

Solar pond as a low grade energy source for water desalination and power generation: a short review

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Abstract. Water and energy are thoroughly linked: water is required to generate, transfer, and use the lot characteristics of energy; and energy is demanded to extract, treat, and distribute water. Shortage in clean water deems as the main challenge facing the world as a result of the escalating in the energy consumption required for desalinating the sea/brackish water which increases costs and provokes on the marine life and environment due to the high concentrate solute produced from desalination plants. Solar pond is a reservoir of water with different salt concentration implements to gather and store the incident solar energy which it can be employed later on in different thermal energy applications, such as industrialized heating process, electricity power generation, farming crop drying and cooling of houses. In this paper a short but concentrated review of the literatures that dealt with the implemented of the solar pond to illustrate succinctly the historical background for the solar ponds as well as the most word-wide established solar ponds. In addition to the theoretical background of heat and mass transfer which governed the solar pond operation is presented and discussed.

1 Introduction

1.1 Water desalination and energy demand

Water and energy are strictly tangled; water is needed to transport and utilize all features of energy to some degree; and energy is needed for the extraction, treatment, and allocation of water, in addition to its gathering and treatment after use. Globally, need for freshwater and energy will remain to amplify over the coming years to meet the requirements of growing up populations, increasing economies, altering lifestyles and developing consumption models. Human communities have reliant on watercourses, meres and borehole waters for clean water necessities in household life, farming and industry. Nevertheless, the fast industrial development plus the globe's inhabitant expansion have become a result due to an enormous growth of requirement to the sweet water, together for domestic necessities and yields to give sufficient amounts of food. To add to this, the issue of contamination for canals, meres, and rivers due to industrial effluent and the sizable

quantities of sewage discharged. According to the universal scale, mankind created the pollution for the environmental resources of water is growing to be one of the greatest reasons for scarcity of the pure water as well as the drawback of unequal division. Water is demand to maintain of life, the significance of providing clean water be able to barely be overdid and supplying clear water is becoming a gradually more challenge in several parts of the world. In barren regions drinkable water is vastly insufficient and the establishing of a humanoid habitation in these regions intensely based upon how water availability. The foundation and prolongation of human has relied on water, water is the best unique of plentiful resources on our planet, occupying about three-fourths of the earth's area. Nevertheless, nearby 97% of water in the earth is salty water at the deep-seas, plus a little of 3% is sweet water. The tiny of this ratio for the earth's water that provisions utmost to the mankind and different creature's necessities – be present in ground water, meres, canals and rivers. The unlimited resources of water are the oceans, which have high salinity. It would be achievable for treating and solving of the water-scarcity issue by desalination of brackish and sea water; however, salts removal process

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from salt-water needs large quantities of energy which, whenever yielded by using fossil fuels, and that will generate chemicals which damage the environment. As a result, there is a necessity to use new methods friend to the ecosystem for the energy resources draw up desalinate saltwater. Water is one of the greatest profuse sources upon the earth, including around 75% of our globe area. The most of the world's aquatic is briny water inside oceans and nearly to 3% (approximately 36 million km³) is sweet water excluded in our planet poles (ice structure), borehole waters, meres, and water-courses, which provide largely of creatures demands. Approximately, 70% from this tiny 3% of the globe's pure water is iced up in glaciers, long-lasting ice included, ice, and permafrost. Thirty percentage of totally sweet water is underground and largely from it at deepness which severe to reach aquifers; ponds and water streams collected and comprise only a tiny in excess of 0.25% of all sweet water; lakes include maximum of it [1]. The scarcity in water turns into one of the main problems in the global, desalination is needed to meet increasing necessities for fresh water. It is expected that near to 70% of the earth residents will suffer water scarcity problems at 2025. [2–4]. Desalination technologies have been grown quickly throughout the earlier a number of years for desalinate a diversity of raw waters such as sea-water, brackish borehole water and industrialized waste-water [5]. Almost just 67% of the worldwide residents consume to clean; sweet and drinkable water [6]. In fact, lack of potable water is a worrying issue which is continuously raising, according to population increase with converts in weather circumstances. Currently, the worldwide requirement of drinking and clear water increases, besides ecological contamination due to fossil fuels, shortage of non-renewable supplies and economic crisis growth which lead to the further usage of renewable energy such as solar energy [7–13]. Water supply depends on a number of factors in the water cycle, comprising the amounts of rainwater, evaporation, the utilization of water by plants (transpiration), watercourse, and groundwater flows. It is valued that less than 1% of all clean water is existing for populations to consume. Globally, about 12 500 km³ of water are considered accessible for mankind use on a yearly basis. These quantities near to 6600 m³ per person in year. Based on the population increase, plans of developing and climate change, it has been assessed that the percentage of the globe's population living in countries with substantial water crises will enlarge from almost 34% in 1994 to 63% in 2025, including big regions of Africa, Asia and Latin America. This will influence their natural life and living [14]. Water is a valuable resource for maintaining life. The quantity total dissolved solids (TDS) computed as part per million (ppm, it usually indicated to as mg/l) calculates the salts concentration of the water. According to TDS measuring, there are commonly three sorts of water:

- Seawater: seawater comprises around 50 elements, where chloride corresponds to 55% from the overall mass of the dissolved salts. Even so, seawater saltiness is nearer to 35 g/l.

- Brackish water: brackish water is described as the water has a salinity range from 1.0 to 3.0 g/l. Even though the salinity for it is less than from seawater, but this is not acceptable to the drinking and other usages [15].
- Sweet water: sweet water encloses to TDS below of 1.0 g/l.

The desalination process is conceivable to the sea-water as supplying water with the saltiness nearer to 35 g/l, or for brackish water with saltiness from 1 to 10 g/l. On the other hand, effectiveness of the desalination process is varied because the thermal specifications for the water provenance than rely on the mass of salt contents. Brackish water (lower salt) requires a low energy for desalination than seawater [16]. The principal function of the desalination technologies is reducing the saline concentration of the water to convert it into potable water which utilized by humans. There are many technologies for desalination, which could be split to two major types, thermal and membrane separation processes. Selection of the technology is built on the operating and maintenance considerations, position, energy strength, capital costs, and water characteristic. Conventional desalination technologies produce more than 90% of desalted water in the world. In reverse osmosis membrane separation (RO); semipermeable and ion-specific membranes can be utilized to desalinate the sea-water. This technology requires the difference in pressure across the membranes; the membrane process is founded on separation preferably than distillation (even though membrane distillation is able to function too). Reverse osmosis membranes are essentially allow water to move across them, only a small percentage, about 0.4% for new membranes of the sea water salts, passes or leakages round closures. For drinkable water, agricultural usage, and commonly for industrialized purposes, this leakage value is satisfactory.

