Enhancement of Useful Heat Extraction and Thermal Efficiency of Solar Pond using Computational Fluid Dynamic Analysis

Avantika Gupta[1], Pankaj Badgaiyan[2], Dheeraj Jain[3]
[1]M. Tech Solar, Department of Energy Technology, Truba Institute of Engineering and Information Technology, Bhopal MP, India
[2]Assistant Professor, Department of Energy Technology, Truba Institute of Engineering and Information Technology, Bhopal MP, India
[3]Assistant Professor, Department of Energy Technology, Truba Institute of Engineering and Information Technology, Bhopal MP, India
avantikagupta2820@gmail.com, pankajbadgaiyan33@gmail.com , djjain2448@gmail.com,

* Corresponding Author: Avantika Gupta

Abstract: *A solar pond is a pool of saltwater which collects and stores solar thermal energy. In the present work mathematical and computational fluid dynamics analysis have been performed for different designs of solar pond for the location of central India with 23o 18' 25" N, Longitude: 77o 23' 09'' E. For that total three different three dimensional CFD model has been developed such as solar pond without pipe, with serpentine tube and solar pond with spiral tube have been used to evaluate the maximum temperature generated inside the solar pond and useful heat extraction with overall thermal efficiency of all the design of solar Pond. Water with different salinity concentration (NaCl 5% for NCZ & NaCl 10% for LCZ) on different layer and water with Al2O3 nano-fluid have been used as heat transfer fluid. Result show that design-3 of the solar pond with spiral tube by using both NaCl & Al2O3 nano-fluid gives that better temperature of generation and overall thermal efficiency as compared with all design of solar pond, in that too solar pond by using Al2O3 nano-fluid gives maximum temperature of 93.75 Co and the overall thermal efficiency of 21.56% which is much better than all other design.*

Keywords: *Solar energy, solar pond, useful heat extraction, thermal efficiency, CFD etc.*,

I. INTRODUCTION

Global energy consumption in the last half-century has rapidly increased and is expected to continue to grow over the next 50 years but with significant differences. The past increase was stimulated by relatively "cheap" fossil fuels and increased rates of industrialization in the world; yet while energy consumption in world continues to increase, additional factors make the picture for the next 50 years more complex. Rapid increase in population in the world and standard of living of human beings, there is problem of energy crisis. The supply of oil will fail to meet the increasing population demand. Hence an alternative energy source had to be chosen to meet the future energy demands. *[52] Energy* is one of the factors necessary for everyone. We use energy in various forms over the year, which causes a number of significant power sources in the World to decline by the amount of time spent. As a result, many countries start to realize and have already began to look for alternative renewable energy to replace those that are vanishing. There are many types of renewable energy such as wind power, hydro power, and biomass. There is also another type of renewable energy that is always available, inexhaustible, and not adversely affecting the environment. It is solar energy. To use such energy; however, there must be a device that can store heat energy from the sun so that the stored energy can be utilized later for various usages. *[51]*

Solar pond is a device to collect and store energy. It can operate continuously all year long. Solar ponds collect energy from solar radiation. The radiant heat is collected at the bottom side of the pond and this amount of heat would be used later.

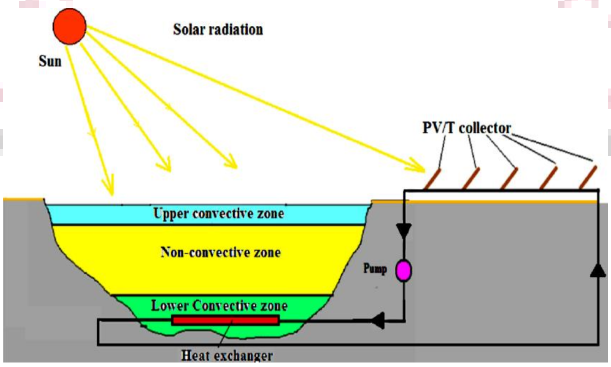

Figure 1: Concept of solar pond

a) Working principle of Solar Pond:

The working of solar pond can be understood with given figure. Consider a pond of depth *L* having salts dissolved in the water. Let the concentration at the top C_1 is less than the bottom concentration C_2, the variation of density with temperature for the two concentrations as shown. Let T_1 and ρ_1 is the temperature and density of the top layer of water indicated by point *P* and T_2&ρ_2 is the temperature and density of the bottom layer indicated by point *Q*. No convection will occur so long as the slope of the curve PQ is positive.

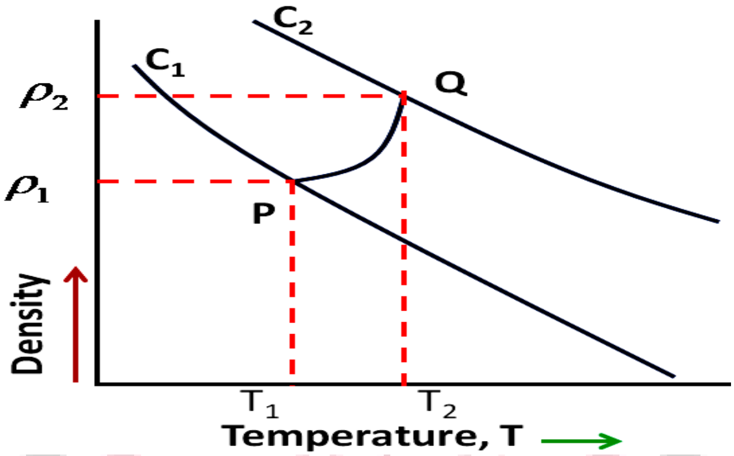

Figure 2: Working principle of Solar Pond

b) Type of solar ponds : There are many kinds of solar ponds such as, salt gradient solar ponds (SGSP), shallow solar ponds, membrane viscosity stabilized solar ponds membrane stratified solar ponds, saturated solar ponds; viscidity stability solar ponds, and partitioned solar ponds. *[18]* Butthere are two main categories of solar ponds:

Non-convecting ponds: which reduce heat loss by preventing convection from occurring within the pond.

Convecting ponds: which reduce heat loss by hindering evaporation with a cover over the surface of the pond.

c) Application of solar ponds: Solar ponds technologies offer good potential for collecting, storing and supplying of heat for different applications requiring low grade thermal energy. Thermal energy stored in the solar pond have been utilized for the better quality salt production by enhanced evaporation or purification of salt, aquaculture: using saline or fresh water to grow fish or brine shrimp, dairy industry to preheat feed water to boilers, fruit and vegetable canning industry, fruit and vegetable drying, grain industry for grain drying, production of drinking water through desalination process. The smaller ponds have been used mainly for space and water heating, swimming pool heating, while the larger ponds are proposed for industrial process heat, electric power generation, and sea water desalination on large scale. *[8]*The solar pond has variety of applications like, heating and cooling of buildings, swimming pool and greenhouse heating, industrial process heat, desalination, power production, agricultural crop drying, etc.

