Development of A Solar Pond And CFD Modeling At Sikar

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Abstract- *Solar pond is a device which absorbs solar energy and stores it as thermal energy. Simple salt gradient solar pond consists of three basic layers: lower convective zone, non-convective zone and last is upper convective zone. In present study a simple working experimental setup of salt gradient solar pond was fabricated in Sobhasaria Group of Institutions, Sikar (Rajasthan) with locally available materials. Different salt concentration layers were made and Salinity gradient was established successfully. Three day field experiment was conducted by considering a 1m3 solar pond. Three different salt concentrations were considered to perform the study. In present study working 3-D full scale solar pond CFD model was also developed and validated with experimental results. CFD results and effect of salt concentration, effect of local time and effect of height was investigated and present in this research paper. It was found that as salt concentration was increased, performance of solar pond was also increased. A good Agreement was found between experimental and CFD results which indicates the validity of data.*

Keywords- Salt gradient solar pond, Salt concentration, Salinity gradient, CFD Modeling.

I. INTRODUCTION

Solar pond is a device which is used to entrap solar radiation and to store it in layers of saline water as thermal energy. It is basically a deep saline water body can be classified in three layers namely upper convective zone (UCZ), non-convective zone (NCZ) and Lower convective zone (NCZ)

The saltwater naturally forms a vertical salinity gradient which is known as a "halocline", in which low-salinity water floats on top of high-salinity water. The concentration (density) of salt solution increases with increase in depth. Below a certain depth, the solution has almost uniform high salt concentration

In an ordinary pond, the sun's rays heats up the water and the heated water from within the pond starts moving upwards and reaches the top but simultaneously loses the heat into the atmosphere. So the total effect is that the pond water remains at the atmospheric temperature. The solar pond restricts this process by dissolving salt in the bottom layer of the pond thus making it too heavy to rise.

UCZ consist of normal water and is the thinnest layer situated at the top of the solar pond. NCZ is the middle layer and has a gradually decreasing salinity gradient while moving upwards; it works as an insulator by restricting the upward movement of hot water due to decreasing density in upward direction. LCZ is the lowest layer has highest density and works as a heat storage.

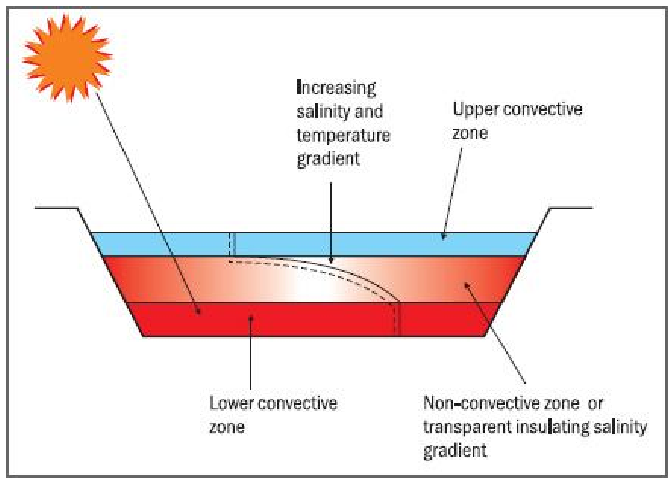

Figure 1.1 Working principle of solar pond

1.1 Types of solar pond

There are many types of solar ponds based on their applications. Some of them are classified as the following:

A. Convective Solar Pond: it is basically a shallow pure water pond which allows convection but restricts evaporation has insulation foam below and bottom is made black, with a glazing sheet placed on top. At night the hot water is pumped out and stored in large heat storage tank.

B. Non-Convective solar pond: It is deep shallow body of water containing dissolved salts to generate a stable density gradient (fresh water on top and denser salt at the bottom) with long time storage capacity. The hot salt water can be used to drive turbine and electric generator with the help of suitable fluids, provision of process hot water for industrial and commercial purposes, space heating, air conditioning and hot water according to need.