2 Energy demands and costs

Energy is necessitated for water providing. The various degrees of water purification are essential for several usages. Potable water normally needs to general treatment, and one time consumed, it demands to be treated once more to accomplish a typical safe for return to the ecosystem. Lots of these steps are consuming highly energy exhaustive. Some treatment procedures, such as ultraviolet (UV), spend comparatively small energy (0.01–0.04 kWh/m³). More advanced methods, such as reverse osmosis, need higher quantities of energy (1.5–3.5 kWh/m³). The costs of desalination are attached to the expenditure and amount of energy consumed in the process. Technologies variety from 1000 kWh/MG to 500 000 kWh/MG, habitually to make desalination the greatest energy-exhaustive water selection, although novel desalination technologies and procedures are dropping the energy intensity of desalination during the long run. The energy cost differs from 0.3 to more than 0.5 the total cost of desalinated water [17].

3 Desalination effects on the environment

Environmental problems associated with desalination are a main feature for the design and application of desalination

technologies. The ecological influence investigations are required to keep the environmentally sensitive regions. Any acceptable desalination project is likely to meet ecological rules such as cost effectual in the construction terms, process and managing, in addition to that costs related with observing and license costs. Several main environmental points contain on setbacks associated with the site of desalination projects and water intake, and concentrate controlling and removal [17]. Desalination plants produce two yields (pure water) stream and concentrated stream (reject/residual stream). Several exponents identify that cost effectual and ecologically –sensitive concentrate management could be major problems in the widespread wastage of desalination equipment. The suitable concentrate removal and erection procedures combined at design of plant can mitigate the R.O. reject concentration effect on the delivery water ambience and ground-water aquifers [17]. Desalination plants are able to have a secondary effect on the ecosystem as a result of various plants get the power from the regional network rather than of generating their private. The combustion for fossil fuels and raised energy utilization permits more atmosphere contamination and gas emissions to happen. Smoky releases from desalination smokestacks involve carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂). These atmosphere toxins could have a hurtful effect on the healthiness of public [17,18]. The massive quantities of chemicals that are deposited at the plants, these Chemicals leak hazards and need to chemicals storage away from housing regions. Intake of water and pipelines constructions to transmit feed water and concentrate reject release may affect troubles to environmentally problematic regions. Concentrate substances such as R.O rejects amounts have a high salinity and may include on low concentrations of chemicals plus high temperatures. The properties to these concentrates can create troubles for the marine life and effect on the water natures. Leaks from pipes that pass feed water into the yard for desalination units with the high concentration brine outside the plants might penetrate underground and occasion harm to ground-water aquifers. It is important to evaluate the potential contaminates effects on the air of atmosphere, soil, and aquatic surroundings and improve mitigation methods for reducing ecological influences [18]. The concentration rejects is byproduct from desalination process by R.O plants. Concentrates are mostly liquefied matters that may be contained up to (20–25%) of the treated water. Brine is a concentration stream that includes the concentrate of T.D.S range 15 000–36 000 p.p.m. the significant of concentration factors are T.D.S, temperature, and specific gravity (density). Concentration of rejects from R.O process could cover little amounts of certain chemicals employed through pre- treatment and post-treatment (cleaning) processes. A strategic energy, water and environmental issue with desalination is the treatment and removal of marinade, the concentrate resultant from removing salts and minerals from the feed-water. Organization of brine is basic to accomplishment of any plant. The marinade saltiness with its ecological influence relies on the primary saltiness, the technique utilized, and the recovery flow (how much of the

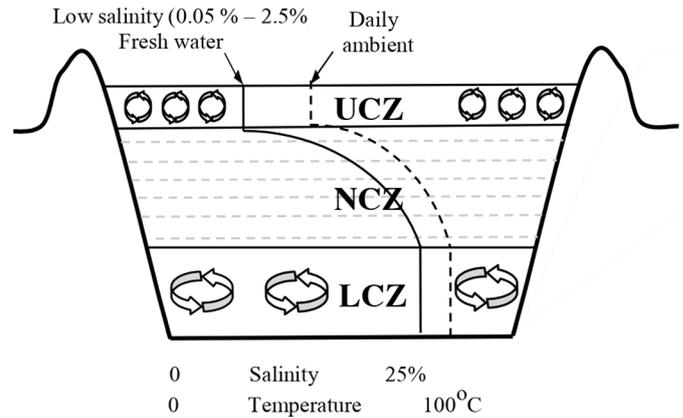


Fig. 1. Diagram of solar pond (salinity gradient).

original water is processed into potable water). Brine usually has double the salt of the feed-water when recovery about 50%. Nevertheless, desalination also concentrates components originate in seawater and groundwater, and chemicals presented thru municipal and agricultural runoff. Concentrates and residuals organization includes waste minimization, treatment, useful reclaim, removal and regular concentrate organization. Every method has its specific set of costs, benefits, environmental influences and restrictions [19].

4 Solar pond

A solar pond is a large water body to save solar energy in heat stores represented by the bottom side of the pond, which is then accessible to use for feasible purpose. Solar ponds utilize to collect heat from solar radiation and the amount of radiant energy would be exploited later [20,21]. It can work continuously during the whole year. A salinity gradient solar pond (SGSP) artlessly employs a sizable area of salt water as a way to save, gather and keep the thermal energy from the landing sun beams. It comprises from three dissimilar layers, upper convective zone (surface zone), lower convective zone (store zone), and between them intermediate zone (gradient zone) as shown in Figure 1. The layer location at the top surface of pond is known as the upper convective zone (UCZ), which has a little salt concentration, it has a small depth and the solar radiation is partly captivated and the surplus is transferred into the beneath layer, it involves a lower saline water (2–3% saltiness) almost fresh water and temperatures range in this layer keep on the mean temperatures of ambience. The intermediate layer is the gradient layer identified as the non-convective zone (NCZ), whereas salinity growths from upper of NCZ to lowest of the NCZ. This zone is distinguished by gradient concentration of salty water and the concentration is varied with the depth determined from the limits of upper convective zone to the limits of lower convection zone. The raising of the depth causes increasing in salty water concentration. The zone function is to be kept the heat convection from the peak thickness as a transparent insulation of this zone generating the high proficiency for energy trap with heat keeping inside the

pond [22–24]. The related concentration gradient assists to restrain heat loss due to natural convection. The lowest layer or lower convective zone (LCZ) has identical highly saline water which captivates and accumulates the solar thermal energy which goes into LCZ in a form of radioactivity. The heat storage zone, lower convection zone, is the greatest salt-density region. The salt concentration at the zone boundary is identical. It has uniform high salinity water which receives heat from solar irradiation on the pond, heat penetrates throughout surface and intermediate zones to be saved at the lowest part of the pond [24].

