Optimization of Solar Pond Equipped with Thermo Siphon using MATLAB

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Abstract

Solar pond is a device which entraps the impinging solar radiation and stores it as thermal energy in its salty layers. 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 equipped with thermo siphon heat exchanger of capacity of 20 l 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 combinations of salt concentrations were considered to perform the study. Model equations are developed for density and temperature variation in solar pond by MATLAB and validated with MOGA optimization technique.
Keywords- Salt Gradient Solar Pond, Thermo Siphon, MATLAB, MOGA

I. INTRODUCTION

Solar pond is a salty water body which absorbs solar radiation falling on it and stores it in its high saline layers as thermal energy for future use. Generally the heated water moves upwards due to its lower density but in a solar pond this natural process is restricted due to high density of lower layers because of their high salt concentration then upper layers.
This stored energy is then used for other applications whenever demanded. Some examples are as follows

A. Heating and Cooling of Buildings
Lower convection zone of the solar pond has large heat storage capacity. So even at high latitude stations and after several cloudy days it can provide energy for heating. Several scientists have attempted and developed solar pond for house heating including community, residential and commercial space heating.

B. Production of Power
A solar pond can be used to produce electricity by driving a thermo-electric setup or an organic Rankine cycle engine - a turbine powered by evaporating an organic fluid with great feasibility in those areas where there is sufficient isolation and terrain, and soil conditions allow for construction and operation of large area solar ponds necessary to generate sufficient quantity of electrical energy. Even low temperature heat that is obtained from solar pond can be converted into electric energy. The conversion efficiency is limited because of low operating temperatures i.e.70-100ºC.

C. Industrial Process Heat
For preparation and treatment of materials and goods manufacturing in the industry; industrial process heat i.e. the thermal energy is required which can be used from solar pond. The economic issue of solar pond for supply of process heat in industries has been described by various scientists. According to them oil, natural gas, electricity, coal and other conventional energy sources can be saved by supplying the process heat to industries using solar pond. It is found in various studies that for crop drying and for a paper industry, the heat from solar pond is highly competitive with oils and natural gas.

D. Desalination
To desalt or purify water for use in drinking or irrigation the low cost thermal energy can be used. For getting distilled water multi-flash desalination units along with a solar pond is an attractive combination because the multi-flash desalination plant below 100ºC which can well be achieved by a solar pond. The areas where portable water is in short supply and brackish water is easily available this system will be suitable. The cost of distilled water seems to be high for industrialized and developed countries but can be used in developing countries where there is a shortage of potable water.

E. Heating Animal Housing and Drying Crops on Farms
Low grade heat can be used in many ways on farms, which have enough land for solar ponds. Several small demonstration ponds are established in Ohio, Iowa and Illinois have been used to heat green houses and hog barns.

II. FABRICATION AND PROCEDURE

In present study 1 m^3 solar pond was coupled with thermo-siphon heat exchanger. Simple copper pipe was installed at bottom of solar pond; this copper pipe was attached with PVC pipes. These PVC pipes were attached with 20 L water tank. The heating process was occurring due to thermo-siphon heat transfer effect.

Aim of this research work is to investigate thermal performance of hybrid solar pond installed in hot and dry climatic conditions of Rajasthan. Simple sea salt is use in this research work. Various salt gradient compositions were used in this study for experimental analysis. 1 m^3 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 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.

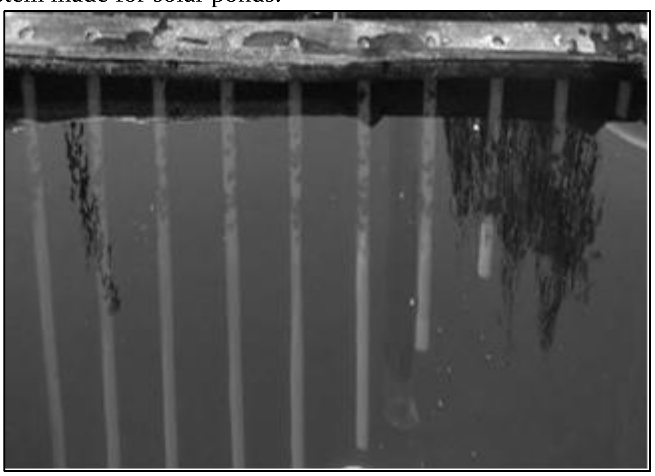

Fig. 1: Pipe systems for zone making for solar pond

Fig. 2: Fabricated solar pond

The above developed model solar pond was equipped with domestic water heating thermo siphon tank of capacity 20 liters with help of plastic pipes and a copper pipe at the bottom of solar pond. Below is the working diagram of thybrid solar pond.

