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EXPERIMENTAL INVESTIGATION ON A MIXED SALT SALINITY GRADIENT SOLAR POND

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ABSTRACT - Solar thermal energy generated by a salinity gradient solar pond (SGSP) is one of the most promising techniques for providing heat for desalination and other applications. A solar pond is a unique, free-energy-source system for collecting, converting and storing solar energy.As the cost and greenhouse gas emissions of traditional fossil fuels are increasing, using renewable sources to generate electricity is one of the strategies for overcoming it. Solar pond is a simple and low cost solar energy system which collects solar radiation and stores it as thermal energy for a relative longer period of time.In this project 10 different types of salts are taken and experiments are made to find the best heat absorbing salt. To increase the efficiency we have mixed two best salts namely sodium sulphate and sodium carbonate and experimented it in a 0.25 m^3 glass solar pond and founded the maximum heat storage or efficiency in the fabricated solar pond.

I . INTRODUCTION

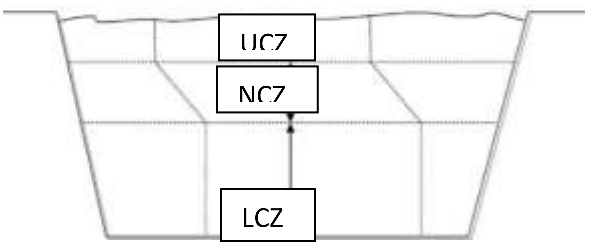
Non-convective solar ponds are simple in design and can be constructed at reasonable cost; they can provide heat for domestic, agricultural, industrial and desalination purposes and they can also generate power[1,2]. A typical salinity-gradient solar pond consists of three main zones (as shown in Figure 1.1):

a)The Upper Convecting Zone (UCZ); this part is sometimes called the surface layer. This involves the least cost, has the lowest level of salinity, and its temperature is close to ambient temperature. The thickness of this zone is typically 0.3m and it should be kept as shallow as possible. The cost of constructing the UCZ is usually neglected, as it can be constructed and operationally maintained through the use of any low-salinity water such as fresh, brackish water or seawater. This layer is essential for preventing the lower layers from being exposed to evaporation, wind effects and falling impurities[2].

b) The Non-Convecting Zone (NCZ); this region can be also called the gradient zone or the middle layer. It is located between the upper and the lower zones of the pond. As the temperature and salinity increase with depth, this layer is not homogeneous. If the salinity gradient is large enough, the NCZ exhibits a convection phenomenon [7,8].

c)The Lower Convecting or Storage Zone (LCZ); this is a homogenous layer and has considerably high salinity and high temperature. Heat is stored in this zone and it can be exchanged in or out of the pond. As the

LCZ's depth increases, the heat storage unit increases and the temperature variation decreases. The gradient layer consists of multi sup-layers in which each sub-layer is heavier [8].



Salinity profile Temperature Profile

Figure 1.1: Salinity and temperature profiles through the salinity gradient solar pond zones

The gradient layer consists of multi sup-layers in which each sup-layer is heavier and hotter than the ones above it. This stratification can make the saline molecules heavy enough to not obey to the convection phenomenon. In other words, the whole gradient zone cab be established to prevent the convection from taking place inside the pond's body and, as a result, the heat loss from the lower zone to the upper zone may occur by conduction but not convection [9]. By this manner, the middle acts as insulator layer to reduce the lower zone upward heat loss significantly.

A . CALCULATION OF SOLAR RADIATION

- Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy
- Variation in solar radiation during 365 days of a year can be calculated by the following expression [15].

  $I_0 = I_{sc} [1+0.034\cos(2\pi n/365.25)]$

  I_0 – Extraterrestrial irradiance on a plane perpendicular to sun's rays (w/m^2)

  I_{sc} - solar constant for the earth (1367 w/m^2)

  n – day of the year
- The average solar influx over the solar pond is estimated to be 5.25 Kwh/m^2 day by using the above equation

B . INCREASE OF HEAT STORAGE

- The basic heat transfer equation is
- $Q = mc_p\Delta T$

  Where

  Q = energy flow (kJ) = energy gained or lost by medium

  Cp =specific heat capacity of medium (kJ/kgK)

  ΔT = change of temperature in medium (^{0}C)

  m = mass (kg) = Volume (m^3) x Density (kg/ m^3)
- With this equation by selecting salts with high density,High thermal conductivity and high solubility of salt in water we can increase the heat storage capacity of the solar pond