4.1 Historical background of solar pond

The phenomenon was discovered the natural solar by Kalecsinsky [25]. Kalecsinsky explained the Medve Lake in Transylvania in Hungary (42°44'N, 28°45'E). This lake indicated temperatures escalating up to reach 70 °C on the depth of 132 cm at the summer ending, and minimum temperature denoted at 26 °C at the beginning of spring [25–26]. At Washington State, a lake in Oroville, another indicating for temperatures at 50 °C in the middle of summer on a depth of 2 m was told by [27]. Despite the outside face being coated by the ice, on Lake Vanda in the Antarctic noticed that the bottommost temperature at the deep 66.45 m was (plus 25 °C) while the ambiance was (minus 20 °C) [28–32]. The first idea for making artificial solar ponds, suggested by Kalecsinsky, was proposed in 1954 by Dr. R. Bloch, afterward Director of Research of the Dead Sea Works, and explained in public at Rehovoth Conference on Science in the Service of New States [29]. Subsequently, different solar ponds have been established. For examples; the University of Texas introduced El Paso solar pond plant at El Paso in 1983. It is as a study, advancement and affirmation plant. It was running with managing from May 1986 displaying electrical energy, heating activity, and clean water could be yielded positively at Southwestern of the United States by employing solar pond technique [33]. In Australia, renewable energy grouping of RMIT University has been accomplished a plan by applying of solar pond which placed at Northern Victoria closely to Pyramid Hill salt workings. The reason from this project is to captivate and save the thermal energy by utilizing pool of water which is able to approach to 80 °C. This pool yielded heat that could be exploited in commercial salty yield in addition to aquaculture, especially in produce saline shrimps for store food. Project is to produce electrical power by storing heat in this pond with a consequent step [33]. An initial big measurement of solar pond in industrialized ambience to provide actual employer need is about 6000 m² solar pool at Bhuj in India. It have been given near to 15 × 10⁶ liters of warm water in average temperature at 75 °C during time from September 1993 to April 1995 [33]. Ohio State School has been planned constructed and worked a few SGSP at Ohio. Twain solar pools have been built in Columbus for physical investigations, one of solar pool has been erected in Ohio Agriculture Research and Development Center in Wooster and another solar pool has been created at Miamisburg to warm a society swimming pool and

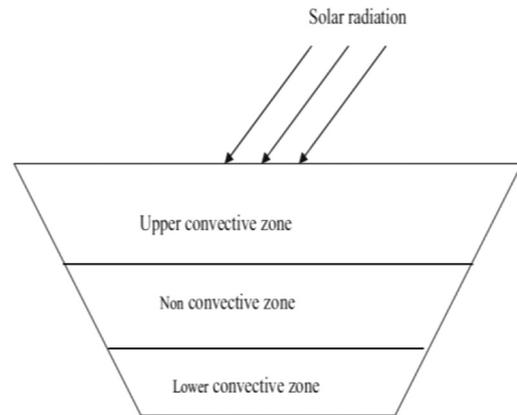


Fig. 2. Salt gradient of solar pond (El-Sebail et al., 2011).

entertaining construction. Statistics and suggestions were advanced from these study works on place choice, in lines choice, salt gradient formation, thermal extraction and ecological safety. NaCl has utilized the stability of salty for every pool. The prices of construction solar ponds differed between \$38 and \$60 per each square meter [34].

5 Solar ponds categories

There are many kinds of solar ponds such as, (1) salt gradient solar ponds (SGSP), (2) partitioned solar ponds, (3) viscosity stability solar ponds, (4) membrane stratified solar ponds, (5) saturated solar ponds; (6) membrane viscosity stabilized solar ponds, and (7) shallow solar ponds. Salt gradient solar pond (SGSP) around (1–2 m) deep as well as the lowest side has better coated blacken as shown in Figure 2. The convection currents, usually develop as a result of the hot water existence in the lowermost with cold water in the upper are averted by the existence of concentration gradient as a density from the bottom to the upper. The concentration gradient is achieved as a result of employing a high density of the appropriate salt like NaCl in the lowest zone from this type of pond. The thermal conductivity for the salty liquid which is a fewer than from the inert water lessens by the rise of saltiness and lead to represent as an insulation zone [35]. Salt gradient of solar pond comprise of three layers; the upper face layer is described as the convective zone (UCZ), this zone has invariable temperature closely to ambient with slight saltiness near to be fresh water. The depth for this upper convective layer fluctuates from 10 to 40 cm and is created by reason of upward salt movable, top-face calefactory; cooling; and wave-action. The second layer is the intermediate layer or non-convective zone (NCZ) which it has thickness varieties from 60 to 100 cm; it performs an isolate layer for the pond. The concentration in this layer amplifies with rising thick to the gradient layer. Depth for this layer varies according to the wanted temperature. The last layer or bottom zone which it has high temperature described as the heat storing zone. This layer has an invariable temperature and saltiness. Beneficial heat of solar energy is mostly absorbed at this zone, it has depth rely on wanted temperatures and heat quantity (thermal energy) to be collected with the storage [35].