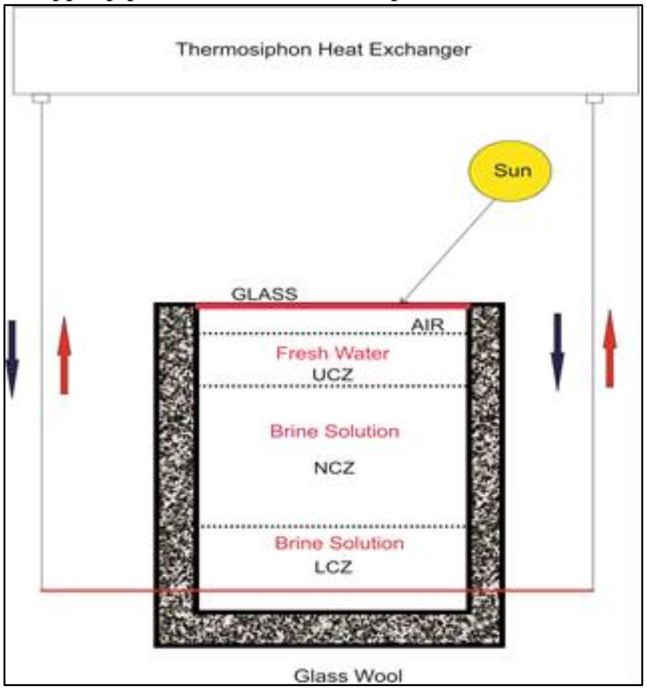

Fig. 3: Working diagram of Salt gradient solar pond

Three full day experiments were conducted for this hybrid solar pond for three different salt concentrations. Solar radiation data was taken from Indian meteorological department. Temperature for copper pipe and thermo siphon tank was recorded at different time. Energy output for the tank was calculated with help of obtained data and efficiency was determined. 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.

III. RESULTS 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.

A. CFD Validation

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 and CFD results are present in table 2.

Table 2: 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: 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.

B. Performance Analysis of Thermo Siphon Heat Exchanger

Total three days experiments are performed with salt gradient solar pond for three conditions as discussed in experimental validation. Figure 4, figure 5, and figure 6 present thermal efficiency for thermo-siphon heat exchanger.