C . EXPERIMENTAL STUDY

- To determine the heat capacity of each salt,an experiment is carried out
- Five number of 500 ml beaker is taken and each beaker is filled with 100 ml of water that to be used in our solar pond
- In each beaker 50 grams of sodium sulphate ,50g of sodium carbonate,50g sodium nitrate ,50g Magnesium chloride and 50g sodium chloride are dissolved separately
- Thermometers have been inserted into the five beakers and kept in sunlight

and for every half an hour,each thermometer readings are noted and the two high heat absorbing salt is selected for our experiment

D . TYPICAL CONSTRUCTION

- Size can range from hundreds up to thousands of square meters in surface area.
- Range from approximately 1-5 meters deep.
- Typically lined with a layer of sand for insulation and then a dark plastic or rubber impermeable liner material.
- Typical salt used is sodium carbonate and sodium sulphate are reported to be used.

E . FORMING THE SALT GRADIENT

- High concentration brine solution mixed in bottom to form the storage layer.
- Layers of decreasing salinity “stacked” on top of the storage layer using a horizontal diffuser.
- Fresh water is the final layer pumped on the surface

II . OBJECTIVES AND METHODOLOGY

The aim of this project was to obtain experience with operating solar ponds in the Northern climate of Pondicherry, where the solar pond would have an advantage over other solar heat collection methods in being able to trap the diffuse component of solar radiation which is 50% of the total radiation incident in this place. The project aims were to study the design, construction, filling, operation, and maintenance of salt gradient solar ponds, and to find the efficiency & performance. To obtain high overall operating efficiency the project aimed to experiment with extracting heat from both the non-convecting insulation layer and the convecting storage layer of the pond. Various thermal models are studied that gave good agreement with the observed performance of the pond and are useful as a design aid and to compare efficiency achievable by different methods of heat extraction.

The work was carried out in three phases:

A . PHASES OF THE WORK

(1). LABORATORY WORK

Different types of salts are taken and they are mixed with water in separate beakers and thermometers are inserted into it and moved to outdoor for finding the temperature ranges of all salts. Instrumentation was developed for temperature measurement and recording, and a new type of densitometer was developed to measure pond density at any depth. Experiments in small laboratory tanks were also carried out to try out and verify procedures for pond filling and gradient establishment.

(2). OUTDOOR EXPERIMENTS

The above said salt mixed beakers are kept in sunlight and each half an hour ,the temperature of those salts are noted.The two high temperature absorbing salts are taken for the pond that to be constructed and filled and then observations of temperature profile and density distribution were made throughout April and May 2015 for comparison with theory. Experiments on heat extraction from the insulation layer and storage layer were conducted, and on their effect on salt diffusion. Methods of pond maintenance and salt gradient control were tried out.

(3). ANALYSIS OF RESULTS

Temperature of the pond was substituted in formula and its efficiency was found to agree well with the measured performance. Collection efficiency (η_c) has been calculated using the relation.

$$\eta_c = \frac{(\Delta t *)G_c}{H_d * F}$$

III . PRICIPLE OF OPERATION AND DECRIPTION OF A SOLAR POND

A solar pond is a mass of shallow water about 1 or 2 metres deep with a large collection area ,which acts as a heat trap. It contains dissolved salts to generate a stable density gradient . Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water , the lower layers would heat up, expand and rise to the surface [26]. Because of the relatively low conductivity ,the water acts as an insulator and permits high temperature (over 90 ^{0}C) to develop in the bottom layers . At the bottom of the pond , a thick durable plastic layers liner is laid. Materials used for liners include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water , the concentration varying from 20 to 30 percent at the bottom to almost zero at the top[20,21].

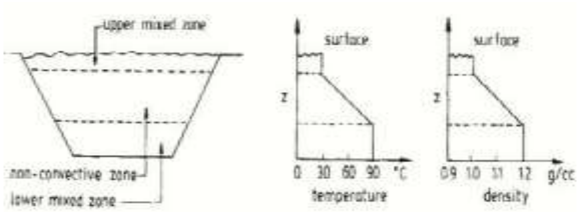


Figure 1.2 :Different Zones in a solar pond

In the salt-gradient ponds , dissolved salt is used to create layers of water with different densities-the more salt, the denser water.Thus a solar pond has three zones with the following salinity with depth [13]:

1) surface convective zone (0.3-0.5m),with salinity<5% concentration

2)Non-convective zone(1-1.5m), salinity inc with depth

3)storage zone (1.5-2m , salt=20%)