II. FABRICATION AND THEORY

Aim of this research work is to investigate thermal performance of solar pond installed in hot and dry climatic conditions of Rajasthan. Simple sea salt is use in this research work. Another aim of this research study is to apply CFD simulation technique on solar pond. This task is fulfilled by Ansys Fluent software. Various salt gradient compositions were used in this study for experimental analysis. 1 m3 volume solar pond is fabricated for this study. Experimental validation of CFD results was also carried out in this research work. Proper insulation was provided in fabricated setup to reduce heat losses. All instruments were properly calibrated and made un-certainty free for this research study.

J-Type Thermocouples were used in this study for taking temperature data at every 10 cm of height difference. Anemometer, multimeter, digital thermometer was used for various purposes.

Table 2.1 Construction material for salt gradient solar pond

S. No.	Material/ Instrument	Purpose
1	Thermocol sheet	Insulating Walls
2	Glass	Transparent layer
3	Wood Sheet	Side walls
4	White paint	All walls
5	Pipes	Inlet/ Outlet
6	Data Logger	Temperature measurement
7	TDS meter	Water quality
8	Measuring jar	Measurement of water
9	Salt	Saline water

Salt Layers for different zones are made with care and time. First of all the actual requirement of salt for every zone in solar pond is calculated, after that proper solution was made by using water and calculated salt quantity. This solution was poured into pond by using proper pipe system made for solar ponds.

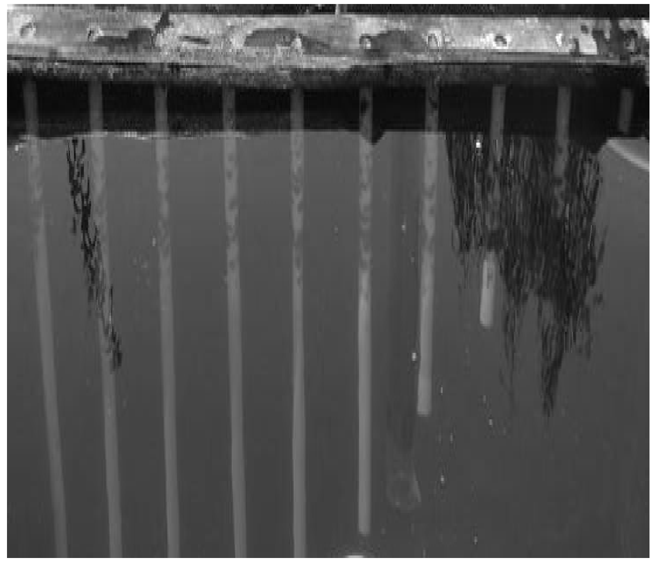

Figure 2.1 Pipe systems for zone making for solar pond

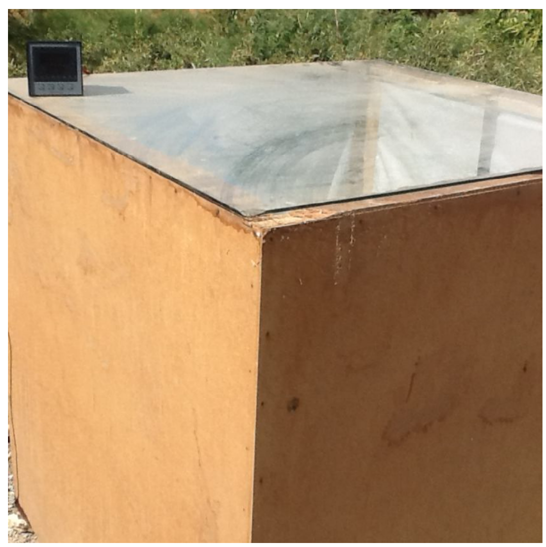

Fig 2.2 Fabricated solar pond

The ANSYS Design Modeler is used to create the 3D geometry of salt gradient solar pond. The Solar pond has dimensions as 1m X 1m X 1m (Length x width x height). A circular tube of diameter 21mm is place above 50mm to the bottom. The tube has 1 m length as shown in figure 2.3, the top of the solar pond is considered as glass top and the bottom as absorber plate. All the side walls of the pond considered as insulated wall (Perfect Thermocol sheet on wood sheet).