Block proposed assumption of the concentration gradient to suppress the thermal convective in solar pond at 1948. In last century fifties, a vital study has been inducted by [36–38]. They have conducted the study for a number of mini-ponds and they have denoted temperatures as highest value as 103 °C across mini-ponds through gathering proficiencies of 15% order. Theoretical with investigational studies at the workshop scale solar ponds for identification the physics for solar pond have been executed by [39–48] and progressed mathematical models to forecast temperature allocations in the solar pond. A few theoretic studies of solar ponds were carried out by [43]. Principally the binary main features to characterize, (1) advanced solar pond (ASP) in contrast with, (2) the conventional salt gradient solar pond (CSGSP). Firstly, total brininess for the pond is amplified and secondly, the graded next layer has formed at the bottom position for the gradient zone. With the purpose of improving the conventional salt gradient solar pond (CSGSP) performing, increasing in salinity is advised principally to the top layer so as to decrease evaporation heat losses. The conceptual idea of advanced solar pond (ASP) has been presented by [44]. This concept necessitates salinity in the remainder from pond to be increased by way of satisfactory demand that preserve steadiness, the stratified next layer is employed to add the capture heat, comparable with that flow could be formed at lower convective zone to the similar function. Thus, thermal energy has been absorbed throughout a higher in deep for pond with heat has been recaptured gathering to conduct upward out of the LCZ [48]; (3) Viscosity stability solar pond (VSSP), salt gradient solar ponds have a number of obstacles, as a result to the non-convective layers which it constituted of salt gradient layers for the solar pond, they could be produced ecological contamination in the result for the saline outflow and the briny gradient layer demands regular upkeep. Therefore, Shaffer suggested another category of solar ponds by employing a see-through polymer gel as a non-convective layer for eradicating these obstacles [45,46]. This polymer gel has small value of thermal conductivity with it is used at nearby solid status; thus it will not to be convicted [47]. The appropriate matters for viscosity stabilized solar ponds ought to have highly transference for the solar fallout, large proficiency to the height selected and must be efficient to performing when the temperatures trend up to 60 °C. Polymers for instance Arabic gum, Locust bean gum, starch and gelatin are altogether these ingredients have the useful capability. The indications for the viscosity stabilized solar pond seems to be encouraging but currently unacceptable economy of the salt gradient solar pond; (4) Membrane stratified solar pond (MSSP): is a category of non-salt solar ponds, that bulk of salty water fluid is employing densely spaced see-through membranes. The function of this membrane space is to be controlling of convection, it must be very small with a significant high obvious films are wanted. The influence of buoyancy would be steadied due to weightiness of water, thus the solar radioactivity changed to the heat of sensible. There are three kinds of membranes proposed to membrane stratified of solar pond, horizontal sheets, vertical tubes, and vertical sheets [49]; (5) the shallow solar pond (SSP) represent the collector of

solar energy that is proposed to provision significant amounts of the heat using in the industrial purposes for reducing the cost as a competitive energy to fossil fuels energy. Its employ for conversion the solar energy into low rank as thermal energy has investigated by way of interesting topic for number of the studies during many years, specifically thru the solar energy cluster by Lawrence Livermore Laboratory (USA) [50]. The expression shallow solar pond was developed from the solar still. The appellation suggests of the water deepness in the SSP is insignificant, usually just a little inches, which is similar to a traditional solar still comprising blacked plate embracing a few of water in it. This still gains benefit from vaporization process of salty water through solar thermal energy. The height of (SSP) shallow is included a plastic film, the film is in interaction beside at the upper water face which lead to prevent the cooling effect as a result of evaporation. A large amount of water can be heated to a significant temperature with its easiness at the running, it holds out possibilities to one of inexpensive method recognized techniques to exploiting the solar heat. The solar pond (shallow type) is basically a big water case otherwise, pad located inside an enclosed area by a perfect upper verification. Water is positioned inside the case, which is mostly created from obvious upper plastic film with the bottom blacken plastic film. The water deepness inside this case has a range ordinarily from 40 to 150 mm. The solar energy gathering proficiency is clearly related with the deepness of water whereas, temperature of the water is inversely related to the deepness of water. Solar energy can be changed to heat due to the water calefactory for the duration of the day. The water is reserved from the (SSP) before sundown (or more exactly whilst the gathering proficiency approximately to zero) for use or storing (Fig. 3) (Garg et al., 1982). The conception for using to this simple device, via, the water pad to collect solar energy is not novelty idea. The Japanese have used several differences for this conception to heat water for household use at the thirties of the past period. Sodha et al., constructed the (SSP) technique by utilizing PVC films in the bag method [51]. For lowering the heat loss due to the convective and the radioactivity, one or two of the see-through sheets were used above the pond [51]. El-Sebaili et al. [26] have experimented the running for the horizontal plastic of solar water heater. It was involved on a polyethylene water bag with the transparent upper and blacken lowest positioned inside a Styrofoam box and roofed by a proper supplementary to a woody surround, such as Tedlar attached. The rate collection of solar energy could amplify by the averages of reflector transmitting to the sun beams on top of the collector shallow. To enhance the solar collector could be provided a thermally insulated cover to the system and also its have function as an isolating reflector at duration the heat gathering time. At time ending of the solar heat gathering, the covering was sealed supplying the unit by means storage during the night [52,53]. Upkeep concentration difficulties at the conventional salt gradient solar pond (CSGSP) could be overtaken through construction of the saturated pond with a salt whose solubility rises with temperature. The saturated ponds have not diffusion setbacks seemingly,

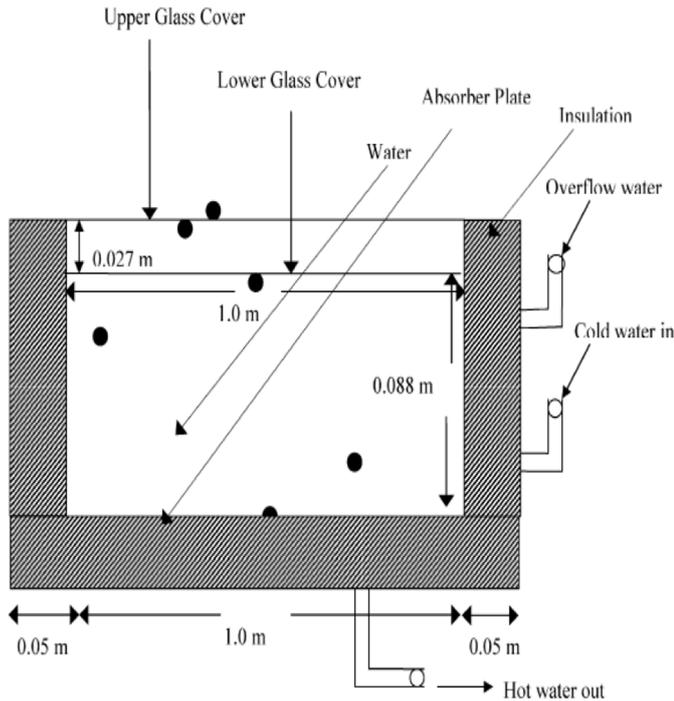


Fig. 3. Shallow solar pond with double glass cover; (●) thermocouple positions (Garg et al., 1982).

and the gradients are self-maintaining reliant on field temperature; therefore the principal advantage for this pond is characteristic to the stabilization, vertical diffusion of salt is prohibited with stability for the density gradient which it is earned free of the pond sustainability [26]. As comparison, non-salt solar ponds for instance, membrane graded ponds and shallow solar ponds that are more proper for short-term energy storing for the reason that the temperature for the pond water is growth quickly, so the salt gradient solar ponds have benefits for long-term energy storing. The performance of the non-salt solar ponds was founded through site examinations, and indication statistics of the outline to these solar ponds were achieved by the outcomes of the tests and investigation [54].