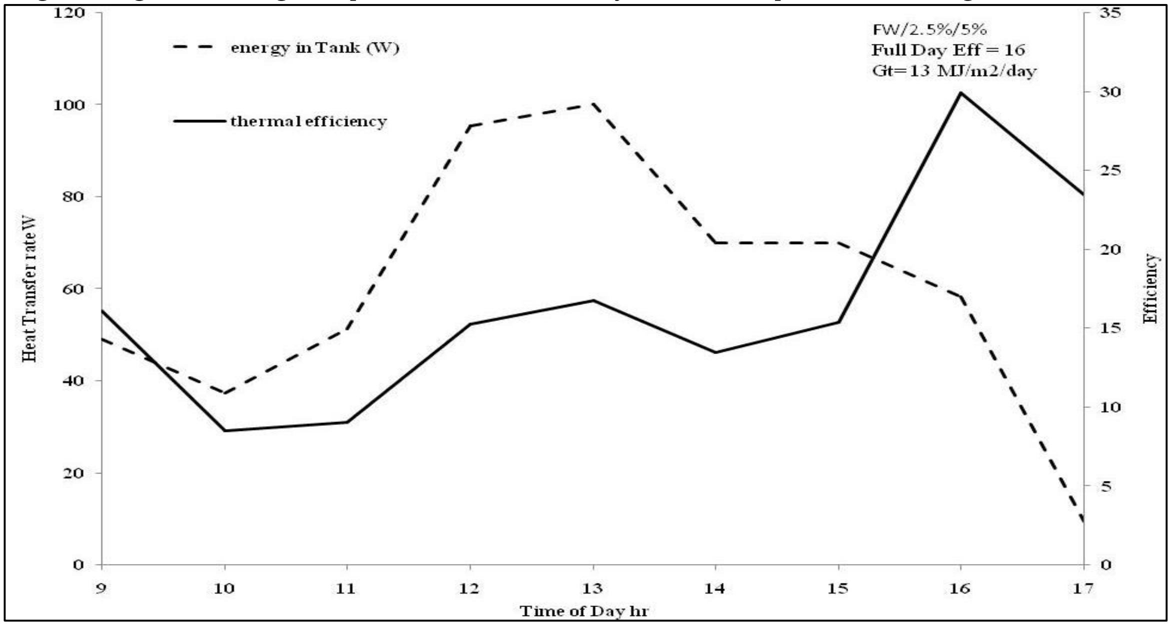

Fig. 4: Thermal efficiency for FW/2.5%/5% salt concentration

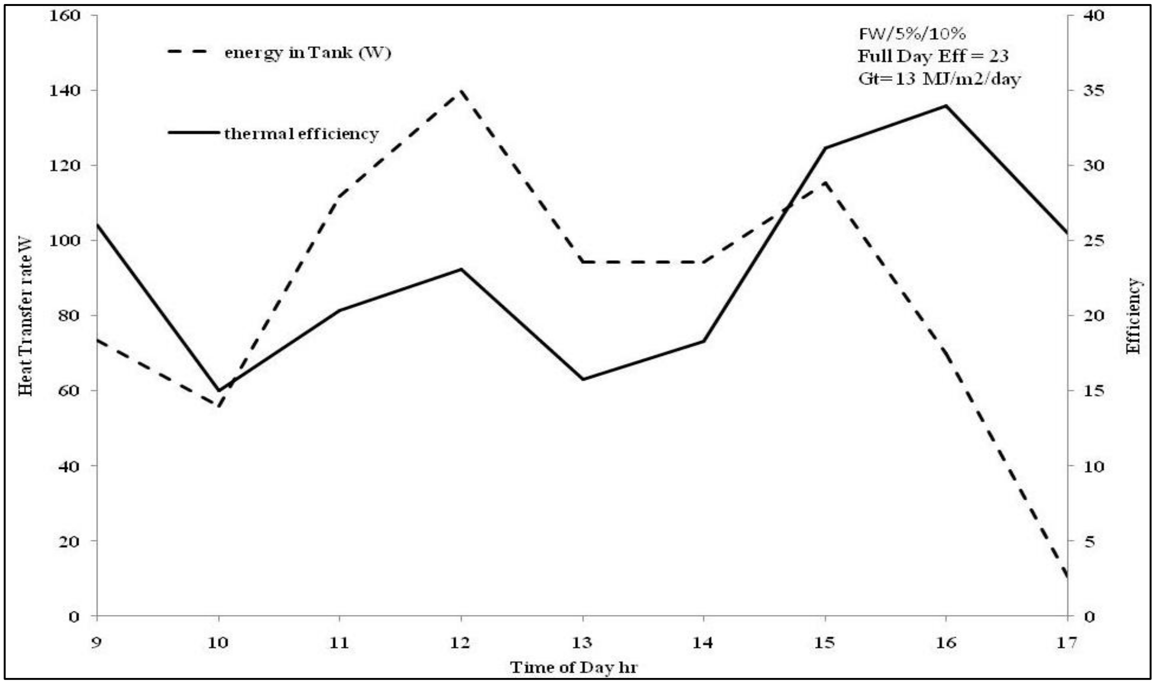

Fig. 5: Thermal efficiency for FW/5%/10% salt concentration

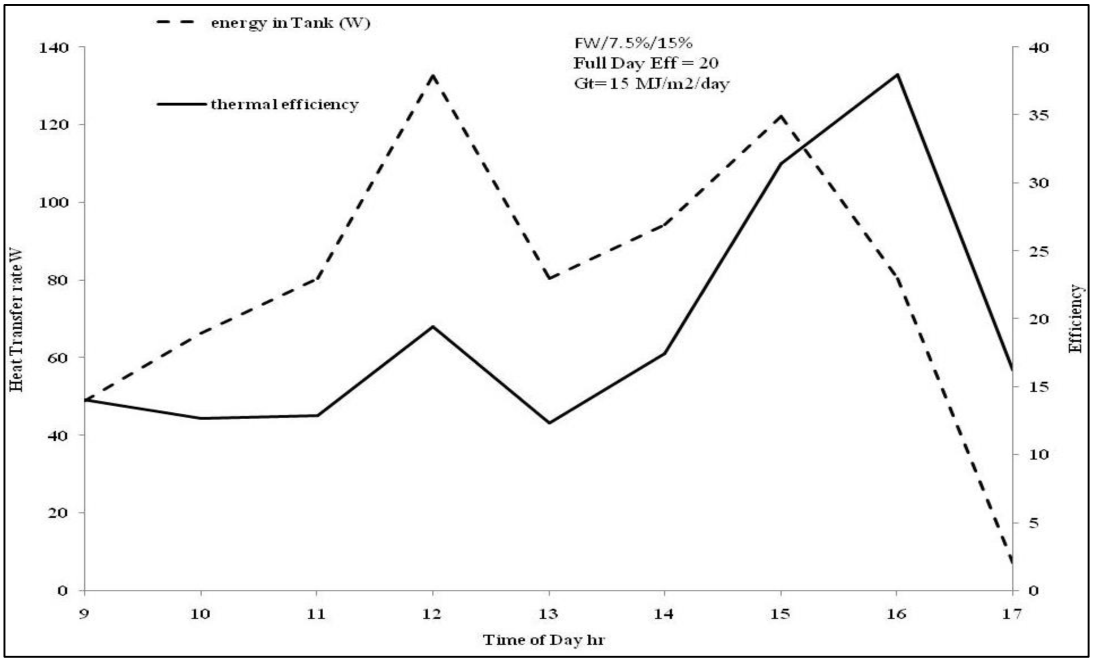

Fig. 6: Thermal efficiency for FW/7.5%/15% salt concentration

C. Optimization using MOGA (Multi Objective Genetic Algorithm)

Model equation for two factors (depth of solar pond and salt concentration) were generated in this study. Mat lab software was used to develop this equation. Equation was optimized by using global optimization tool box available in mat lab software. Total 30 cases were use in this optimization which is present in table 4.

Table 4: Total cases for MOGA based optimization

Sr. No	Depth	Salt Concentration	Temperature	Density
1	10	5	289.69	1032.85
2	20	5	289.31	1032.85
3	30	5	289.21	1031.26
4	40	5	288.89	1028.11
5	50	2.5	288.56	1026.52
6	60	2.5	288.19	1023.36
7	70	2.5	287.87	1020.61
8	80	2.5	287.53	1015.46
9	90	2.5	287.25	1007.56
10	100	0	286.95	1002.82
11	10	10	289.96	1065.31
12	20	10	289.78	1065.31
13	30	10	289.56	1062.34
14	40	10	289.07	1059.39
15	50	5	288.88	1056.44
16	60	5	288.46	1050.54
17	70	5	288.02	1041.69
18	80	5	287.68	1032.83
19	90	5	287.45	1021.03
20	100	0	287.07	1015.13
21	10	15	290.56	1140.61
22	20	15	290.19	1140.61
23	30	15	289.98	1134.54
24	40	15	289.78	1122.41
25	50	7.5	289.35	1110.29
26	60	7.5	288.86	1098.11
27	70	7.5	288.56	1088.45
28	80	7.5	288.21	1079.94
29	90	7.5	287.99	1060.45
30	100	0	287.56	1042.53

MATLAB curve fitting tool was used for non-linear curve fitting for response density and temperature. All necessary steps are present in figure 7 and figure 8 Model equations are present in equation form.