Boundary conditions are given to CFD domain in pre-processing and this is the last step for pre-processing and shown in figure 2.4 for same domain.

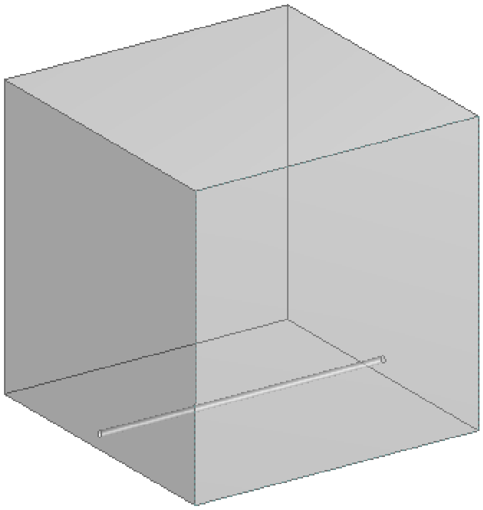

Figure 2.3 CFD Domain Geometry

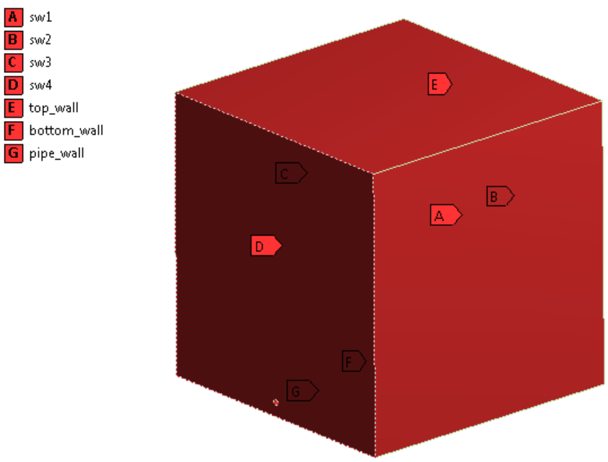

Figure 2.4 Boundary named Selection in ICEM CFD

In CFD numerical modeling, various governing equations are used, as per problem requirement, but some equations are mandatory for every type of simulation, from these some important governing equations are present here with short description of these equations. All important governing equations are present in following table.

Table 2.2 Important governing equations

Physics	GE	Application in Current Study
Energy	1 GE for 3D mode	Perform analysis for Heat Transfer
Momentum	GE for x-momentum GE for y-momentum GE for z-momentum	Describe the flow in problem
Mass Conservation	GE for Continuity	Describe the phase in fluid flow
Turbulence	GE for two Equation Model 1 GE for k (Kinetic Energy) and 1 GE for e(dispassion rate)	Describe the turbulence in model used for current study

III. RESULT AND DISCUSSION

After fabrication of solar pond and CFD simulation various results were studied. Comparison between temperature data of experimental and CFD results was carried out. Detailed study of the setup was carried out in CFD.

CFD simulation of salt gradient solar pond is only acceptable, when CFD results will be validated with experimental results. In this section experimental validation was conduct for different salty layers in solar pond. Three different combinations made of 5 %, 10% and 15 % salt concentration in LCZ are validated with experimental results. Experimental results are present in table 3.2 and CFD results are present in table 3.1.

Table 3.1 CFD Results for Solar Pond using Ansys Fluent

Height (cm)	CFD Temperature (K)		
	FW/2.5/5% -CFD	FW/5/10 %-CFD	FW/7.5/15 %-CFD
10	289.69	289.96	290.56
20	289.31	289.78	290.19
30	289.21	289.56	289.98
40	288.89	289.07	289.78
50	288.56	288.88	289.35
60	288.19	288.46	288.86
70	287.87	288.02	288.56
80	287.53	287.68	288.21
90	287.25	287.45	287.99
100	286.95	287.07	287.56

Table 3.2 Experimental data for solar pond set up

Height (cm)	Experiment Temperature (K)		
	FW/2.5/5% -Exp	FW/5/10 %-Exp	FW/7.5/15 %-Exp
10	291	291	292
20	290	291	291
30	290	290	291
40	289	290	291
50	289	290	291
60	288	289	290
70	288	289	290
80	287	288	289
90	287	288	288
100	287	288	288

In above tables it can be seen that there was a good agreement between experimental and CFD setup reading of temperature. The graphs made on based of above readings are made and presented below for easy learning of agreement between CFD and experimental results.