6 Effect of operating conditions on the solar pond

Many parameters impact the performance of solar pond. The significant of these parameters come into view as limitations of the solar pond cost and operating efficiency. In order to accomplish a smooth setting up and operability of the solar pond, these parameters should be accessible and they can be instructed as; uncomplicated to approach the water provision for pond formation with outside rinsing; good landing solar radioactivity for high thermal activity; a lower of speed wind to reduce the mixing between three-zones of pond with little quantity for the wind-borne remains to simply sustain pureness; a lower evaporating rate to lessen the make-up water required.

6.1 Salt selection

An appropriate salt utilized in the solar ponds be required to meet with many Features. There are different features that influence on selection of appropriate salt for the solar pond. The rate of diffusion and temperature dependent solubility of salts in water are very essential to the selection with it should have to the great value of solubility which it permits the highest concentrations to the solution, the solubility must not change significantly with temperature. In addition to that, the practical causes; the cost, availability, and the environmental pollution are the most important aspects to choose a suitable salt of solar pond. Salty-water solute should be satisfactorily obvious to solar radioactivity, it should be friendly to environment and benign to handle and it must be accessible plenty nearby solar pond place, the total supply cost is low and the salt available nearby from the site to lower costs [55,56].

6.2 Salt diffusion

Sodium chloride has a low value for the diffusion rate comparison with other salts. Laboratories results are displayed a slow movement of NaCl throughout the gradient zones and thus reducing interfere with admixing for the layers. The value of diffusion coefficient to the mainly salts normally varieties from (10^{-4} to 10^{-6} m²/s) reliant on the temperature and type of salt, while the diffusion coefficient of NaCl fluctuates between (1.59×10^{-9} to 3.2×10^{-9} m²/s) at temperatures range between 25 °C and 65 °C, correspondingly [56].

6.3 Temperature effect on the solubility of salt

The NaCl has a very small difference in its solubility in the water with the rise in temperature contrast with the other type of salts. Figure 4 shows the difference of solubility curves of various salts with temperature. The solubility of NaCl in the water. Keep on closely constant and just rises to a fewer than 8% with temperature change from 0 °C to 100 °C [56].

6.4 Pond location

Place chosen is identical significant to the solar pond in order for the structure employment and operating to be at least cost. The perfect location must plentiful plane land to lessen earth moving expenditures. The position should have simple approach to salt, fresh water for pond organization and external wash. The location must be a high elevation of incident solar rays and this shall completely influence on the functioning of any solar pond. The functioning of any solar pond would rely on site evaporation percentages. Evaporation in excessive and high water table will be weakened the pond functioning because thermal energy is effortlessly gone to the environments. One more characteristics which should be measured; a minimal normal of the wind speeds to lessen tendency of provoked mix-up and the deepness

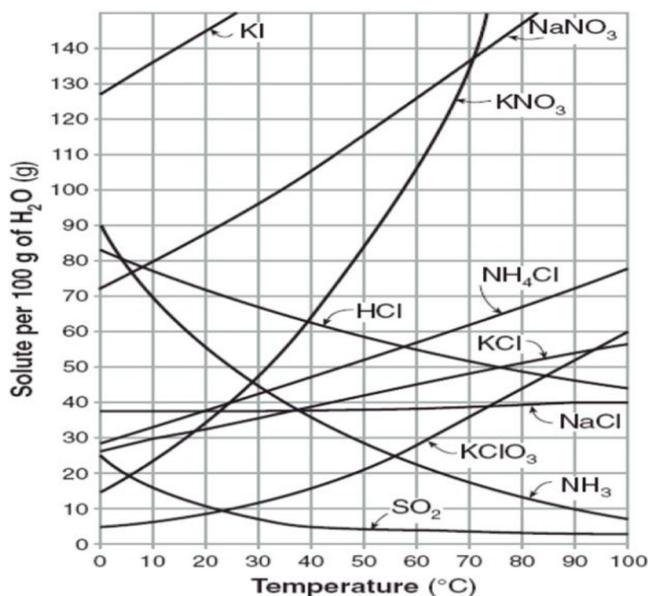


Fig. 4. Solubility curves (Aizaz and Yousaf, 2013).

of surface gradient zone, it could decrease the NCZ thickness thus influence on the functioning of pond. The minimal speed of wind will lower the amount of remains falling to the pond, so supporting in continuing purity. The greatest essential characteristic for the location choice to solar pond is the proximity to end managers of the energy generated.

7 Solar pond applications

There are many specific applications of solar pond for differences purposes such as heating and cooling of houses, heat to industrialized process, electricity power production, commercial or farming crop drying, desalination, swimming pool, and greenhouse heating, etc. Practically, the features of a solar pond to provide hot water at 35 °C to an aquaculture facility will be very various from that of a solar pond to be applied to produce electricity where continued running at high value of temperatures reach up to 80 °C or above is vital. Apparently the solar pond should be situated as near to that its implementation as possible. When the wanted application is well-known, the end-use energy necessities to be provided by the solar pond can be pinpointed, and the solar pond designed appropriately.

7.1 Heating

Due to the significant amount of heat storage at lower convective zone (LCZ) of the solar pond, the thermal energy accumulated can be ideally used for many hazy times [26]. Solar pond could be driven in combination with a heat pump. The heat pump may function such as air-conditioner which use at hot seasons, the fresh water layer

over the up partition (at partitioned solar pond) might be fabricated to function like heat sink which enhances the coefficient of working for air-conditioner [57].

7.2 Electrical power production

The biggest solar pond with an area of 250 000 m² was created in the site on the Dead Sea at 1987 with generated about 5 MW of power by applying Rankine cycle engine to reply peak electricity needs [58]. At 1983, Alice Springs pond positively verified that the experimental solar ponds of (2000 m²) could generate 20 kW electricity by using a Rankine cycle engine in Australia [58]. Conception of solar pond to produce electrical power retains the remarkable potential in the regions wherever has adequate solar intensity and land circumstances to be tolerated structure and operating of a big land of the solar ponds. These ponds could be operated to producing significant capacities of the electricity power, it can be gained production of energy from solar pond with changed to electricity energy even though low temperature, as shown in Figure 1. The conversion efficiency is restricted because of its low operational temperature (70–100 °C). As a result of low temperature, solar pond power project demands organic operating liquids which have lower boiling points such as Halocarbons for instance Freon or Hydrocarbons such as Propane [26].