II. LITERATURE REVIEW

Tian (2021) Worked on solar pond stability performance using an external magnetic field, Gaurav (2021) A review of Production of electric power from solar ponds using thermoelectric generator, Iman (2021) Investigating the simultaneous effect of effective parameters on the performance of salinity gradient solar ponds using Taguchi analysis, Keli (2021) Study and Tracking variations in the abundance and composition of dissolved organic matter in solar ponds of oilfield-produced brine, Poyyamozhi (2021) Performance comparison of AgTiO2 and CNT based latent heat materials on a solar pond, Platikanov (2021) Study the multivariate analysis of the operational parameters and environmental factors of an industrial solar pond, Seyed (2021) Case study on Thermodynamic, economic, and sensitivity analysis of salt gradient solar pond (SGSP) integrated with a low-temperature multi effect desalination, Verma (2021) Transient study of a solar pond under heat extraction from non-convective and lower convective zones considering finite effectiveness of exchangers, Susana (2020) Analysis of the thermal performance of an uncovered 1-hectare solar pond in Benguela, Angola, Abdelfattah (2020) Feasibility analysis of reverse osmosis desalination driven by a solar pond in Mediterranean and semi-arid climates, Abhishek (2020) Eigen functions and genetic algorithm based improved strategies for performance analysis and geometric optimization of a two-zone solar pond, Abhishek (2020) Study the Effect of peripheral heat conduction in salt-gradient solar ponds, Amin (2020) Worked on Thermodynamic and thermo economic analysis of three cascade power plants coupled with RO desalination unit, Hadi (2020) Performance comparison of two new cogeneration systems for freshwater and power production based on organic Rankine and Kalina cycles driven by salinity-gradient solar pond, Manar (2020) Analyze the Performance of solar pond integrated with photovoltaic/thermal collectors, Morteza (2020) Employing wavy structure to enhance thermal efficiency of spiral-coil utilized in solar ponds, Nidal (2020) Hydrothermal irreversibility analysis based on multi-criteria assessment in a modified spiral piping system utilized in solar ponds, Osamah (2020) A short review on Solar pond as a low grade energy source for water desalination and power generation, Shyamal (2020) Investigation of temperature development in salinity gradient solar pond using a transient model of heat transfer, Sunirmit (2020) Study the effect of ground heat extraction on stability and thermal performance of solar ponds considering imperfect heat transfer, Alireza (2019) Transient modeling for the prediction of the temperature distribution with phase change material in a salt-gradient solar pond and comparison with experimental data, Amro (2019) Energy and exergy analysis & integration of pressure retarded osmosis in the solar ponds for desalination and photo-assisted chlor-alkali processes, Arezu (2019) Investigation of the performance of modified organic Rankine cycles (ORCs) and modified trilateral flash cycles (TFCs) assisted by a solar pond, Sathish (2019) Effective study of thermal behavior on membrane stratified portable solar pond, Montala (2019) Stability analysis of an industrial salinity gradient solar pond, Ines (2019) Experimental studies on the effect of using phase change material in a salinity-gradient solar pond under a solar simulator, Verma (2019) Study & Wall profile optimisation of a salt gradient solar pond using a generalized model, Alcaraz (2018) Thermal performance of 500 m2 salinity gradient solar pond in Granada, Spain under strong weather conditions, Abhishek (2018) Inverse prediction and optimization analysis of a solar pond powering a thermoelectric generator, Amani (2018) Simulation study of novel multi-stage flash (MSF) desalination plant driven by parabolic trough collectors and a solar pond, Sathish (2018) Relative study of steel solar pond within sodium chloride and pebbles, Morteza (2017) Exergetic performance analysis of a salinity gradient solar pond, Reza (2017) Experiment and optimization of mixed medium effect on small-scale salt gradient solar pond, Morteza (2017) Energetic performance analysis of solar pond with and without shading effect, Sayantan (2017) On the addition of heat to solar pond from external sources, Sayantan (2017) Heat recovery from ground below the solar pond, Shojaeefard (2017) Investigation of Thermodynamic Performance of Salt Gradient Solar Ponds, Abdullah (2016) Construction of sustainable heat extraction system and a new scheme of temperature measurement in an experimental solar pond for performance enhancement, Assad (2016) New theoretical modeling of heat transfer in solar ponds, Ding (2016) Worked on Transient model to predict the performance of thermoelectric generators coupled with solar pond, Safwan (2016) Study the effect of ground conditions under a solar pond on the performance of a solar air-conditioning system, Ismail (2015) Study the effect of sunny area ratios on the thermal performance of solar ponds, Ismail (2015) Performance assessment of a magnesium chloride saturated solar pond, Bozkurt (2015) Exergy analysis of a solar pond integrated with solar collector, Khaled (2015) experimental review on coupling of solar pond with membrane distillation, Appadurai (2015) Performance analysis of fin type solar still integrated with fin type mini solar pond, Assari (2015) Experimental investigation of heat absorption of different solar pond shapes covered with glazing plastic. Ranjan (2014) A comprehensive review on Thermodynamic and economic feasibility of solar ponds. Safwan (2014) A Simple Heat and Mass Transfer Model for Salt Gradient Solar Ponds, Sura (2014) Electric power generation from solar pond using combination of thermosyphon and thermoelectric modules, Goutham 2013 Study of Solar pond technology, Aliakbar (2005) Study of Solar ponds, Hussaini (1998) Using shallow solar ponds as a heating source for greenhouses in cold climates, From the above literature study, it has been observed that there are lot of work have been carried out and still going on, researchers investigate worked on thermal performance for external magnetic field, thermoelectric generator, salinity gradient solar ponds, Taguchi analysis, solar ponds of oilfield, comparison of AgTiO2 and CNT, Multivariate analysis, environmental factors, Thermodynamic, economic, and sensitivity analysis, study of organic Rankine and Kalina cycles, Hydrothermal irreversibility analysis, trilateral flash cycles, Wall profile optimization, shading effect, ground conditions under a solar pond, magnesium chloride saturated solar pond and fin type mini solar pond and many more.

The main objection of the present work is to enhance the thermal storage performance by changing the design of solar pond by using different types of heat transfer fluid by performing mathematical analysis for the selected location such as Global, Diffuse and beam radiations, Reflection and Refraction, Transmissivity etc, and validate the results of CFD analysis and calculate the rate of useful heat extraction and overall thermal efficiency of the solar pond.

III. METHODOLOGY

a) Transmissivity based on Reflection-Refraction:

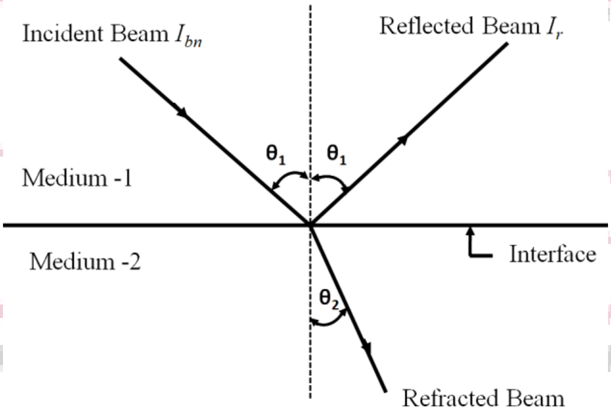

Figure 3: Reflection and Refraction at the interface of two media

When a beam of light of intensity I_{bn} travelling through a transparent medium I strikes the interface separating it from another transparent medium 2, it is reflected and refracted as shown in figure. The reflected beam has a reduced intensity I_r and has a direction such that the angle of reflection is equal to the angle of incidence. On the other hand, the direction of the direction of the incident and refracted beams are related to each other by Snell's law which states that

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Where θ_1 = Angle of incidence, θ_2 = Angle of refraction, and

$n_1 \& n_2$ = refractive indices of the two media.

The reflectivity $\rho = (I_r/I_{bn})$ is related to the angle of incidentce and refraction by the equations.

$\rho = \frac{1}{2}(\rho_I + \rho_{II})$

$\rho_I = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)}$

$\rho_{II} = \frac{tan^2(\theta_2 - \theta_1)}{tan^2(\theta_2 + \theta_1)}$

ρ_I *and* ρ_{II} being the reflected of the two components of polarization.
For the special case of normal incidence $\theta_1 = 0^o$

$\rho = \rho_I = \rho_{II} = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$

The transmissivity τ_r is given by an expression similar to that for ρ
Thus

$\tau_r = \frac{1}{2}(\tau_{r1} + \tau_{r2})$

Where τ_{r1} and τ_{r2} are the transmissivities of the two components of polarization.
For angle of incidence from 0 to 60o the loss due to reflection is small i.e. 2-6%.
Consider one of the components of polarization of a beam incident on a single cover. Because of the fact that there are two interfaces, multiple reflections and refraction will occurs as shown in figure.

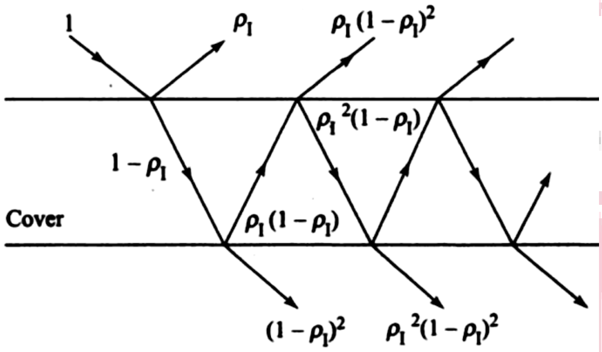

Figure 4: Ray diagram though a single cover considering reflection-refraction alone

The transmissivity τ_r based on reflection and refraction at the air-water interface can be calculated using above equations. Refractive index for water relative to air taken equal to 1.33. Value of τ_r can be obtained for different angle of incidence (0 to 60°)

$\cos\theta_1 = \sin\emptyset . \sin\delta + \cos\emptyset . \cos\delta . \cos\omega$

$\theta_2 = \sin^{-1}\left\{\frac{\sin\theta_1}{1.33}\right\}$

b) Transmissivity based on absorption:

Transmissivity τ_a based on absorption can be been calculated using beam intensity incident normally on the top layer and beam intensity absorbed by lower layer and the sum of four exponentials as given equation.

$\tau_a = \sum_{j=1}^{4} A_j\, e^{-K_j x}$

Where x = Depth of water and A_j & K_j = constant

c) Calculation of Transmissivity alternatively:

$\tau_a = 0.36 - 0.08 ln. x$

If the radiation is not incident normally,

$\tau_a = 0.36 - 0.08 ln \frac{x}{\cos\theta_2}$

Where x = depth of water in meter, valid for x >0.01 m

Energy flow in and out of the surface convective zone and the lower convective zone:
The calculation of the temperature distribution in a solar pond is rather involved since the pond consists of three zones. For an exact solution, need to solve the appropriate differential equation for each zone, use matching condition at the interface between the zones and satisfy the boundary conditions at the top and bottom surface of the pond because of the complexity. For the formulation, the surface convective zone and the lower convective zone are assumed to be perfectly mixed layer at uniform temperature which change only with time.