In CFD simulation one more salt concentration combination of 20% salt in LCZ was considered for more detailed high concentration study of solar pond. All effects are studied in CFD simulation.

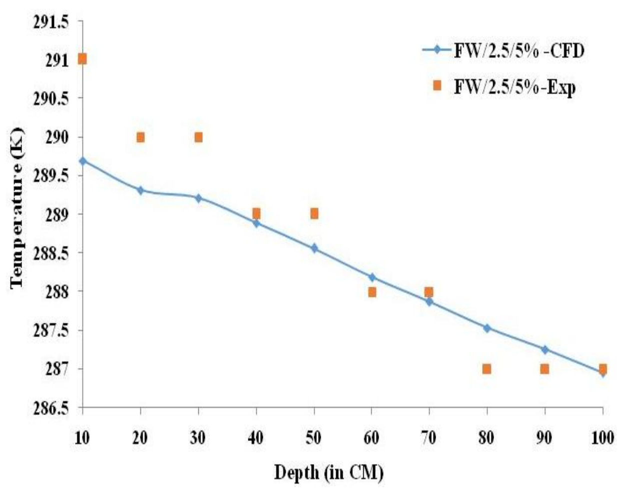

Figure 3.1 CFD and Experimental results for Salt concentration 5%

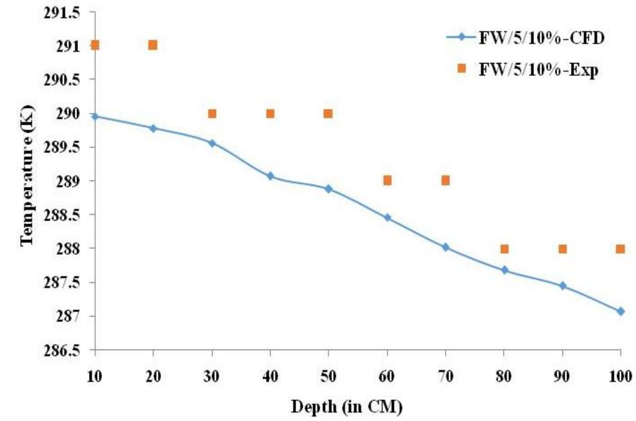

Figure 3.2 CFD and Experimental results for Salt concentration 10 %

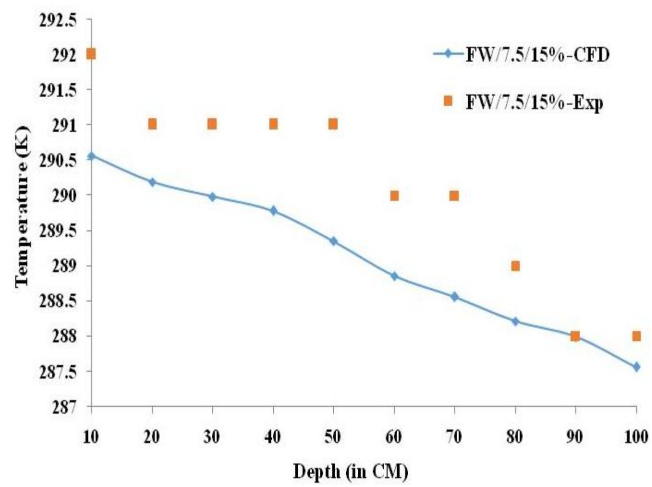

Figure 3.3 CFD and Experimental results for Salt concentration 15 %

As CFD simulations are used in the current study effect of various parameters are studied and various graphs was made for more learning on the topic. Here are some graphs presented.

Effect depth on different salt concentration and temperature

In present study various salt concentrations was prepared in solar pond and investigated their effect on density on salty water as per different depths which are present in fgure 3.4. It was seen that highest density was observed in LCZ of solar pond for various different salt concentrations.