7.3 Electricity generated by using heat pipe turbine or organic rankine cycle engine

The low-rating heat in the solar pond could apply to produce electricity by using a turbine of the heat pipe or Organic Rankine Cycle Engine (ORCE). The heat pipe turbines generating have been produced some hundred watts electrical yield from water on 54 °C. The using to this turbine or the (ORCE) in combination with a solar pond proposes the exciting outlook of the cost-competitive methods of providing process heat and power for the widespread industries at remote regions [59]. Essentially heat pipe turbines could be used to generate electricity by other the lower temperature heat suppliers, the supreme particularly geothermal and manufacturing waste heat, consequently theoretically opening up a limitless variety of the commercial applications. Work has been developed and fabricated an investigational 5 kW heat pipe turbine for use with a solar pond in Australia and conjunction with Fujikura Ltd of Tokyo [60].

7.4 Industrial process heating

Solar pond can perform a significant function in providing heat of process heat to industriousness thus saving; oil, natural gas, electricity, and coal. Thermal energy may be utilized directly in preparing and/or treating of materials and things constructed in manufacturing by industrial process heating [26,59]. Solar pond knowhow gets effective projections to reduce the costs of fuel plus greenhouse gas radiations in the range of the rural industries demanding of process heating. Solar ponds be able to give heat range

(45–80 °C) of industrialized with commercial applications, comprising; salt production, water provision for desalination, aquaculture, grain drying, dairy industry, fruit and vegetable drying and canning [59].

8 Desalination and salinity mitigation

Multi-flash desalination plants with the solar pond is an engaging offer to obtain the distilled water by reason of that the multi-flash desalination unit operates less than 100 °C which could be accomplished via the solar pond. This technique might be appropriate at locations where drinkable water in a shortage provision and brackish water in obtainable supply. It has been approximated about 4700 m³/day distilled water may be taken from the pond of 0.31 km² area by a multi-effect distillation plant. Several approaches to the salinity control and mitigation have been used counting tree planting, groundwater pumping joined with evaporation ponds, surface drains to eliminate surplus surface water, and subsurface drains to get rid of groundwater [61]. Akbarzadeh and Earl [61] investigated the role of solar ponds for salinity control at the northern Victoria of Australia and founded that a 0.4 Hectare solar pond could produce more than 6000 GJ/y in the form of low-grade heat. This thermal energy can be used to yield fresh water by desalination, or to produce high-value salt. Burston and Akbarzadeh [62] investigated how solar ponds could be integrated into existing salinity mitigation systems [62]. Because of solar ponds need sunbeams, salt, water and evaporation ponds, some motivating possibilities for incorporating solar ponds into salinity mitigation methods in salt affected zones which have these elements in abundance. The system of solar pond – heat pipe turbine technique to use in an integrated salt making, aquaculture and salinity mitigation method which is planned to be demonstrated in some study places in Australia. The fundamental conception is to apply the evaporation pond used in salt production like the solar pond to yield heat for aquaculture and salt purification with electricity for pumping water and further purposes. The electricity is to be generated from the heat store in the solar pond by employing a heat pipe turbine from renewable sources. The water driving would be used to reduce the water table being as part of salinity control. The aquaculture system will use water heated by heat from the solar pond to increase the brine shrimps as a feeding fish and sustain the temperature for the fish ponds, the fish will provide to the marketplace products later [62].

9 Consideration of heat and mass transfer

Tow driving forces is controlling in mathematical model equation that can dominate on the operation of solar pond, the difference in concentration values among three layers is one of these driving force and the mass transfer by diffusion take place at three zones of the pond with escalated direction in values from up to down at pond. The other driving force which could be dominated on amount of thermal energy for solar pond is the difference in temper-

atures among the three layers of the solar pond and heat transfer by convection, conduction and radiation occur with opposite escalated direction compare with concentration direction, the escalated trend in values from down towards up of solar pond.

9.1 Consideration of heat transfer

It is the crucial way to enter for energy computation by evaluation most of heat transfer types, conduction, convection, and radiation. The common heat transfer equations may be used to calculate temperatures profile inside the three layers of solar pond.

9.1.1 Energy (heat) balance for the upper convective zone (CZ)

The net thermal energy at the top surface convective zone can be estimated by using the overall energy (heat) balance for solar pond, the thermal energy net at the top of solar pond (UCZ) is accumulated with the time [63]:

$$Q_{\text{net}} = Q_{\text{accumulation}} = Q_{\text{in}} - Q_{\text{out}}. \quad (1)$$

The input of heat energy is generated in the (UCZ) due to effect insolation beams intensity and the heat conveying from gradient zone to upper (surface) zone by conduction.

$$Q_{\text{in}} = Q_{\text{solar}} + Q_{\text{bottom}}. \quad (2)$$

The output heat from upper convective solar pond is heat loss as result to provoke of pond surrounding and the wall structure for the pond.

$$Q_{\text{out}}(\text{heat loss}) = Q_{\text{wall}} + Q_{\text{to surrounding}}, \quad (3)$$

where, Q_{net} = the net of heat (energy) store at UCZ. Q_{solar} = net fallen of solar irradiation captivated through the UCZ. Q_{bottom} ($Q_{\text{coned.1}}$) = total heat transient into the zone from under it (from NCZ to UCZ). $Q_{\text{accumulation}}$ = heat accumulated in UCZ due to heat capacity of fresh water during the period of time. Q_{wall} = heat (energy) loss of the pond sides. $Q_{\text{to surrounding}}$ = heat (energy) lost into the surroundings from zone layer (UCZ).

The solar energy, fallout and penetrating into the water reservoir, weakening exponentially with depth, as liquid layers take in energy. The amount of weakening is a function of the wavelength of the radiation and for the total spectrum of wavelengths. This exponential formula was suggested by Bryant and Colbeck, (Bryant and Colbeck., 1977), and appears to be in excellent accord with [64]. We can use Bryant and Colbeck formula [63]:

$$\frac{H_{X_1}}{H_0} = 0.36 - 0.08 \ln \frac{X_1}{\cos \varnothing_r}, \quad (4)$$

H_0 = Monthly average insolation incident on horizontal surface from the sun (w/m^2). H_{x_1} = The amount radiation flux at depth x_1 (w/m^2). θ_r = Refraction angle at the pond's surface.

According to Snell's law [65] we can calculate θ_r :

$$\frac{\sin \theta_i}{\sin \theta_r} = 1.333 \tag{5}$$

θ_i = Incident angle at direct radiation to horizontal plane with zenith angle which we can calculate from [65–67]: (normal)

$$\cos \theta_i = \cos \zeta \cos \alpha \cos \omega + \sin \zeta \sin \alpha \tag{6}$$

ζ = Declination angle.

$$\zeta = 23.45 \sin \left(\frac{360(284 + N)}{365.25} \right). \tag{7}$$

N = the day of the year. α = latitude angle. ω = hour angle which it defines as an angular gauge of the time measured from noon according to local time h , and is expressed as:

$$\omega = \frac{2\pi(h - 12)}{24} \tag{8}$$

h = Local time (hrs.)