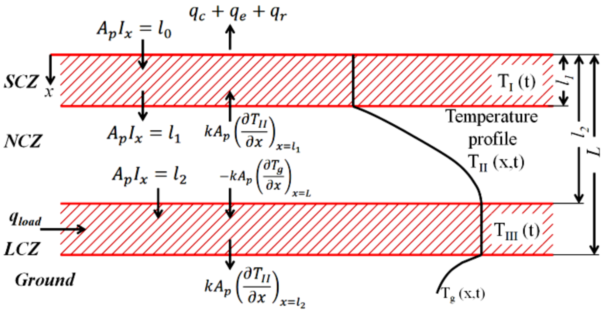

Figure 5: Energy flow in and out of the surface convective zone and the lower convective zone

Solar radiation absorbed in the pond

$$\rho C_p \frac{\partial T_{II}}{\partial t} = k \frac{\partial^2 T_{II}}{\partial x^2} - \frac{dI}{dx}$$

$$I = I_b \tau_{rb} \tau_{ad} + I_d \tau_{rd} \tau_{ad}$$

c) Rate of useful heat extraction:

$$T_{III} - T_a = \frac{\tau_r . H_g}{k} . \sum_{j-1}^{4} \frac{A_j}{K_j'} \left(1 - e^{-K_j' l_2}\right) - \frac{l_2}{k} . \frac{q_{load}}{A_p}$$

$$K_j' = \frac{K_j}{\cos \theta_2}$$

Where θ_2 is the angle of refraction corresponding to an effective angle of incidence. This is taken to be the angle of incidence on the equinox day ($\delta = 0$) at 1400 hour at the location under consideration.

l_2 = Depth of solar pond at the bottom of the non convective zone

$\frac{q_{load}}{A_p}$ = Rate of useful heat extraction

Table 01: Properties of the insulation and water in each zone of the solar pond:[20][21]

Domain number	**D1**	**D2**	**D3**
Layer of Solar pond	LCZ	NCZ	UCZ
Depth of Solar pond [m]	0.1	0.3	0.1
Density [Kg/m^3]	1045.1	1020	992.2
Specific heat Cp [J/kg-k]	3740.9	3945.6	4182
Thermal conductivity k [W/m-K]	0.661	0.648	0.630
Kinematic Viscosity [Nm-s]	0.000462	0.000528	0.001003
Absorption coefficient [m^{-1}]	1.2	0.25	0.15
Scattering coefficient [m^{-1}]	0.15	0.12	0.1

d) Transmissivity based on absorption at different depth of solar pond

According to Bryant and Colbeck:

Transmissivity whem the radiation is not incident normally,

$$\tau_a = 0.36 - 0.08 ln \frac{x}{\cos \theta_2}$$

Transmissivity based on absorption for beam radiation

$$\tau_{ab} = 0.36 - 0.08 ln \frac{x}{\cos \theta_2}$$

Transmissivity based on absorption for diffused radiation

For the diffuse radiation take the angle of incidence θ_2 to be 60°

$$\tau_{ad} = 0.36 - 0.08 ln \frac{x}{cos\, \theta_2}$$

Overall thermal efficiency of the solar Pond

$$\eta_{th} = \frac{MC_p(T_{III} - T_a)}{A_{sur} H_g} = \frac{V \rho C_p (T_{III} - T_a)}{A_{sur} H_g}$$

e) CAD geometry of solar pond for design-1:

Three dimensional CAD model of solar pond without tube has been created using ANSYS design modular. The dimensional parameters are use to create solar pond for design-1 are such as; length and width of solar pond is 1 m, height of solar pond is 0.5 m, and depth of UCZ, NCZ & LCZ are 0.1 m, 0.3 m & 0.1 m respectively as shown in figure.

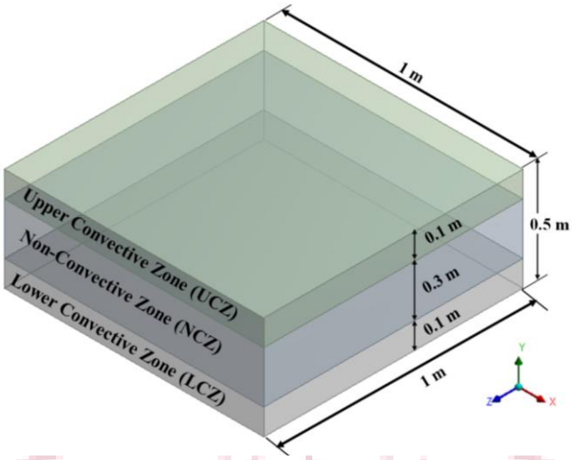

Figure 6: CAD geometry of solar pond for design-1

In the present work is 202848 and total no. of elements is 44180. Types of elements used are hexahedral in shape.

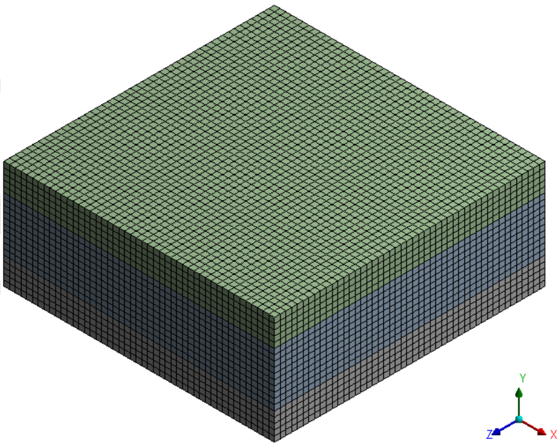

Figure 07: Meshing of solar pond for design-1

f) CAD geometry of solar pond for design-2:

The length and width of solar pond is 1 m, height of solar pond is 0.5 m, and depth of UCZ, NCZ & LCZ are 0.1 m, 0.3 m & 0.1 m respectively, Diameter of serpentine tube is 25 mm with 12 turns as shown in figure.

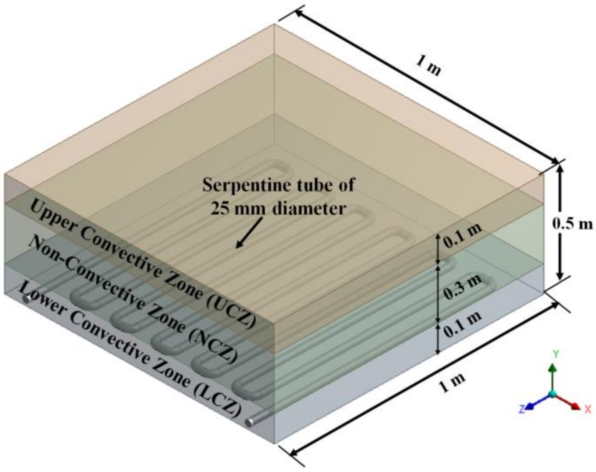

Figure 8: CAD geometry of solar pond for design-2

In the present work is 2767916 and total no. of elements is 814337. Types of elements used are hexahedral and tetrahedral in shape due to complexity of LCZ.

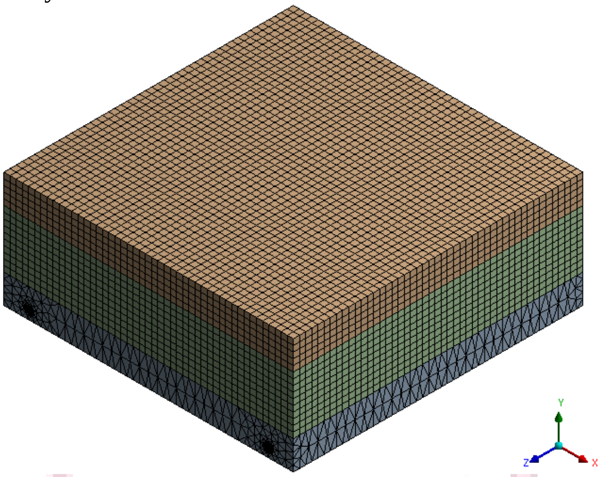

Figure 9: Meshing of solar pond for design-2

g) CAD geometry of solar pond for design-3:

The length and width of solar pond is 1 m, height of solar pond is 0.5 m, and depth of UCZ, NCZ & LCZ are 0.1 m, 0.3 m & 0.1 m respectively, Diameter of spiral tube is 25 mm with 8 coil as shown in figure.

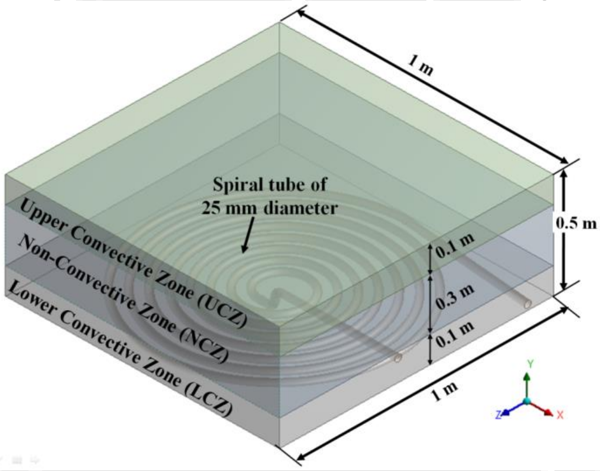

Figure 10: CAD geometry of solar pond for design-3

In the present work is 1045105 and total no. of elements is 559134. Types of elements used are hexahedral and tetrahedral in shape due to complexity of LCZ.