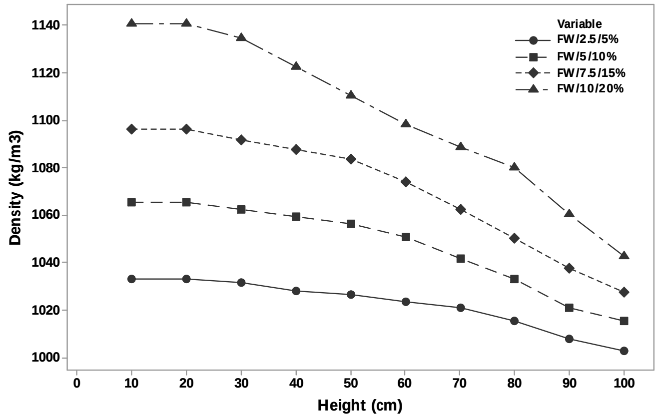

Figure 3.4 Effect of depth on density on solar pond

The effect of salt concentration on the basis of depth on temperature of salty water was present in figure 3.5. It was seen from this figure that temperature was decreased as we approach to top layer of UCZ. It means maximum temperature was stored at LCZ zone of solar pond.

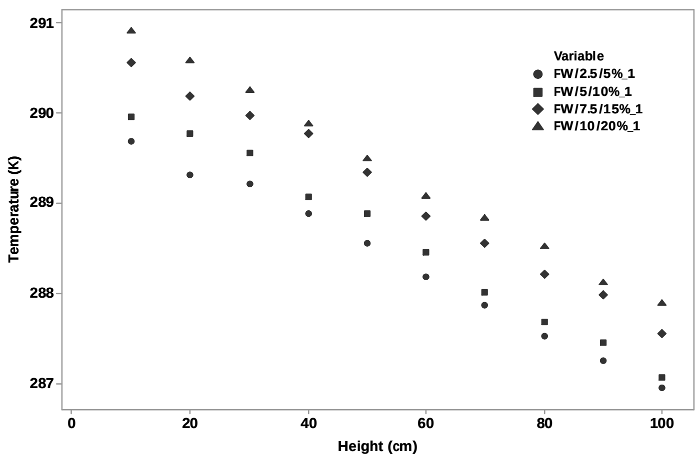

Figure 3.5 Effect of Depth on temperature on Solar Pond

Effect of Local Time

Full day temperature effect on solar pond was present in this section and present in figure 3.6

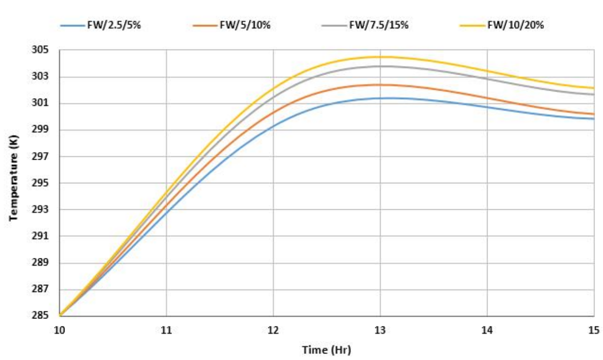

Figure 3.6 Effect of time on temperature on solar pond

As seen from figure 3.6, temperature was increased till 1 pm but decreased from 1 pm till evening time. The figure was generating for LCZ zone only, because our main interest was on this zone. Figure 3.7 present only temperature variation for LCZ zone in detailed manner and it was seen that at bottom temperature was maximum but as we approach to NCZ, temperature decreased till NCZ layer.