The Non-convective zone is much thicker and occupies more than half the depth of the pond. Both the concentration and the temp increase with the depth in it. It mainly serve as a insulating layer and reduces the heat transfer. A some part of this zone also acts as thermal storage [27]. The lower zone is the storage zone. Both the concentration and temp are constant in this zone. It is the main thermal storage medium. The deeper the zone. The more is the heat stored. The lowest zone traps heat energy for longer periods. The capacity to store heat for long periods is the chief advantage of solar ponds. Even in the cloudy days and in the ice covered regions the energy can be stored , since the salt water near the bottom heats up and expands. However it cannot rise to the because it is denser than the less salty water above. Hence a non convective solar pond is best utilized for storing the solar energy at a reasonable cost.

IV . MODELLING OF THE MSGSP POND

The MSGSP has 3 zones namely Upper convective zone (UCZ),Non convective zone (NCZ) and Lower Convective Storage Zone (LCSZ). Heat loss from the surface of the pond has been accounted. Edge effects due to the absorption of solar radiation as well as heating of side walls are neglected. In this model, the ground heat loss has been considered negligible as assumed by Kaushik and Bansal in their model. Attenuation of solar radiation through the depth of the pond has been calculated.

Solar flux at the depth x meters is calculated using the following equation [31]

$$S(x) = \tau s_0 \sum_{j=1}^{5} \mu\, je - njx$$

$$\mu_1 = 0.237\ and\ \eta_1 = 0.032m^{-1}$$

$$\mu_2 = 0.193\ and\ \eta_2 = 0.450m^{-1}$$

$$\mu_3 = 0.169\ and\ \eta_3 = 3.000m^{-1}$$

$$\mu_4 = 0.179 \ and \ \eta_4 = 35.00 m^{-1}$$

Where

τ = Transmissivity or coefficient of transmission.

S_0 = Solar radiation striking the surface of the solar ponds W/m2

x = Depth in meters

S (x) = Solar flux at depth (x) W/m2

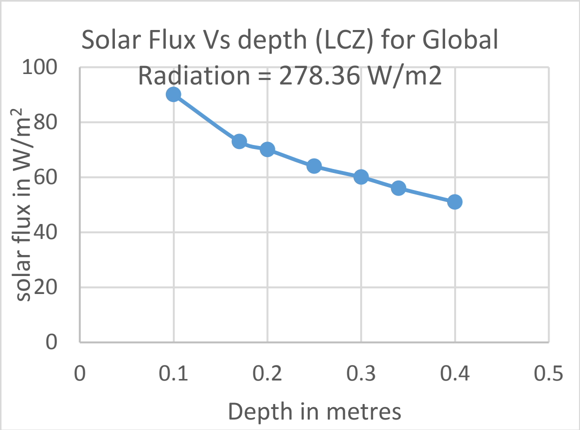


Figure 1.3: Solar flux reaching the bottom of the MSGSP Pond

V . SELECTION OF SALTS

To determine the heat capacity of each salt,an experiment is carried out.Five number of 500 ml beaker is taken and each beaker is filled with 100 ml of water that to be used in our solar pond.In each beaker 50 grams of sodium sulphate ,50g of sodium carbonate,50g sodium nitrate ,50g Magnesium chloride and 50g sodium chloride are dissolved separately.Thermometers have been inserted into the five beakers and kept in sunlight and for every half an hour,each thermometer readings are noted and the two high heat absorbing salt is selected for our experiment

Figure 1.4:Experimental Analysis of high heat absorption in salts

VI . EXPERIMENTAL INVESTIGATION ON A 0.25 m^2 MSGSP POND

Non Convective solar ponds are ordinarily composed of salt gradient layers. Salt gradient solar ponds are found to have a number of difficulties. They cause environment pollution in the event of a salt leakage, and the salt gradient layers needs frequent maintenance. In order to get a high storage capacity ,two different types of high heat capacity salts are mixed. The selected salts namely sodium sulphate and sodium carbonate should have high thermal conductivity which enhances the heat conduction.The first experimental study on the SGSP was performed by Wilkins et. al at the University of New Mexico. They reported their results of their experimental and theoretical studies of the SGSP pond which also included a cost benefit economic analysis comparing the economics of a MSGSP pond with a conventional salt gradient pond. Many thickeners for the nonconvecting layer of the SGSP pond have been examined and special techniques for the cross-linked salts to form permanent layers have been developed at Battelle Laboratories.