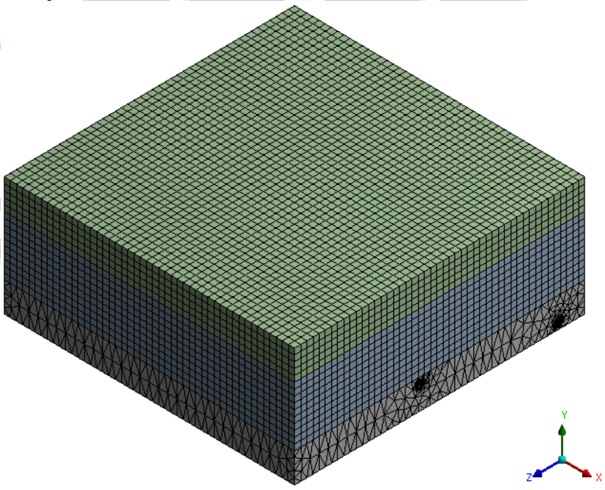

Figure 11: Meshing of solar pond for design-3

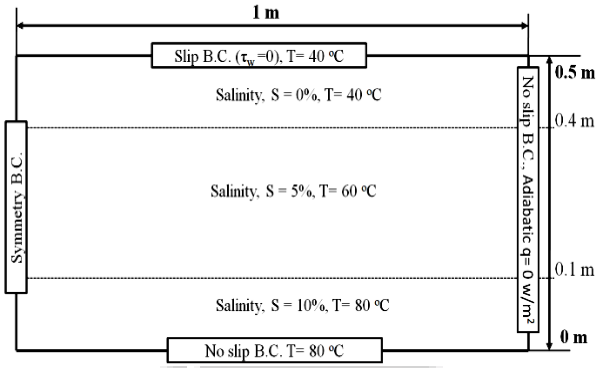

Figure 12: Boundary condition for the computational domain of solar pond

Axisymmetrytwo dimensional CAD model of solar pond with three zone (LCZ = lower convective zone, NCZ = Non-convective zone & UCZ = upper convective zone) has been created. Depth of LCZ = 0.1 m, Depth of NCZ = 0.3 m and Depth of UCZ = 0.1 m with total depth of 0.5 m. Fresh water with zero salinity used for UCZ, for NCZ – 5% salinity used and for LCZ- 10% salinity used. To determine the thermal distribution need to on energy equation. Slip boundary condition assigned to the top wall of solar pond. Though the solar pond is cylindrical and only half section has been created, for that symmetry boundary is assigned to the left wall. No slip boundary condition assigned to the bottom &right side wall of solar pond. Species transport with internal diffusivity has been used to define mass diffusivity between water and NaCl and the value of mass diffusion = 2.32E-9 m^2/Sec assigned. Transient analyses are performed using time step of 1 sec for 1 hour to ensure the bounded stability for accurate progressive evaluation of the flow filed.

LCZ and UCZ are patched with their prescribed temperature and salinity. Temperature values for different zones (LCZ, NCZ & UCZ) are 40 C°, 60 C°& 80 C° for CFD simulation.

IV. RESULT AND DISCUSSION

Total three different three dimensionalCFD model has been developed such as solar pond without pipe, with serpentine tube and solar pond with spiral tube have been used to evaluate the thermal storage performance of the solar pond.

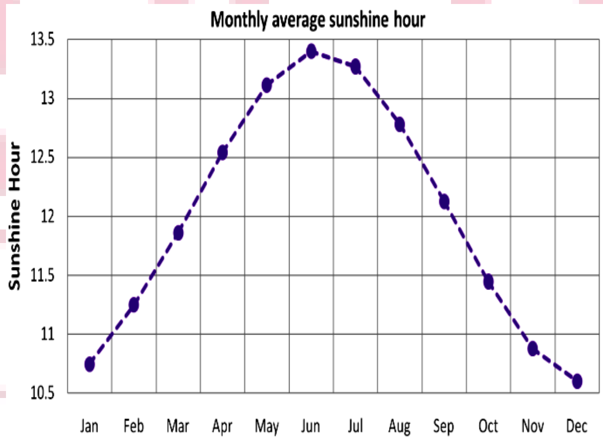

Figure 13: Monthly average sunshine hour

The average sunshine hour for the year ranges from 10.9 hours in the month of December to 13.39 hours in the month of Jun as shown in figure.

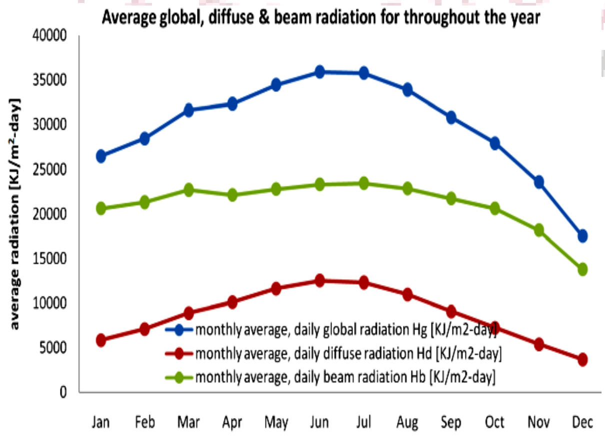

Figure 14: Average global, diffuse & beam radiation for throughout the year

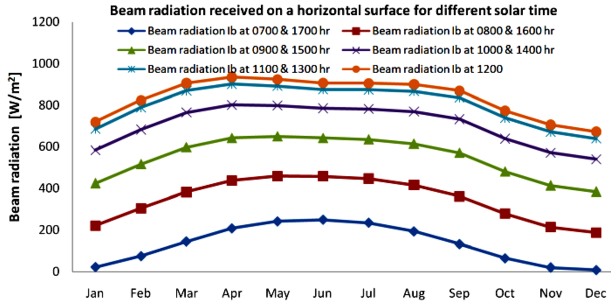

Figure 15: Beam radiation received on a horizontal surface for different solar time