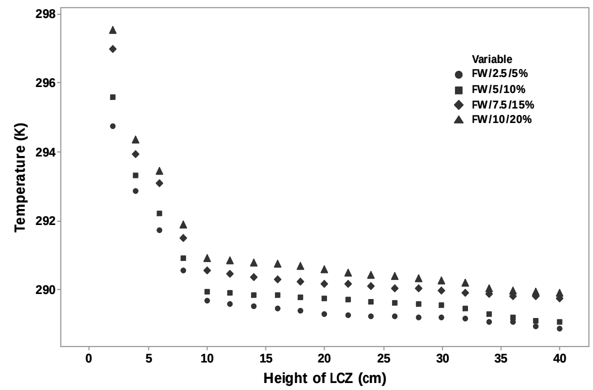

Figure 3.7 Effect of LCZ depth on temperature of pond

CFD Temperature Contours

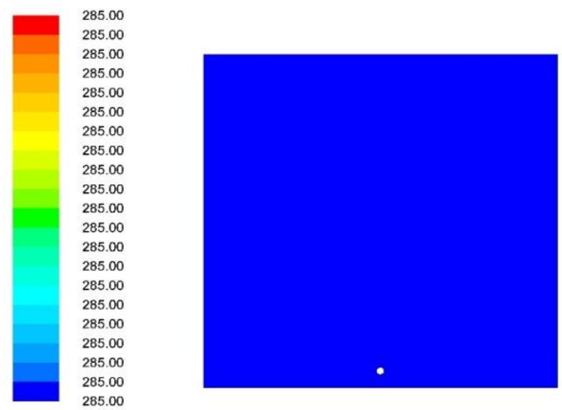

Figure 3.8 Temperatures at 10:00 AM for 5% salt Concentration

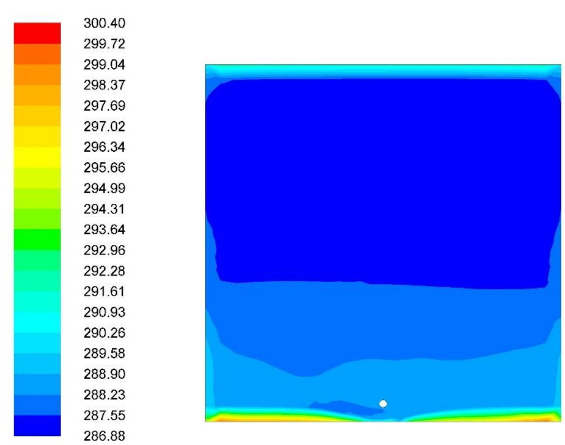

Figure 3.9 Temperature at 12:30 PM for 5% salt Concentration

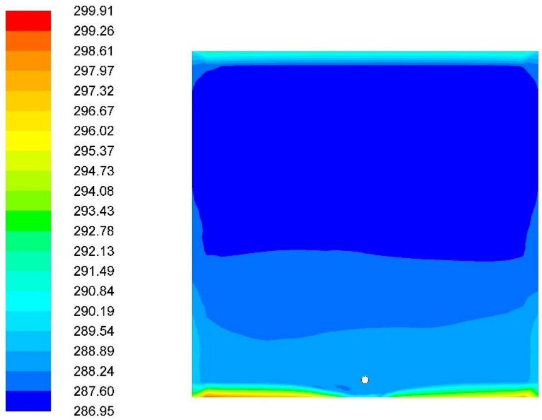

Figure 3.10 Temperature at 3:00 PM for 5% salt Concentration

CFD Density Contours

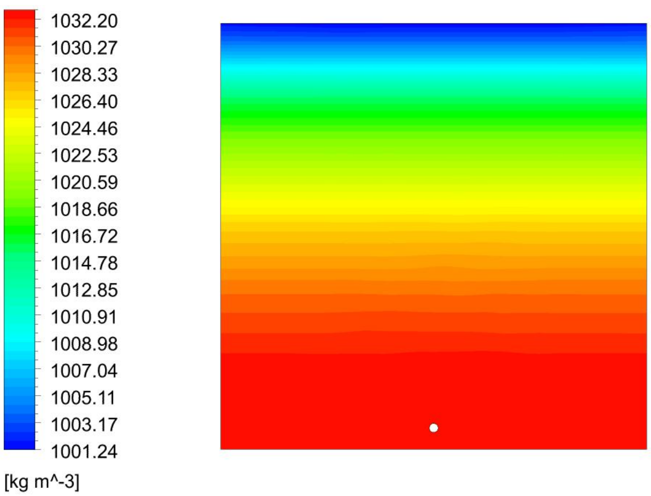

Figure 3.11 Density variations for 5% salt Concentration at LCZ

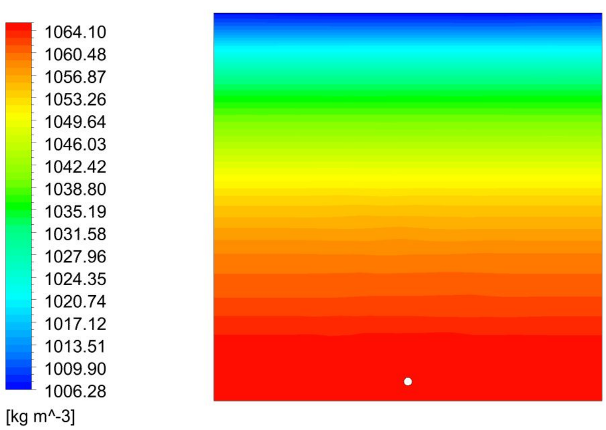

Figure 3.12 Density variations for 10% salt Concentration at LCZ

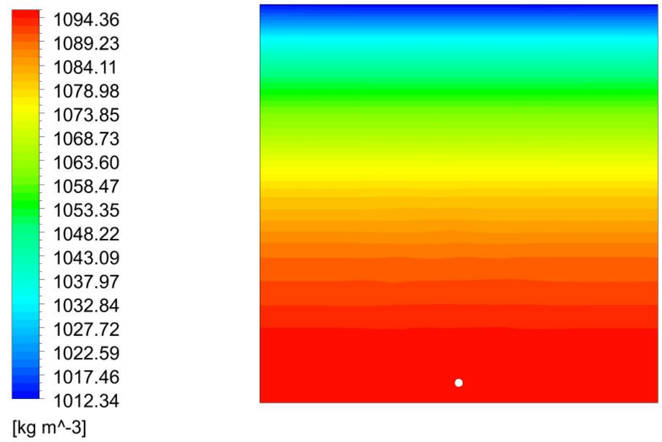

Figure 3.13 Density variations for 15% salt Concentration at LCZ

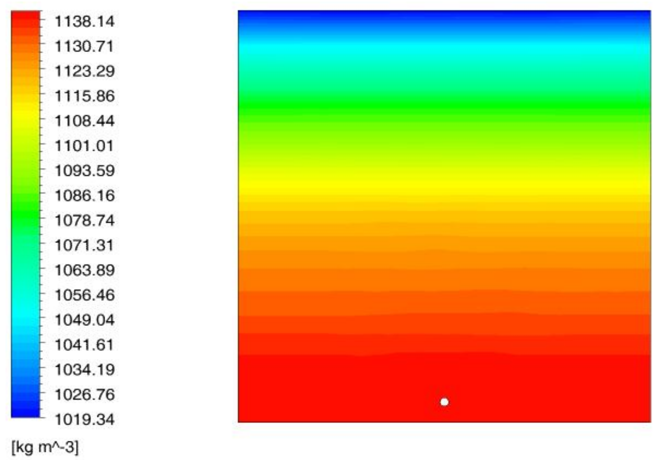

Figure 3.14 Density variations for 20% salt Concentration at LCZ

The above contours were generated from CFD and only one case of salt concentration is presented here for understanding purpose of temperature distribution pattern inside the solar pond.

IV. CONCLUSION

A salt gradient solar pond was successfully fabricated by using locally available material. Three different combinations of salt concentrations were considered for experimental study of solar pond. CFD modeling was carried out for same experimental solar pond with four salt concentration combinations. Experimental and CFD results were validated and a good agreement was found in them. It was observed that temperature rises rapidly till 1 PM and then there is a slow decline in it afterwards.

Maximum temperature was found in the bottom of LCZ and it decreases when moving towards the top of solar pond. In LCZ temperature is almost constant in the lower layers after certain depth. Density decreases from bottom to top direction and develops a salt gradient. The maximum temperature was observed for the combination of 20% salt concentration of LCZ. All experiments are performed for full day production in which minimum hourly energy output were found after 3 pm due to lack of solar radiation in water basin of solar pond. Yield productivity of solar pond heavily depend upon solar radiation which is directly associated with climatic condition.

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