A . IMPORTANT PROPERTIES OF SALTS

(1) TRANSMISSIVITY

Transmissivity of the salt is most important property as far as energy collection is concerned. It was measured with maximum possible accuracy in the laboratory as well as outdoor. Laboratory measurements were conducted using UV Double beam spectrophotometer [23] .

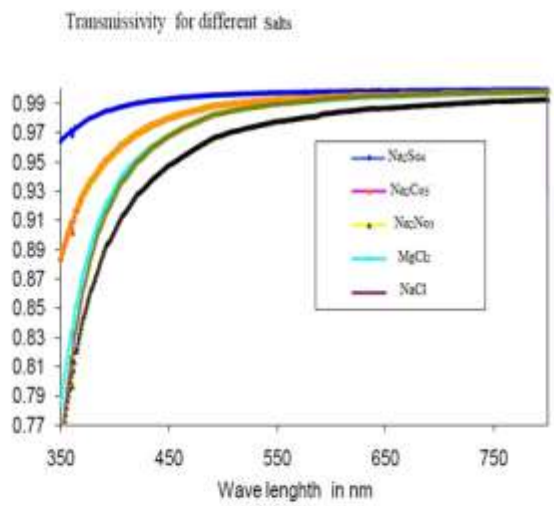


Figure 1.5:Transmissivity measurements for different salt samples

(2) OTHER PROPERTIES

SL NO.	NAME OF THE SALTS	DENSITY P (g/cm³) At 298	SOLUBILITY IN WATER (g/100g H_2O)	SPECIFIC HEAT CAPACITY C_p(J/molk)	THERMAL CONDUCTIVITY K (w/mk)	BOILING POINT (°C)
1	Sodium sulphate	2.671	49.7	128.2	7.53	1700
2	Sodium carbonate	2.53	30.7	112.3	6.98	1600
3	Sodium nitrate	2.3	91.2	93.05	6.7	380
4	Magnesium chloride	2.325	35.5	71.37	6.52	1412
5	Sodium chloride	2.17	35.7	50	6.5	1413

Table 1.1 : Important Properties of Salts

VII . DESCRIPTION OF MODEL MSGSP POND

Prototype model is square in shape of dimension 0.5 x 0.5 x 0.5 m. Its walls and base were made up of transparent float glass of 6 mm thick pasted with silicon. Inner surface of the glass plate were painted with matt black to absorb solar radiation. The model was insulated with saw dust of thickness 10 cm, polystyrene foam of 5 cm thick to reduce the heat loss through the walls. The top surface of the pond was covered with transparent glass plate of 2 mm plate of dimension 50 x 50 cm in order to reduce the wind effect on the stability of the pond. 6 „K" type thermocouples made of Chromel alumel was used to measure the temperatures.

Five thermocouples were fixed at 0, 25, 40, 40.5, 41 cm from the bottom and one thermocouple was used to measure the ambient temperature. A 12 channel temperature indicator (MICROSENSOR) was used to measure the temperature of the thermocouples with an accuracy of 1^0 C. However a thermometer was used to confirm the values indicated by the digital thermometer. Calculated amount of sodium sulphate and sodium carbonate salts were placed on the base of the pond with 2.5 % of total volume added with 100 litres of fresh water. Mixing was carried out in order to ensure that the salt has completely dissolved in the water to obtain a homogeneous mixture. Na_2So_4 and Na_2Co_3 was found to be suitable as it satisfied the requirement of the following properties like solubility, uniformity, specific gravity, transmissivity, cost, harmlessness, resistance to corrosion and anti bacterial nature. The pond was filled with these mixed salts of and the above setup was tested in open atmosphere for one week. In order to study the effect of climate and operational parameters on the performance of Mixed salt salinity gradient solar pond, experiment has been carried out during the month of March and April 2015. The global solar radiation incident as a horizontal surface was measured using Eppley- Pyranometer.