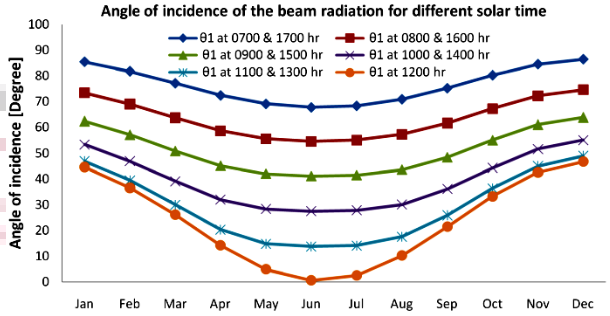

Figure 16: Angle of incidence of the beam radiation for different solar time

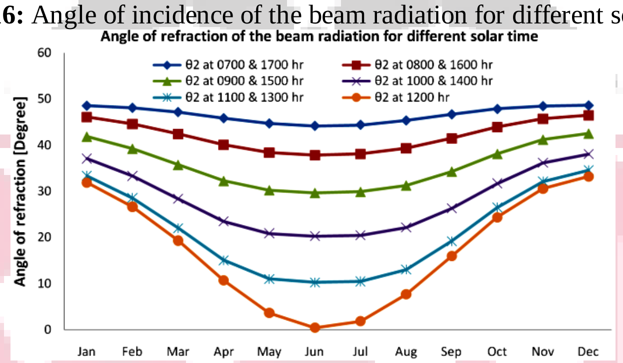

Figure 17: Angle of refraction of the beam radiation for different solar time

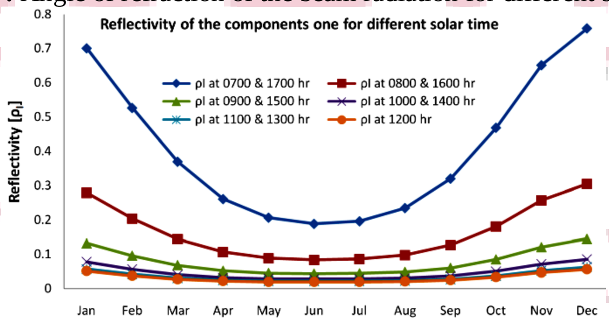

Figure 18: Reflectivity of the components one for different solar time

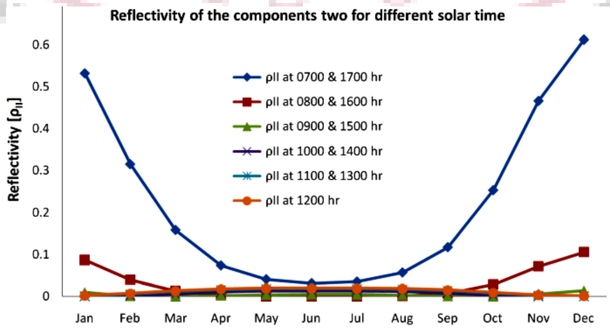

Figure 19: Reflectivity of the components two for different solar time

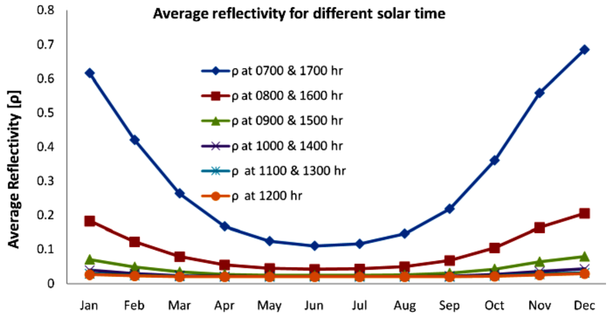

Figure 20: Average reflectivity for different solar time

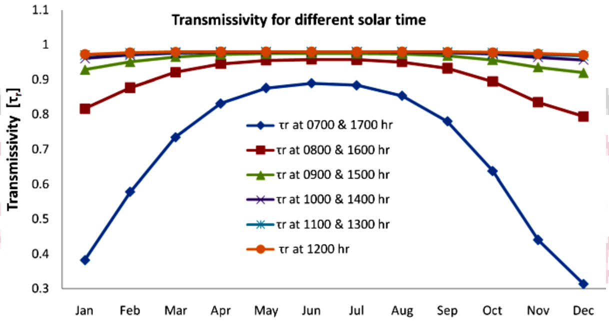

Figure 21: Calculated Transmissivity for different solar time

a) Calculation of Flux reflected from the water surface

$I_{r,water} = I_b.\rho_b + I_d.\rho_d$

For the diffuse radiation take the angle of incidence to be 60°

Calculation of transmissivity of a cover system when the diffuse radiation is incident on it present some diffusivity, because the radiation comes from many direction. The usual practice is to assume that the diffuse radiation is equivalent to beam radiation coming at an angle of incident of 60° by assuming that the amount of diffuse radiation coming from all direction is the same.

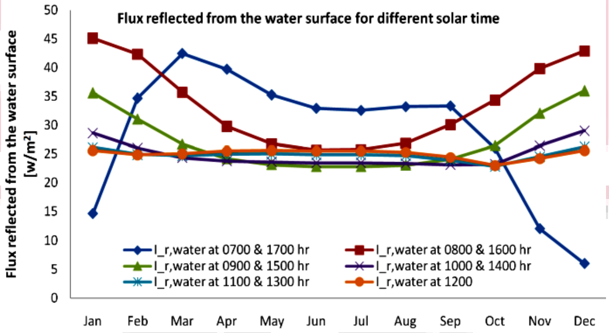

Figure 22: Flux reflected from the water surface for different solar time

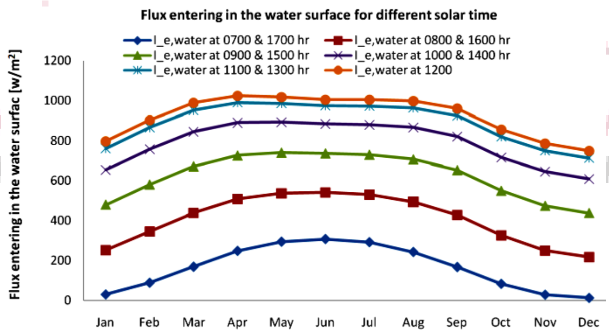

Figure 23: Flux entering in the water surface for different solar time

b) Calculation of Transmissivity based on absorption at different depth of solar pond

According to Bryant and Colbeck:

Transmissivity whem the radiation is not incident normally,

$$\tau_a = 0.36 - 0.08ln\frac{x}{\cos\theta_2}$$

Transmissivity based on absorption for beam radiation

$$\tau_{ab} = 0.36 - 0.08ln\frac{x}{\cos\theta_2}$$

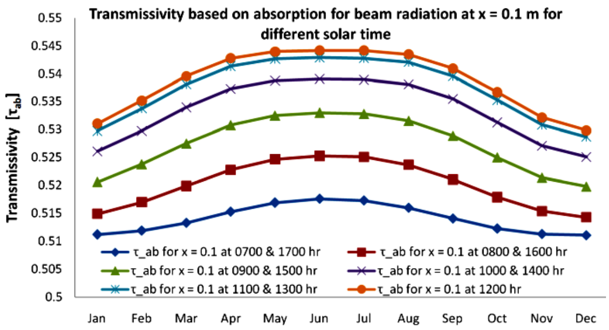

Figure 24: Transmissivity based on absorption for beam radiation at x = 0.1 m for different solar time

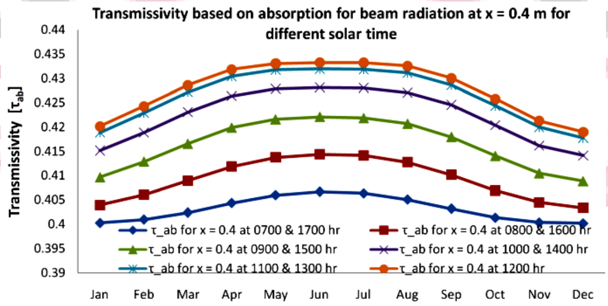

Figure 25: Transmissivity based on absorption for beam radiation at x = 0.4 m for different solar time

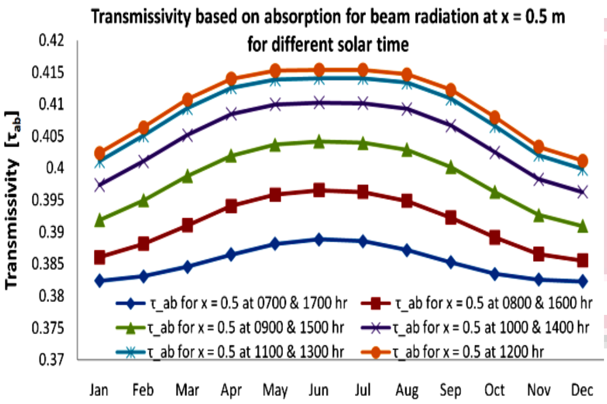

Figure 26: Transmissivity based on absorption for beam radiation at x = 0.5 m for different solar time

c) Transmissivity based on absorption for diffused radiation

For the diffuse radiation take the angle of refraction θ_2 to be 40.63°

$$\tau_{ad} = 0.36 - 0.08 ln \frac{x}{\cos\theta_2}$$

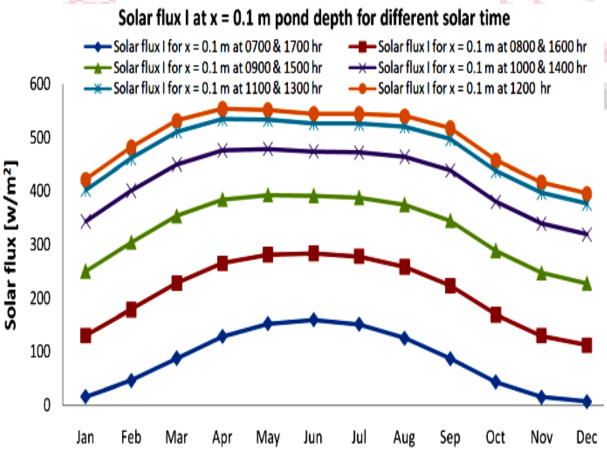

Figure 27: Solar flux I at x = 0.1 m pond depth for different solar time

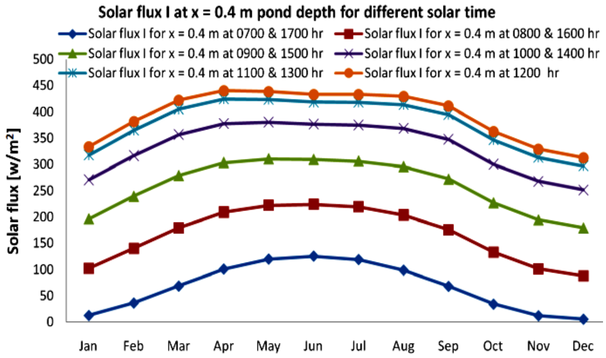

Figure 28: Solar flux I at x = 0.4 m pond depth for different solar time

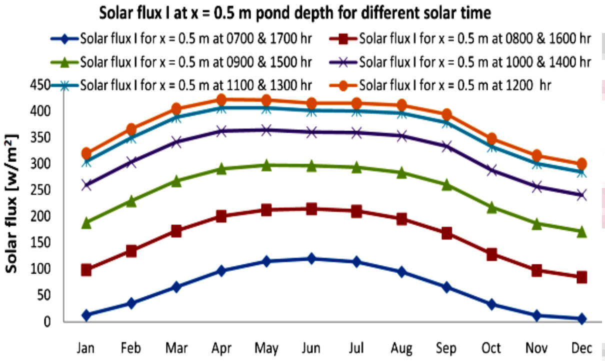

Figure 29: Solar flux I at x = 0.5 m pond depth for different solar time

d) Computational fluid dynamic analysis of solar pond for design-1

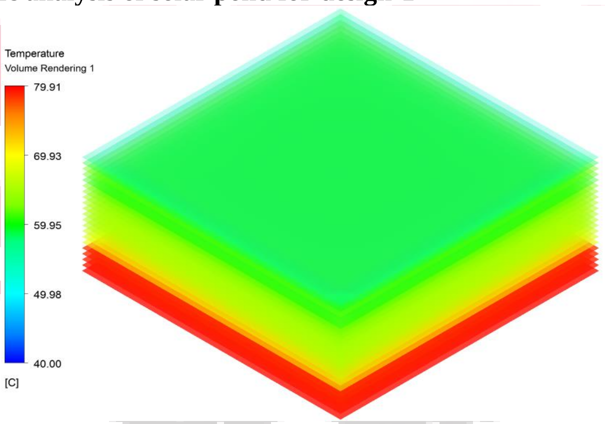

Figure 30: Temperature volume rendering on different layer of solar pond using different salinity concentration for design1

After performing computational fluid dynamics analysis of solar pond without tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with different salinity concentration (NaCl 5% for NCZ & NaCl 10% for LCZ) on different layer has been analyzed, the maximum temperature of 79.91 C° has been observed at the LCZ of the solar pond while the minimum temperature of 40 C° has been observed at the top layer of UCZ.

