Muraliet al. (2019) [11] In simulating flow via a solar airborne heater and continuous flow into a rectangle shaped duct having artificially ribbed bottom least surface, numerical investigations have been carried out and findings are reported. The numerical analysis takes into account ribs with different cross-sections, such as triangular, semi-circular, rectangular, and arc in form. At the bottom of both the rectangular shaped duct, a constant heat flux boundary condition was utilised. “Heat transfer rates for flow through a rectangular shaped duct with such a flat bottom most surfaces were compared to ribbed bottom least surface values. Parametric variables include Reynolds number (2300-20000), relative roughness pitch (6.67, 10, 13.33), and relative roughness altitude (0.055, 0.073, 0.11).

When ribbed rectangular bottom extremity surfaces were compared to flat rectangular bottom more surfaces, heat transmission rates were reported to be greater. When compared to rectangular, triangular, and semi-circular ribs, arc shaped ribs provide a greater increase in heat transmission across the duct. When compared to a level surface, arc shaped ribs with such a relative roughness altitude of 0.055 as well as a relative roughness pitch of 10 increase Nusselt number by 1.66 times. Assuming relative roughness altitudes of 0.073 and 0.11, arc shaped ribs with the same relative roughness pitch enhance Nusselt number by 1.78 and 1.48 times, correspondingly.”

IV. RESEARCH GAP

From the literature review the following can be drawn as gaps in the current research work. “Along with its ability to provide high energy storage density and also its property to store heat at practically constant temperature towards the phase transition temperature of phase change material, latent heat thermal energy storage is an ever-popular method of storing thermal energy (PCM). Solid–strong, solid– fluid, solid– gas, liquid– gas, as well as the other side around is examples of phase changes.”

Most of the other studies on heat transfer enhancement have advised the use of high conductivity materials, but there has been no study on heat transfer enhancement employing expanded surfaces, such as fins. It might be a different approach in terms of increasing the heat transfer rate to the HTF, as well as successfully using heat that has been stored using phase change material (PCM).

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