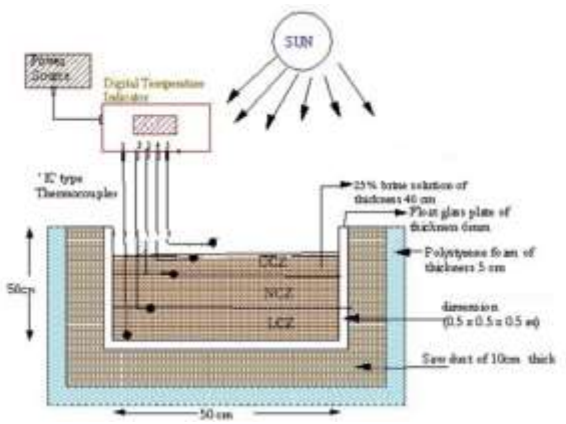


Figure 1.6: Schematic diagram of the model MSGSP Pond

VIII . RESULTS AND DISCUSSION

A . TEMPERATURE DISTRIBUTION

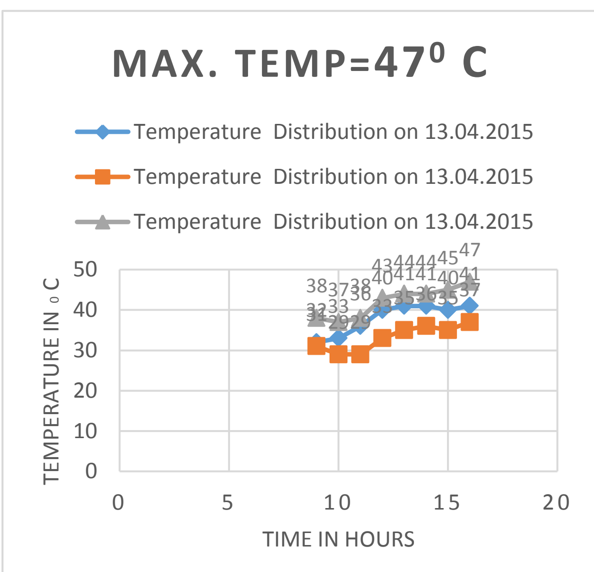


Figure 1.7: Temperature distribution of the MSGSP on 13.04.2015

Fig. 1.7 shows the temperature of the lower convective storage zone, upper convective layer and non convective layer temperature on 13th April 2015. It is observed that the maximum temperature of 47^0 C is obtained around 13.30 hours and the total temperature increase was found to be 8 ^{0}C. The salt temperature increased from 31 ^{0}C at 9.00 hours to 38 ^{0}C at 16.00 hours with total temperature increase of 7 ^{0}C.

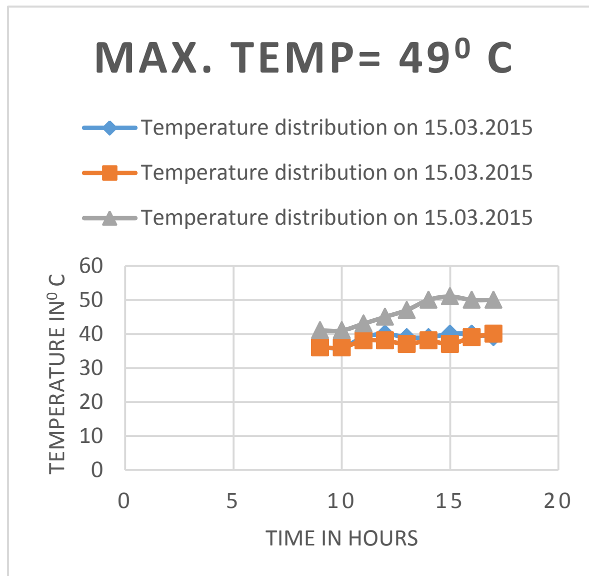


Figure 1.8: Temperature distribution of the MSGSP Pond on 15.03.2015

Fig. 1.8 shows the temperature of the lower convective storage zone, upper convective layer and non convective layer temperature on 15th March 2015. It is observed that the maximum temperature of 49 ^{0}C is obtained around 13.30 hours and the total temperature increase was found to be 7 ^{0}C. The salt temperature increased from 33 ^{0}C at 9.00 hours to 41 ^{0}C at 16.00