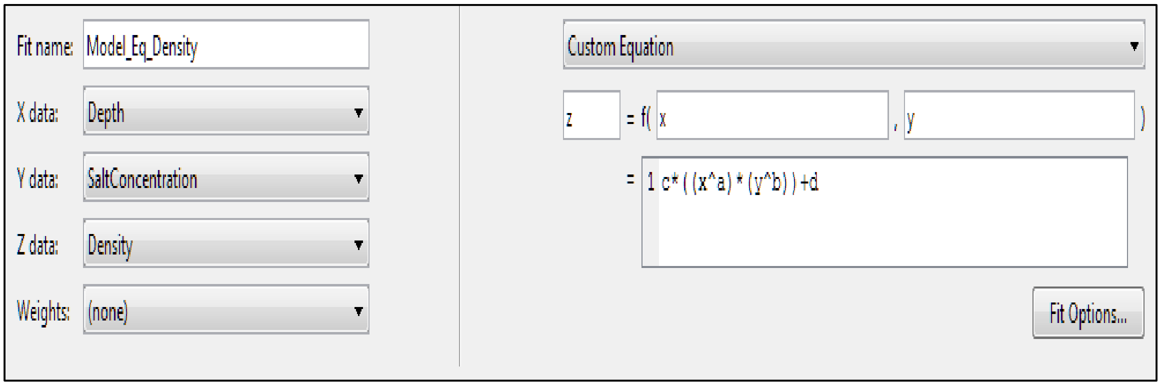

Fig. 7: Equation for density response

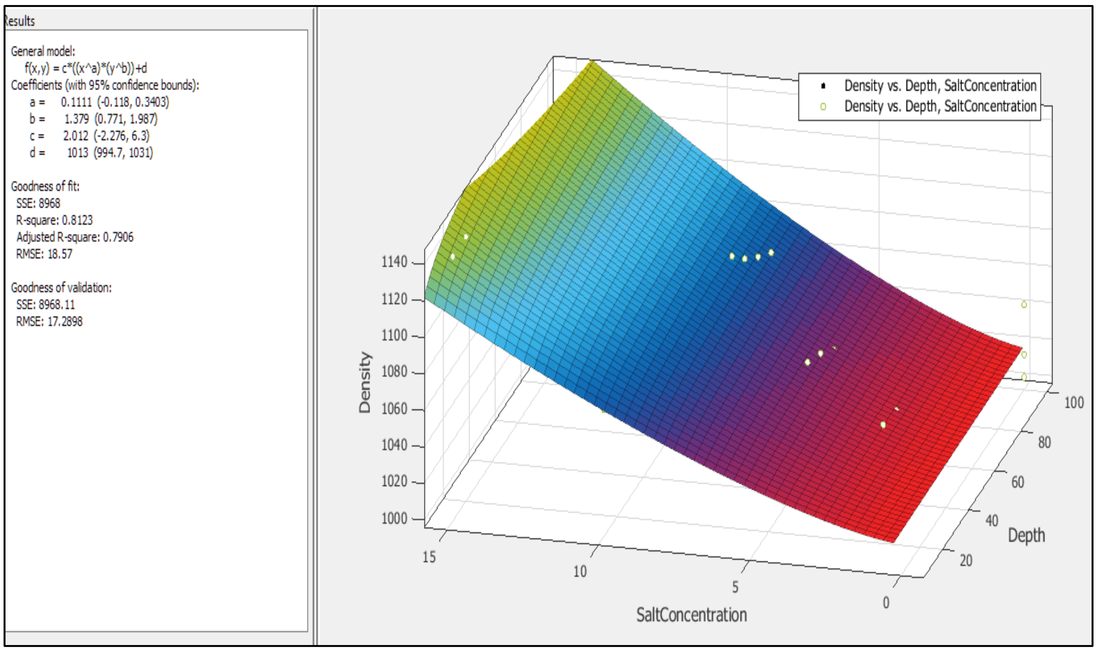

Fig. 8: Results of curve fitting tool

1) *Model equation for Density*

Density= 2.012(depth$^{0.1111}$×saltconc$^{1.39}$) +1013

R^2=0.8123

2) *Model Equation for Temperature*

Temperature=2.865(depta$^{-0.3428}$×saltconc$^{0.4091}$) +287

R^2=0.8652

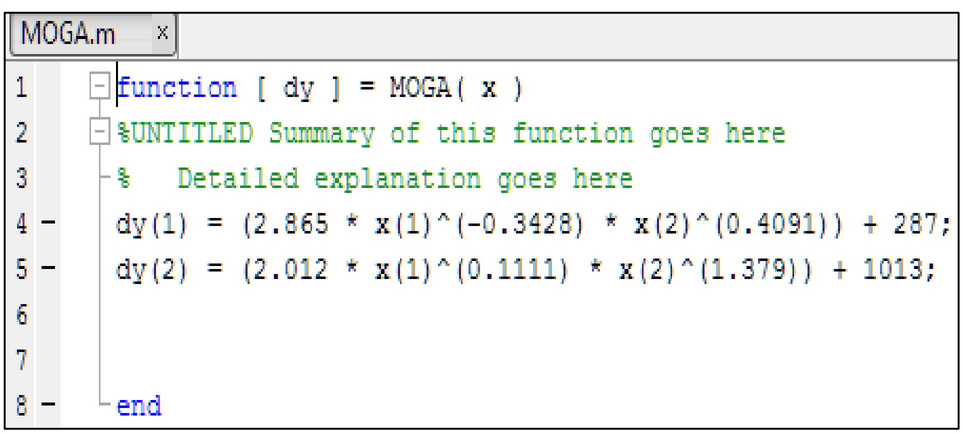

Fig. 9: Objective function for MOGA of Density and Temperature

Results from MOGA optimisation tool are presented below for Average distance between individuals, Score Histogram, Selection Function, Stopping Criteria, Pareto Front, Distance of individuals, Rank Histogram and Average Spread.