It was assumed that:

$H_{x_1} = Q_{solar}$ at UCZ layer.

The UCZ layer thickness = x_1 .

$$Q_{bottom\ 1}(Q_{cond.1}) = \frac{K}{x_1} A_{UCZ}(T_{bottom\ 1} - T_{UCZ}) \tag{9}$$

$$Q_{bottom\ 2}(Q_{cond.2}) = \frac{K}{x_2} A_{NCZ}(T_{bottom\ 2} - T_{NCZ}),$$

where, x_1, x_2 = Thickness of the UCZ and NCZ layers (m). K = Thermal conductivity of water ($w/m\ ^\circ C$)

$$Q_{wall} = U_{wall} A_{wall} (T_{UCZ} - T_{wall}), \tag{10}$$

U_{wall} = Wall heat transfer coefficient ($w/m^2\ ^\circ C$). A_{wall} = Surface area of wall sides of the pond.

$$Q_{to\ surrounding} = q_c + q_e + q_r, \tag{11}$$

where, q_c = Heat lost as a result of convection to surrounding. q_e = Heat lost due to evaporation. q_r = Heat lost radiation in the upper zone to surrounding. Therefore, heat loss convection is given by:

$$q_c = h_c(T_{UCZ} - T_{amb.}) \tag{12}$$

Heat transfer convection from the upper zone to air surrounding depends largely on the wind speed and the temperature distinction between the air surrounding (atmosphere) and surface water of the pond. Where,

convection heat transfer coefficient is given by [69]:

$$h_c = 5.7 + 3.8 V, \tag{13}$$

h_c = Convection heat transfer coefficient ($w/m^2\ ^\circ C$). V = average monthly wind speeds (m/s).

Heat loss at the surface caused by evaporation phenomenon, it can be calculated by [63]:

$$q_e = \frac{L_v h_c (P_{UCZ} - P_a)}{1.6 C_s P_{atm.}}, \tag{14}$$

where, L_v = Latent heat of vaporization of water (J/Kg). P_{UCZ} = Partial pressure for the water surface temperature in UCZ (pa). P_a = Partial pressure of water vapor at the ambient air (pa). C_s = Humid heat capacity of air (J/Kg $^\circ C$). $P_{atm.}$ = Atmospheric pressure (pa).

The vapor pressure of water at the surface, P_{ucz} , is related to the surface temperature by the Antoine equation [63] given by:

$$P_{UCZ} = \exp \left(18.403 - \frac{3885}{T_{UCZ} + 230} \right) \tag{15}$$

Due to the meaning of relative humidity, the percentage of the partial pressure of water vapor in the atmosphere; P_a , to the saturated vapor pressure of water related to the ambient temperature, P_s (T_{air}), we get:

$$P_a = RH * \exp \left(18.403 - \frac{3885}{T_{air} + 230} \right). \tag{16}$$

Humid heat capacity of air can be calculated by [63]:

$$C_s = 1.005 + 1.82 H, \tag{17}$$

where, 1.005 kJ/kg $^\circ C$ is the heat capacity of dry air, 1.82 kJ/kg $^\circ C$ the heat capacity of water vapor, and H is the specific humidity in kg water vapor per kg dry air in the mixture. The radiation heat loss equation could be expressed as the following:

$$q_r = \sigma E_w A_{UCZ} [(T_{UCZ} + 273.15)^4 - (T_{sky} + 273.15)^4], \tag{18}$$

where, $\sigma = 5.6704 \times 10^{-8} w/m^2 k^4$ = Stefan–Boltzman's constant ($W/m^2 k^4$). E_w = Emissivity of water surface, we can assume = 0.83 [63]. T_{UCZ} = The upper layer temperature ($^\circ C$). T_{sky} = The sky temperature ($^\circ C$).

We can write sky temperature equation:

$$T_{sky} = 0.0552(T_{amb.})^{1.5} \tag{19}$$

$$Q_{accumulation} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_1, \tag{20}$$

where, C_P = Specific heat capacity for the fresh water solution (J/Kg $^\circ C$) ρ = Density of water solution (Kg/ m^3)

The equation governing of solar pond for an upper convective zone is:

$$\begin{aligned} Q_{\text{net}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_1 = & \left[\left\{ H_0(0.36 - 0.08 \ln \frac{X_1}{\cos \varnothing_r}) \right. \right. \\ & + \left. \left\{ \frac{K}{X_2} \cdot A_{\text{NCZ}} \cdot (T_{\text{bottom } 2} - T_{\text{NCZ}}) \right\} \right. \\ & - \left. \left\{ \frac{K}{X_1} \cdot A_{\text{UCZ}} \cdot (T_{\text{bottom } 1} - T_{\text{UCZ}}) \right\} \right. \\ & + \{ U_{\text{wall}} \cdot A_{\text{wall}}(T_{\text{UCZ}} - T_{\text{wall}}) \} \\ & + \left\{ \frac{(5.7 + 3.8 V) \times (T_{\text{UCZ}} - T_{\text{amb.}})}{\text{Lv hv}(\text{P}_{\text{ucz}} - \text{Pa})} + \sigma \cdot E_w \cdot A_{\text{UCZ}} \right. \\ & \left. \left. + \frac{1.6 \text{ Cs Patm.}}{(T_{\text{UCZ}})^4 - (0.052 T_{\text{amb.}}^{1.5})^4} \right\} \right] \quad (21) \end{aligned}$$

9.1.2 Energy (heat) balance for the non-convective zone (NCZ)

The net heat from the (UCZ) is input thermal energy to the intermediate layer (NCZ), and accumulation with the time inside this zone.

The net thermal energy at (NCZ) can be valued by:

$$Q_{\text{net}} = Q_{\text{accumulation}} = Q_{\text{in}} - Q_{\text{out}} \quad (22)$$

$$Q_{\text{in}} = Q_{\text{solar}} + Q_{\text{bottom}} \quad (23)$$

$$Q_{\text{accumulation}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_2 \quad (24)$$

$$Q_{\text{out}} (\text{heat loss}) = Q_{\text{wall}} + Q_{\text{cond.2}} \quad (25)$$

$$\frac{H_{X_2}}{H_0(x_1)} = 0.36 - 0.08 \ln \frac{X_2}{\cos \varnothing_r} \quad (26)$$

We assume that:

H_{X_2} = The amount radiation flux at depth x_2 (w/m^2).
 $H_0(x_1)$ = The input net radiation flux from the (UCZ) which transfer into intermediate layer (NCZ). \varnothing_r = Refraction angle at the pond's surface.