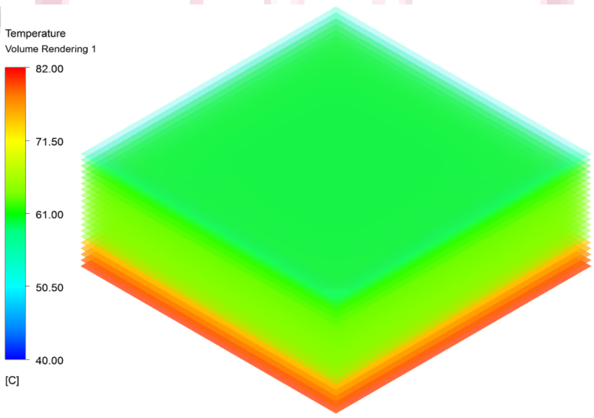

Figure 31: Temperature volume rendering on different layer of solar pond using $Al_2O_3$for design-1

e) Computational fluid dynamic analysis of solar pond for design-2

The maximum temperature of 82.16 C° has been observed at the LCZ of the solar pond while the minimum temperature of 40 C° has been observed at the top layer of UCZ.

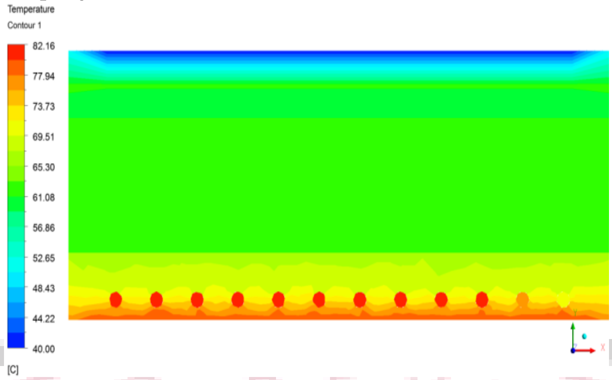

Figure 32: Temperature distribution on different layer of solar pond using different salinity concentration for design-2

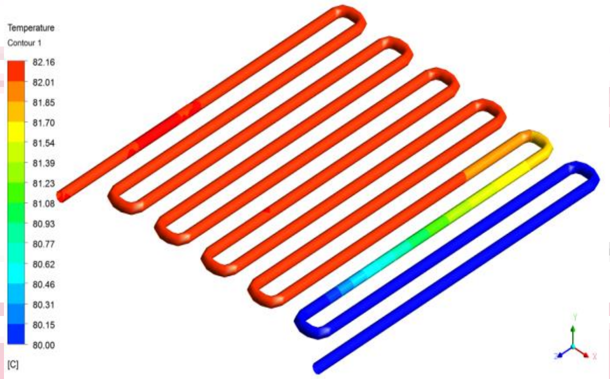

Figure 33: Temperature volume rendering on different layer of solar pond using different salinity concentration for design2

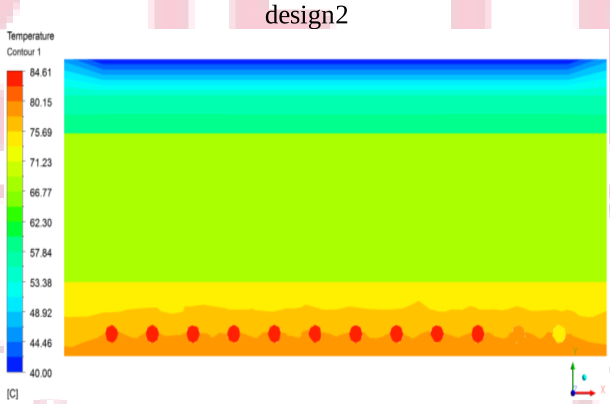

Figure 34: Temperature distribution on different layer of solar pond using $Al_2O_3$for design-2

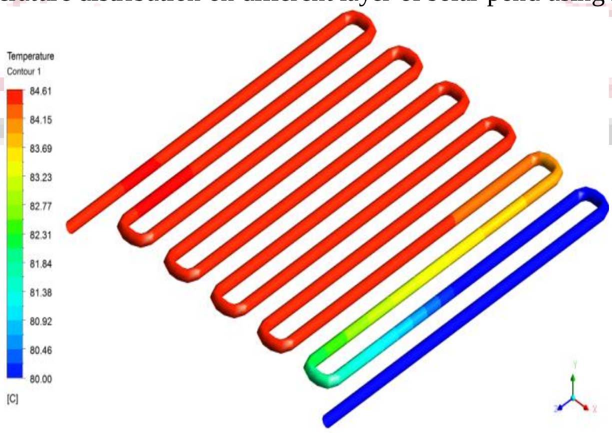

Figure 35: Temperature volume rendering on different layer of solar pond using $Al_2O_3$for design-2

The maximum temperature of 84.61 C° has been observed at the LCZ of the solar pond while the minimum temperature of 40 C° has been observed at the top layer of UCZ.

f) Computational fluid dynamic analysis of solar pond for design-3

The maximum temperature of 91.26 C° has been observed at the mid plane of the solar pond while the minimum temperature of 40 C° has been observed at the top layer of the solar pond.

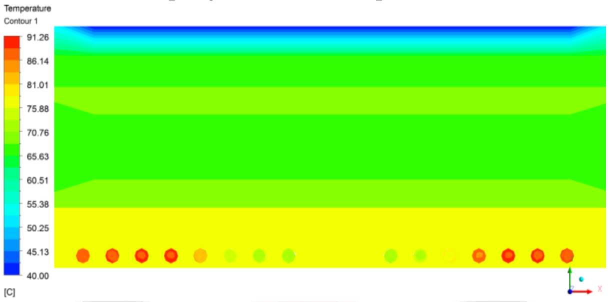

Figure 36: Temperature distribution on different layer of solar pond using different salinity concentration for design-3

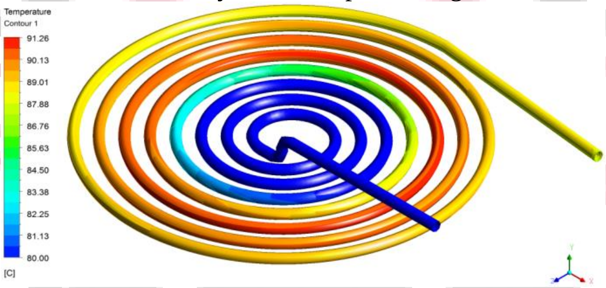

Figure 37: Temperature volume rendering on different layer of solar pond using different salinity concentration for design2

The maximum temperature of 93.75 C° has been observed at the LCZ of the solar pond while the minimum temperature of 40 C° has been observed at the top layer of UCZ.

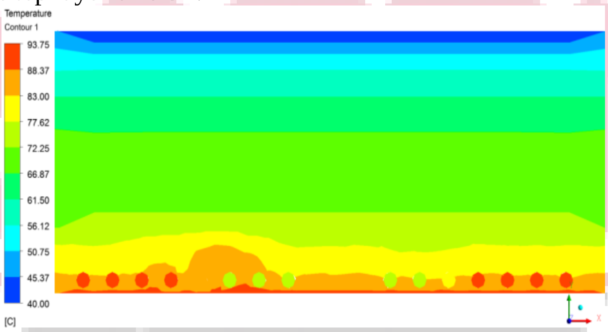

Figure 38: Temperature distribution on different layer of solar pond using $Al_2O_3$for design-3

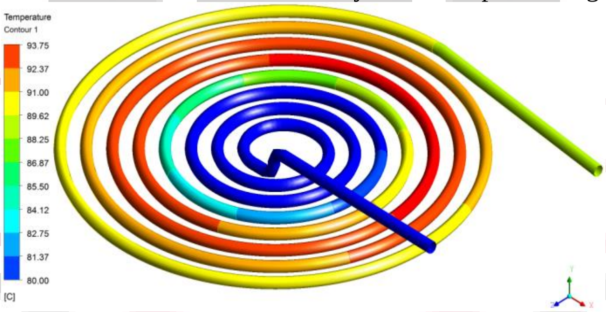

Figure 39: Temperature volume rendering on different layer of solar pond using $Al_2O_3$for design-3