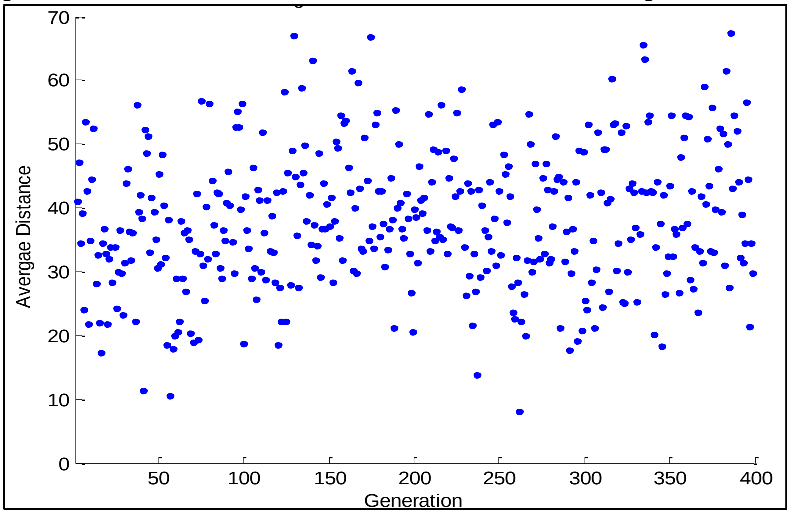

Fig. 10: Average distance between individuals

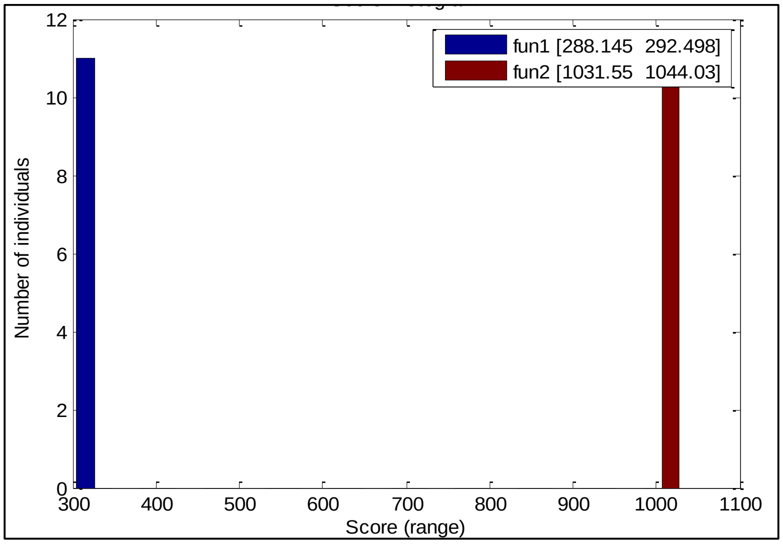

Fig. 11: Score Histogram

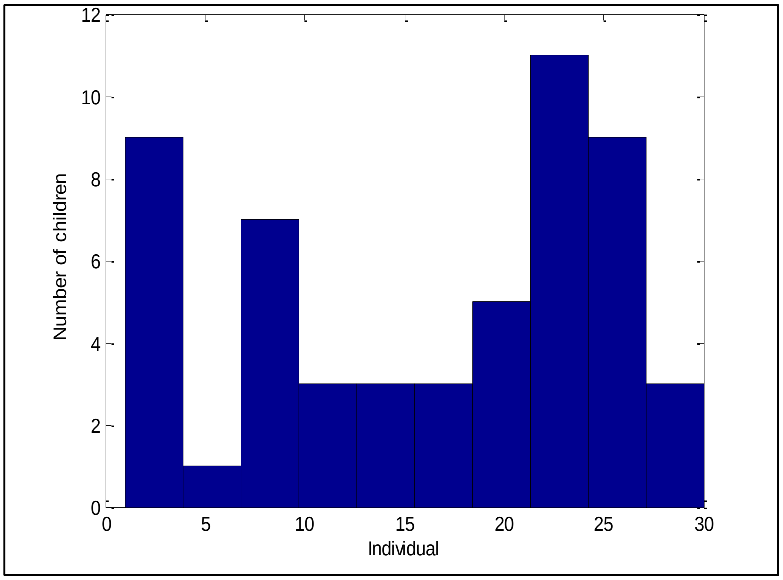

Fig. 12: Selection Function

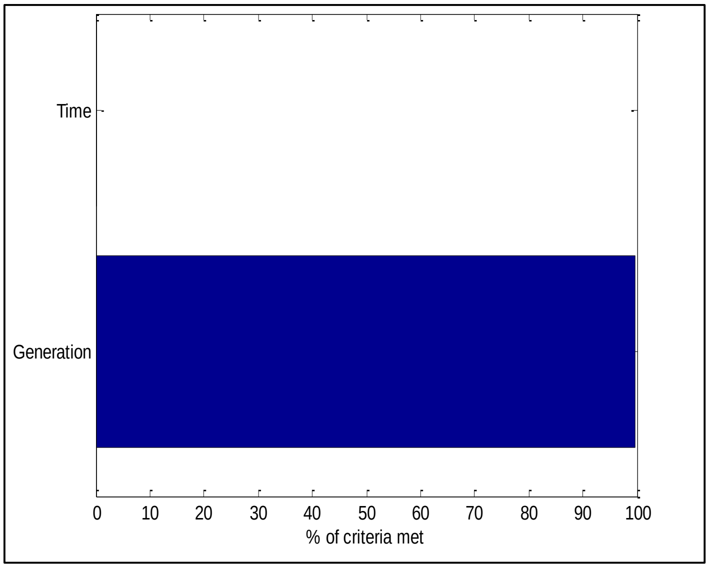

Fig. 13: Stopping Criteria

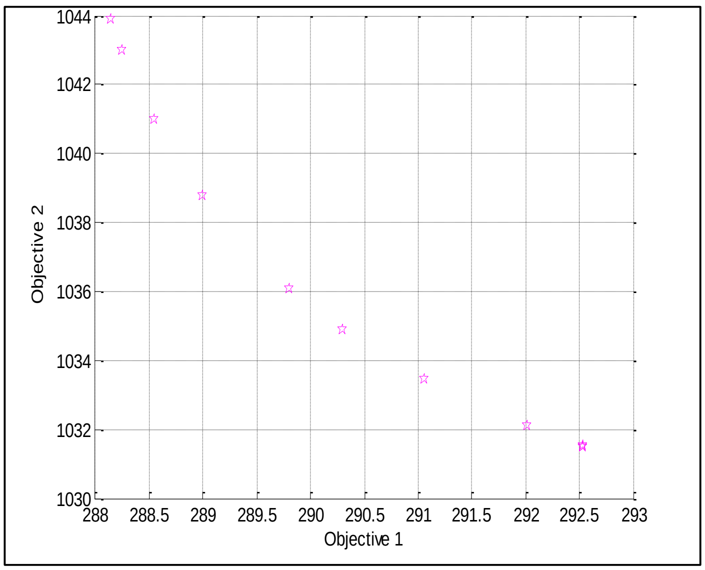

Fig. 14: Pareto Front

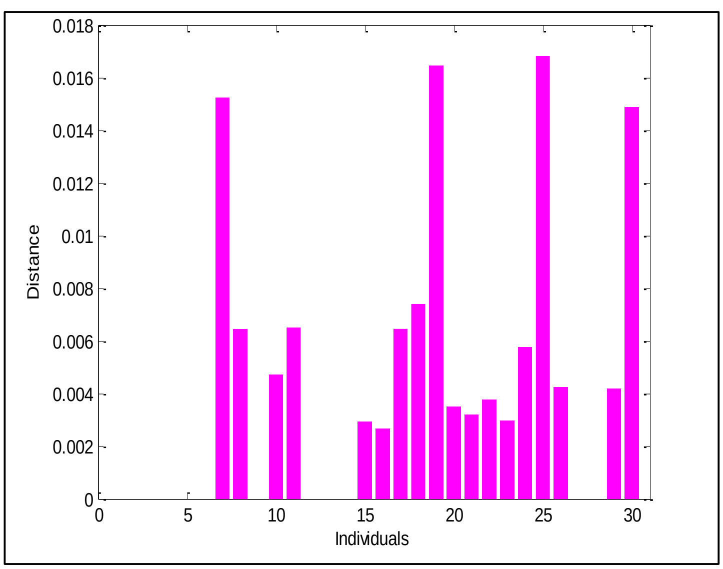

Fig. 15: Distance of individuals

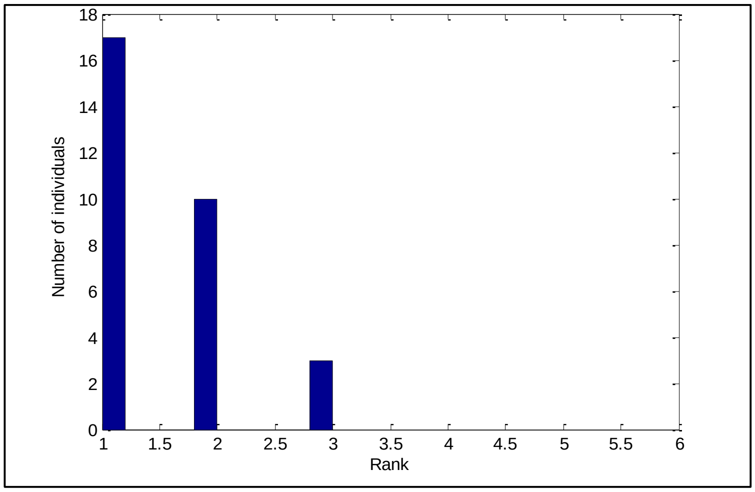

Fig. 16: Rank Histogram

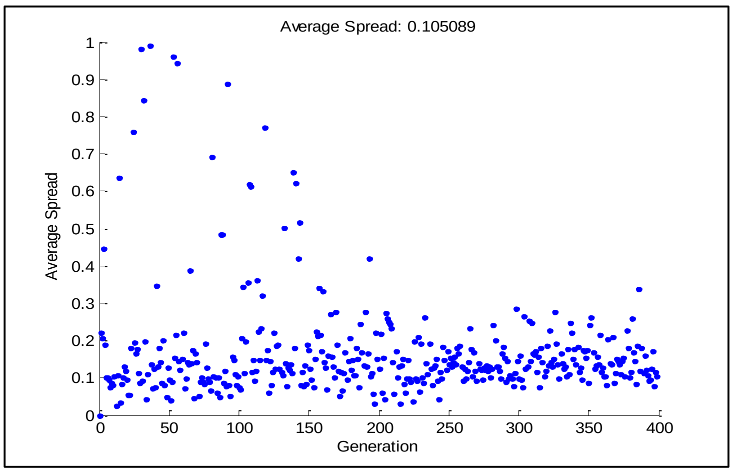

Fig. 17: Average Spread

Pareto front - function values and decision variables

Index	f1	f2	x1	x2
1	292.534	1,031.515	1	5
2	289.984	1,035.62	6.065	5
3	289.283	1,037.67	13.246	5
4	288.148	1,043.829	98.452	5
5	290.601	1,034.282	3.503	5
6	289.576	1,036.724	9.314	5
7	291.894	1,032.268	1.432	5
8	290.363	1,034.758	4.275	5
9	289.984	1,035.62	6.065	5