We assume that $H_{X_2} = Q_{\text{solar}}$ inside NCZ layer.

$$Q_{\text{bottom } 2} (Q_{\text{cond.2}}) = \frac{K}{X_2} A_{\text{NCZ}} (T_{\text{bottom } 2} - T_{\text{NCZ}}) \quad (27)$$

$$Q_{\text{bottom } 3} (Q_{\text{cond.2}}) = \frac{K}{X_3} A_{\text{LCZ}} (T_{\text{bottom } 3} - T_{\text{LCZ}}) \quad (28)$$

The thickness of NCZ layer and LCZ = X_2, X_3 .

K = Thermal conductivity of water ($\text{w}/\text{m} \text{ } ^\circ\text{C}$)

$$Q_{\text{wall}} = U_{\text{wall}} A_{\text{wall}} (T_{\text{NCZ}} - T_{\text{wall}}) \quad (29)$$

The accumulated heat in the intermediate layer (NCZ) can be evaluated by:

$$Q_{\text{accumulation}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_2 \quad (30)$$

C_P = Specific heat capacity of salt- water solution ($\text{J}/\text{Kg} \text{ } ^\circ\text{C}$). ρ = Density of salt- water solution (Kg/m^3)

The equation governing of solar pond for non-convective zone is:

$$\begin{aligned} Q_{\text{net}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_2 = & \left[\left\{ H_{X_1} \left(0.36 - 0.08 \ln \frac{X_2}{\cos \varnothing_r} \right) \right\} \right. \\ & + \left\{ \frac{K}{X_3} \cdot A_{\text{LCZ}} \cdot (T_{\text{bottom } 3} - T_{\text{LCZ}}) \right\} \left. \right. \\ & - \left[\frac{K}{X_2} \cdot A_{\text{NCZ}} \cdot (T_{\text{bottom } 2} - T_{\text{NCZ}}) \right. \\ & \left. \left. + U_{\text{wall}} \cdot A_{\text{wall}} \cdot (T_{\text{NCZ}} - T_{\text{wall}}) \right] \right] \quad (31) \end{aligned}$$

9.1.3 Energy (heat) balance for the lower convective zone (LCZ)

The net heat from the (NCZ) is input thermal energy to the heat storage layer (LCZ); accumulated; collected; and stored with the time inside the (LCZ) zone. It can be approximated the net thermal energy at this zone by [63]:

$$Q_{\text{net}} = Q_{\text{accumulation}} = Q_{\text{in}} - Q_{\text{out}} \quad (32)$$

$$Q_{\text{accumulation}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_3 \quad (33)$$

C_P = Specific heat capacity of salt-water solution ($\text{J}/\text{Kg} \text{ } ^\circ\text{C}$). ρ = Density of salt-water solution (Kg/m^3). $Q_{\text{in}} = Q_{\text{solar}}$ = heat absorbed of solar radiation in the storage zone (LCZ) which it moved from intermediate layer to the lower layer of the pond.

$$\frac{H_{X_3}}{H_0(x_2)} = 0.36 - 0.08 \ln \frac{X_3}{\cos \varnothing_r} \quad (34)$$

H_{X_3} = The amount radiation flux at depth x_3 (w/m^2).
 $H_0(x_2)$ = The input net radiation flux from the (NCZ) which move into lower (heat store) layer (LCZ).

We assume that $H_{X_3} = Q_{\text{solar}}$ in LCZ layer.

The thickness of LCZ layer = x_3 .

$$Q_{\text{out}} = Q_{\text{wall}} + Q_{\text{cond.3}} + Q_g \quad (35)$$

$$Q_{\text{wall}} = U_{\text{wall}} A_{\text{wall}} (T_{\text{LCZ}} - T_{\text{wall}}) \quad (36)$$

We assume that solar pond is in warming up status, therefore the heat extraction could be exploited as a heat (thermal energy) in the solar pond application.

$$Q_g = U_g \cdot A_{\text{LCZ}} (T_{\text{LCZ}} - T_g) \quad (37)$$

T_g = Ground sink temperature ($^{\circ}\text{C}$)

$$U_g = \frac{K_g}{L_g} + b K_g \frac{\varepsilon}{A}, \quad (38)$$

where, K_g = Ground thermal conductivity (w/m $^{\circ}\text{C}$).
 L_g = The distance of the water table from the bottom of the pond. ε = Pond perimeter.

A and b = Pond area and empirical parameter which that assume; $b = 1.37$.

In research that an artificial mini solar pond is used and manufactured from the steel with thermal isolation material utilized, the heat loss ground could be negligible as one of the assumptions study. The equation governing of solar pond for lower convective zone is:

$$\begin{aligned} Q_{\text{net}} = \rho \cdot C_P \cdot \frac{\partial T}{\partial t} \cdot X_3 = & \left[\left\{ H_{0(x_2)} \left(0.36 - 0.08 \ln \frac{X_3}{\cos \Theta r} \right) \right\} \right. \\ & - \left. \left\{ U_{\text{wall}} A_{\text{wall}} (T_{\text{LCZ}} - T_{\text{wall}}) \right\} \right] \\ & + \left\{ \frac{K}{X_3} \cdot A_{\text{LCZ}} (T_{\text{bottom 3}} - T_{\text{LCZ}}) \right\} \\ & + \left\{ \left(\frac{K_g}{L_g} + b K_g \frac{\varepsilon}{A} \right) \cdot A_{\text{LCZ}} (T_{\text{LCZ}} - T_g) \right\} \end{aligned} \quad (39)$$

9.2 Consideration of mass transfer

In solar pond a lot of phenomena take place as a physical process for solar pond operation, it depends on mass conservation. Convective mass transfer happens in LCZ, UCZ and mass transfer, diffusion phenomenon occur in the NCZ. There are many assumptions to do mathematical model for mass transfer: The entire mass of system by control volume is constant, none of chemical reaction happens at the system, the process of mass transfer occurs as a result of molecular diffusion only, and density gradient can be evolved by molecular diffusion.

10 Conclusion

Solar pond is one of the most important and promising of sustainable energy sources. It can use as a technology to convert the solar landing beams to useful renewable energy and can be employed for water desalination, power generation, heating, and many other applications. Simple energy balance technique is generally and successfully used to model the overall performance of the solar pond. The summary of the literatures showed ability of the solar pond in various industrial applications. However, in comparison with the simplicity, cost effectiveness and environmental friendly operation, the solar pond deems as one of the most useful energy resources especially in remote areas.

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