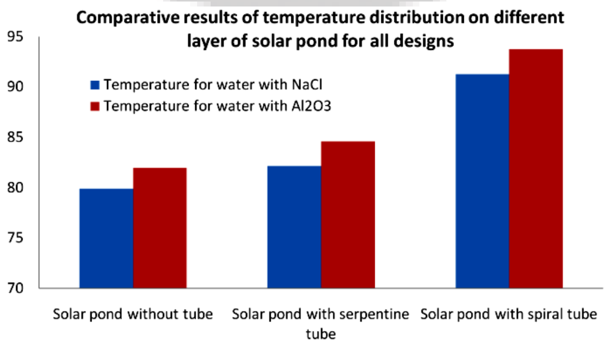

Figure 40: Comparative results of temperature distribution on different layer of solar pond for all designs

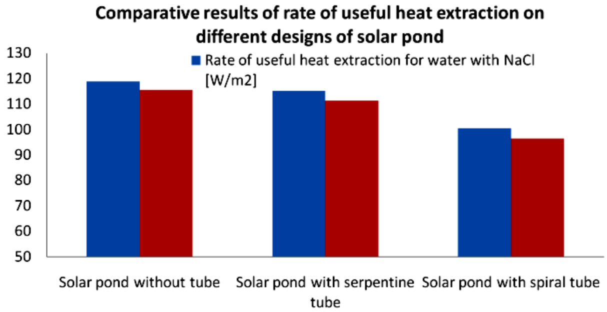

Figure 41: Comparative results of rate of useful heat extractionon different designs of solar pond

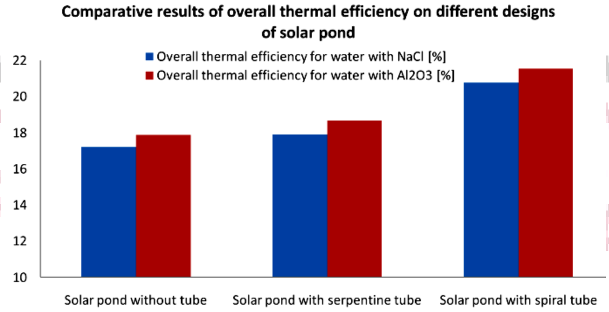

Figure 42: Comparative results of overall thermal efficiencyon different designs of solar pond

V. CONCLUSION

- After performing mathematical and computational fluid dynamics analysis of solar pond without tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with different salinity concentration on different layer has been analyzed, the maximum and minimum temperature of 79.91 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 118.9107 W/m2 and the overall thermal efficiency of the solar pond was observed as 17.22%.
- Solar pond without tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with Al2O3 nano-fluid has been analyzed, the maximum and minimum temperature of 82 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 115.5250 W/m2 and the overall thermal efficiency of the solar pond was observed as 17.87%.
- Solar pond with serpentine tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with different salinity concentration on different layer has been analyzed, the maximum and minimum temperature of 82.16 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 115.2658 W/m2 and the overall thermal efficiency of the solar pond was observed as 17.92%.
- Solar pond with serpentine tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with Al2O3 nano-fluid has been analyzed, the maximum and minimum temperature of 84.61 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 111.2969 W/m2 and the overall thermal efficiency of the solar pond was observed as 18.69%.
- Solar pond with spiral tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with different salinity concentration on different layer has been analyzed, the maximum and minimum temperature of 91.26 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 100.5242 W/m2 and the overall thermal efficiency of the solar pond was observed as 20.78%.
- Solar pond with spiral tube for temperature distribution on different layer such as LCZ, NCZ & UCZ by using water with Al2O3 nano-fluid has been analyzed, the maximum and minimum temperature of 93.75 Co was observed at the LCZ & UCZ respectively, while the useful heat extraction was 96.4905 W/m2 and the overall thermal efficiency of the solar pond was observed as 21.56%.

From the above conclusion it has been observed that design-3 of the solar pond with spiral tube by using both NaCl & Al2O3 nano-fluid gives that better temperature of generation and overall thermal efficiency as compared with all design of solar pond, in that too solar pond by using Al2O3 nano-fluid gives maximum temperature of 93.75 Co and the overall thermal efficiency of 21.56% which is much better than all other design.

REFERENCES

[1] D. Tian et al. (2021) “Enhancement of solar pond stability performance using an external magnetic field” Energy Conversion and Management 243 (2021) 114427; https://doi.org/10.1016/j.enconman.2021.114427.
[2] Gaurav Mittal et al. (2021) “Production of electric power from solar ponds using thermoelectric generator: A review” Materials Today: Proceedings 43 (2021) 608–613 https://doi.org/10.1016/j.matpr.2020.12.148.

[3] Iman Nourollahi et al. (2021) "Investigating the simultaneous effect of effective parameters on the performance of salinity gradient solar ponds using Taguchi analysis: Determination of optimum thickness of the middle layer" Alexandria Engineering Journal (2022) 61, 5607–5619 https://doi.org/10.1016/j.aej.2021.08.088.
[4] Keli Yang et al. (2021) "Tracking variations in the abundance and composition of dissolved organic matter in solar ponds of oilfield-produced brine" Applied Geochemistry 131 (2021) 105008 https://doi.org/10.1016/j.apgeochem.2021.105008.
[5] N. Poyyamozhi & A. Karthikeyan (2021) "Performance comparison of AgTiO2 and CNT based latent heat materials on a solar pond" Materials Today: Proceedings 20 May 2021 https://doi.org/10.1016/j.matpr.2021.05.423.
[6] S. Platikanov et al. (2021) "Multivariate analysis of the operational parameters and environmental factors of an industrial solar pond" Solar Energy 223 (2021) 113–124 https://doi.org/10.1016/j.solener.2021.05.045.
[7] Seyed Masoud Parsa et al. (2021) "Thermodynamic, economic, and sensitivity analysis of salt gradient solar pond (SGSP) integrated with low-temperature multi effect desalination (MED): Case study, Iran" Sustainable Energy Technologies and Assessments 47 (2021) 101478 https://doi.org/10.1016/j.seta.2021.101478.
[8] Sunirmit Verma & Ranjan Das (2021) "Transient study of a solar pond under heat extraction from non-convective and lower convective zones considering finite effectiveness of exchangers" Solar Energy 223 (2021) 437–448 https://doi.org/10.1016/j.solener.2021.05.072.
[9] Susana Cardoso et al. (2021) "Analysis of the thermal performance of an uncovered 1-hectare solar pond in Benguela, Angola" Case Studies in Thermal Engineering 27 (2021) 101254 https://doi.org/10.1016/j.csite.2021.101254.
[10] Abdelfattah El Mansouri et al. (2020) "Feasibility analysis of reverse osmosis desalination driven by a solar pond in Mediterranean and semi-arid climates" Energy Conversion and Management 221 (2020) 113190 https://doi.org/10.1016/j.enconman.2020.113190.
[11] Abhishek Kumar et al. (2020) "Eigen functions and genetic algorithm based improved strategies for performance analysis and geometric optimization of a two-zone solar pond" Solar Energy 211 (2020) 949–961 https://doi.org/10.1016/j.solener.2020.10.032.
[12] Abhishek Kumar & Ranjan Das (2020) "Effect of peripheral heat conduction in salt-gradient solar ponds" Journal of Energy Storage 2020 https://doi.org/10.1016/j.est.2020.102084.
[13] Amin Shekari Namin et al. (2020) "Thermodynamic and thermo economic analysis of three cascade power plants coupled with RO desalination unit, driven by a salinity-gradient solar pond" Thermal Science and Engineering Progress 18 (2020) 100562 https://doi.org/10.1016/j.tsep.2020.100562.
[14] Hadi Ghaebi & Hadi Rostamzadeh (2020) "Performance comparison of two new cogeneration systems for freshwater and power production based on organic Rankine and Kalina cycles driven by salinity-gradient solar pond" Renewable Energy 156 (2020) 748e767 https://doi.org/10.1016/j.renene.2020.04.043.
[15] Manar M. Ali et al. (2020) "Performance of solar pond integrated with photovoltaic/thermal collectors" Energy Reports 7 November 2020 https://doi.org/10.1016/j.egyr.2020.11.037.
[16] Morteza Khoshvaght-Aliabadi & Amir Feizabadi (2020) "Employing wavy structure to enhance thermal efficiency of spiral-coil utilized in solar ponds" Solar Energy 199 (2020) 552–569 https://doi.org/10.1016/j.solener.2020.02.059.
[17] Nidal H. Abu-Hamdeh et al. (2020) "Hydrothermal irreversibility analysis based on multi-criteria assessment in a modified spiral piping system utilized in solar ponds" Renewable Energy 162 (2020) 355e370 https://doi.org/10.1016/j.renene.2020.08.046.
[18] Osamah A.H. AL-Musawi et al. (2020) "Solar pond as a low grade energy source for water desalination and power generation: a short review" EDP Sciences, 2020 https://doi.org/10.1051/rees/2019008.
[19] Shyamal G. Chakrabarty et al. (2020) "Investigation of temperature development in salinity gradient solar pond using a transient model of heat transfer" Solar Energy 202 (2020) 32–44 https://doi.org/10.1016/j.solener.2020.03.052.
[20] Anagnostopoulos A et al. (2020) "Finite element modelling of the thermal performance of salinity gradient solar ponds", Energy (2020), doi.org/10.1016/j.energy.2020.117861.
[21] Khadije El Kadi et al. (2019) "Flow simulation and assessment of a salinity gradient solar pond development" 10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, Energy Procedia 158 (2019) 911–917. Doi: 10.1016/j.egypro.2019.01.230.
[22] Alireza Jafar Gholi Beik et al. (2019) "Transient modeling for the prediction of the temperature distribution with phase change material in a salt-gradient solar pond and comparison with experimental data" Journal of Energy Storage 26 (2019) 101011 https://doi.org/10.1016/j.est.2019.101011.
[23] Amro M.O. Mohamed & Yusuf Bicer (2019) "Integration of pressure retarded osmosis in the solar ponds for desalination and photo-assisted chlor-alkali processes: Energy and exergy analysis" Energy Conversion and Management 195 (2019) 630–640 https://doi.org/10.1016/j.enconman.2019.05.032.
[24] Arezu Zeynali et al. (2019) "Investigation of the performance of modified organic Rankine cycles (ORCs) and modified trilateral flash cycles (TFCs) assisted by a solar pond" Solar Energy 182 (2019) 361–381 https://doi.org/10.1016/j.solener.2019.03.001.
[25] D. Sathish & S. Jegadheeswaran (2019) "Effective study of thermal behavior on membrane stratified portable solar pond" Materials Today: Proceedings 16 August 2019 https://doi.org/10.1016/j.matpr.2019.08.177.
[26] M. Montala et al. (2019) "Stability analysis of an industrial salinity gradient solar pond" Solar Energy 180 (2019) 216–225 https://doi.org/10.1016/j.solener.2019.01.017.