10	292.184	1,031.912	1.21	5
11	288.833	1,039.486	25.104	5
12	289.029	1,038.63	18.677	5
13	290.954	1,033.649	2.668	5

Fig. 18: Table Optimum results for MOGA

IV. Conclusion

Present study was carried out by considering a 1 m^3 hybrid solar pond equipped with a 20 L thermo siphon tank. Pond was developed and worked successfully as a 20 liter tank shows increment of 5 to 7^o C in temperature.

From study it can be concluded that Yield productivity of solar pond heavily depend upon solar radiation which is directly associated with climatic condition. Minimum hourly energy output is 10 W/hour for water depth of 0.03 m simple and maximum hourly output is 15 W /hour when heavy salt concentration is used in water basin. MATLAB curve fitting tool was used for equation generation and MOGA optimization tool was successfully applied to optimize the results.

Solar pond has a large scope and can be used as an economical source of energy. As we can see it is very easy to construct and operate. It has no moving parts and almost nil maintenance cost. The only running cost is of salt which has to be replaced frequently. Salt is easily available and also very cheaper in price.

In India there is a solar pond working in Gujarat from 1990 and some experimental solar ponds have been constructed in IIT Delhi, IIS Bengaluru etc. Still there is to be a lot of research work to be done on salt gradient solar pond to extract more, continuous and cheaper energy from it. Different salt concentration, type of salt, duration of changing salt solution, enhancing the duration etc. may be considered for area of research. Different geometry, orientation of pond, portability is still area of deep research.

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