[27] Mahfoudh Ines et al. (2019) “Experimental studies on the effect of using phase change material in a salinity-gradient solar pond under a solar simulator” Solar Energy 186 (2019) 335–346 https://doi.org/10.1016/j.solener.2019.05.011.

[28] Sunirmit Verma & Ranjan Das (2019) “Wall profile optimisation of a salt gradient solar pond using a generalized model” Solar Energy 184 (2019) 356–371 https://doi.org/10.1016/j.solener.2019.04.003.

[29] A Alcaraz et al. (2018) “Thermal performance of 500 m2 salinity gradient solar pond in Granada, Spain under strong weather conditions” Solar Energy 171 (2018) 223–228 https://doi.org/10.1016/j.solener.2018.06.072.

[30] Abhishek Kumar et al. (2018) “Inverse prediction and optimization analysis of a solar pond powering a thermoelectric generator” Solar Energy 169 (2018) 658–672 https://doi.org/10.1016/j.solener.2018.05.035.

[31] Amani Al-Othman et al. (2018) “Novel multi-stage flash (MSF) desalination plant driven by parabolic trough collectors and a solar pond: A simulation study in UAE” Desalination 443 (2018) 237–244 https://doi.org/10.1016/j.desal.2018.06.005.

[32] D Sathish & S Jegadheeswaran (2018) “Relative study of steel solar pond within sodium chloride and pebbles” Materials Science for Energy Technologies 1 (2018) 171–174 https://doi.org/10.1016/j.mset.2018.07.002.

[33] Morteza Khalilian (2017) “Exergetic performance analysis of a salinity gradient solar pond” Solar Energy 157 (2017) 895–904 http://dx.doi.org/10.1016/j.solener.2017.09.010.

[34] Mohammad Reza Assari et al. (2017) “Experiment and optimization of mixed medium effect on small-scale salt gradient solar pond” Solar Energy 151 (2017) 102–109 http://dx.doi.org/10.1016/j.solener.2017.04.042.

[35] Morteza Khalilian (2017) “Energetic performance analysis of solar pond with and without shading effect” Solar Energy 157 (2017) 860–868 http://dx.doi.org/10.1016/j.solener.2017.09.005.

[36] Sayantan Ganguly et al. (2017) “On the addition of heat to solar pond from external sources” Solar Energy 144 (2017) 111–116 http://dx.doi.org/10.1016/j.solener.2017.01.012.

[37] Sayantan Ganguly et al. (2017) “Heat recovery from ground below the solar pond” Solar Energy 155 (2017) 1254–1260 http://dx.doi.org/10.1016/j.solener.2017.07.068.

[38] Shojaeefard et al. (2017) “Investigation of Thermodynamic Performance of Salt Gradient Solar Ponds” Journal of Solar Energy Research 21 (2017) 25-30.

[39] A.A. Abdullah et al. (2016) “Construction of sustainable heat extraction system and a new scheme of temperature measurement in an experimental solar pond for performance enhancement” Solar Energy 130 (2016) 10–24 http://dx.doi.org/10.1016/j.solener.2016.02.005.

[40] Assad H. Sayer et al. (2016) “New theoretical modeling of heat transfer in solar ponds” Solar Energy 125 (2016) 207–218 http://dx.doi.org/10.1016/j.solener.2015.12.015.

[41] L.C. Ding et al. (2016) “Transient model to predict the performance of thermoelectric generators coupled with solar pond” Energy 103 (2016) 271e289 http://dx.doi.org/10.1016/j.energy.2016.02.124.

[42] Safwan Kanan et al. (2016) “The effect of ground conditions under a solar pond on the performance of a solar air-conditioning system” Energy Procedia 91 (2016) 777 – 784 (http://creativecommons.org/licenses/by-nc-nd/4.0/).

[43] Ismail Bozkurt & Mehmet Karakilcik (2015) “The effect of sunny area ratios on the thermal performance of solar ponds” Energy Conversion and Management 91 (2015) 323–332 http://dx.doi.org/10.1016/j.enconman.2014.12.023.

[44] Ismail Bozkurt et al. (2015) “Performance assessment of a magnesium chloride saturated solar pond” Renewable Energy 78 (2015) 35e41 http://dx.doi.org/10.1016/j.renene.2014.12.060.

[45] Ismail Bozkurt & Mehmet Karakilcik (2015) “Exergy analysis of a solar pond integrated with solar collector” Solar Energy 112 (2015) 282–289 http://dx.doi.org/10.1016/j.solener.2014.12.009.

[46] Khaled Nakoa et al. (2015) “An experimental review on coupling of solar pond with membrane distillation” Solar Energy 119 (2015) 319–331 http://dx.doi.org/10.1016/j.solener.2015.06.010.

[47] M. Appadurai & V. Velmurugan (2015) “Performance analysis of fin type solar still integrated with fin type mini solar pond” Sustainable Energy Technologies and Assessments 9 (2015) 30–36 http://dx.doi.org/10.1016/j.seta.2014.11.001.

[48] Mohammad Reza Assari et al. (2015) “Experimental investigation of heat absorption of different solar pond shapes covered with glazing plastic” Solar Energy 122 (2015) 569–578 http://dx.doi.org/10.1016/j.solener.2015.09.013.

[49] K.R. Ranjan & S.C. Kaushik (2014) “Thermodynamic and economic feasibility of solar ponds for various thermal applications: A comprehensive review” Renewable and Sustainable Energy Reviews 32 (2014) 123–139; http://dx.doi.org/10.1016/j.rser.2014.01.020.

[50] Safwan Kanan (2014) “A Simple Heat and Mass Transfer Model for Salt Gradient Solar Ponds” International Journal of Mechanical, Industrial Science and Engineering Vol:8 No:1, 2014; DOI: 10.13140/2.1.1953.6328.

[51] Sura Tundee et al. (2014) “Electric power generation from solar pond using combination of thermosyphon and thermoelectric modules” Energy Procedia 48 (2014) 453 – 463; doi: 10.1016/j.egypro.2014.02.054.

[52] Karakavalasa.Goutham & Chukka .Siva Krishna (2013) “Solar pond technology” International Journal of Engineering Research and General Science Volume 1, Issue 2, December 2013;

[53] Aliakbar Akbarzadeh et al. (2005) “Solar ponds” solar energy conversion and photoenergy systems – Vol. I - Solar Ponds.

[54] H. Al-Hussaini & K. O. Suen (1998) “Using shallow solar ponds as a heating source for greenhouses in cold climates” Energy Conversion and Management Volume 39, Issue 13, 1 September 1998; https://doi.org/10.1016/S0196-8904(98)00007-7.

[55] A. Belhadj et al. (2018) “numerical investigation of forced convection of nanofluid in micro channels heat sinks” Journal of Thermal Engineering, Vol. 4, No. 5, pp. 2263-2273 July, 2018 Yildiz Technical University Press, Istanbul, Turkey. DOI: 10.18186/thermal.438480.

[56] K N Shukla et al. (2016) “Mathematical Modeling of Solar Radiation incident on Tilted Surface for Photovoltaic Application at Bhopal, M.P, India” International Journal of Ambient Energy, year 2016, PP DOI: 10.1080/01430750.2015.1023834 DOI: 10.1080/01430750.2015.1023834.

[57] SP sukhatme 2008” Solar energy principles of thermal collection and storage” textbook, The McGraw-hill companies, third edition.