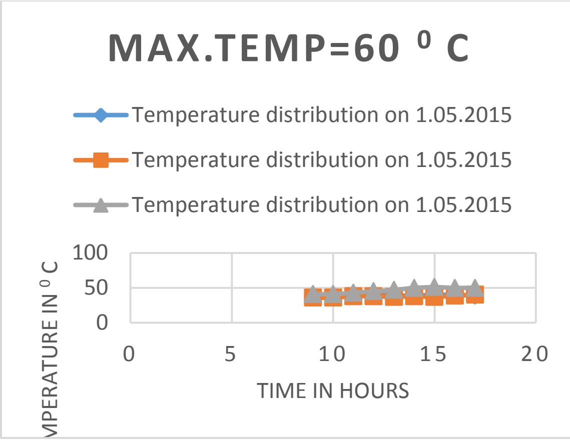


Figure 1.9 : Temperature distribution of the MSGSP Pond on 01.05.2015

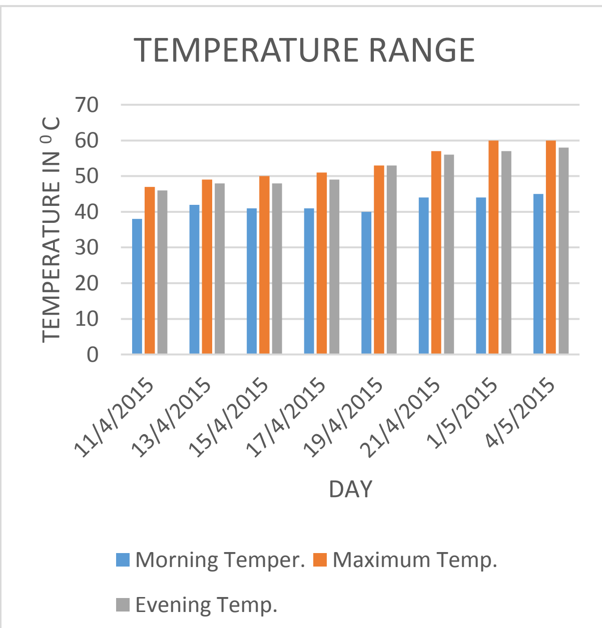


Figure 1.10: Morning, Evening and Maximum Temperature in the 0.25 m^2 MSGSP Pond

The experimental investigations were conducted from 11th April 2015 to 4th May 2015. It was observed that the maximum storage temperature was recorded around 15.30 hours which was found to increase from 47 to 60 ^{0}C from 1st May 2015 to 4th May 2015 gradually. An increase of 1 ^{0}C per day was recorded between 13th to 15th April 2015. However the temperature from 16th April 2015 to 18th April 2015 recorded were the same due to cloudy weather. From 19th to 24th April 2015 an increase of 3 ^{0}C per day was observed. From the graph, it is observed that the MSGSP shows an increase in the maximum storage day by day. On 24th April 2015, a maximum storage temperature of 60 ^{0}C was achieved. From the above experimental investigations, it is concluded that the MSGSP of 0.25 m^2 requires at least 12 days to get stabilized in order to store enough heat to increase the storage temperature of the salt solution to 60 ^{0}C. It is also observed that the night loss temperature was found to be between 5 to 8 ^{0}C. The temperature difference between the storage and gel temperature was around 10 ^{0}C.

IX . EFFICIENCY CALCULATION

Collection efficiency (η_c) has been calculated using the relation.

$$\eta_c = \frac{(\Delta t *)G_c}{H_d * F}$$

Where

η_c = collection efficiency

Δt = Increase in storage water layer ^{0}C.

G_c = heat capacity of storage water layer, j/k

H_d = total solar energy per unit area during a day W/m^2

F = Surface area of storage water layer, m^2

Experimental Collection efficiency on 24th April 2015 = (30 x 0.880) / (534.50 x 0.25) = 18.68 %

Sl.No.	Date	Solar	Collection

		radiation in w/m^2	Efficiency in %
1	11.04.2015	553.6	10.81
2	13.04.2015	500.7	13.36
3	15.04.2015	521.7	13.49
4	17.04.2015	576.7	12.82
5	19.04.205	574.6	14.09
6	1.05.2015	536.1	17.73
7	4.05.2015	534.5	19.76

Table 1.2 : Collection Efficiency of Experimental Values for 0.25m^2 MSGSP Pond

X . CONCLUSION

From the experimental study on the 0.25 m^2 MGSP pond, the following conclusions have been arrived. Sodium sulphate and sodium carbonate were found to be promising as it was found to be stable for longer period without undergoing any reaction . The maximum storage temperature was observed at 15.30 hours which was found to increase from 47 ^{0}C to 60 ^{0}C within a span of 10 days. The average temperature difference between storage zone and upper convective zone was 10 ^{0}C .Experimental Collection efficiency for 0.25 m^2 model for the maximum storage temperature of 60 ^{0}C is 18.68 %. .From the above investigations, the Mixed salt salinity gradient solar pond is technically feasible and comparable to the performance of the normal Salt Gradient Solar Pond.

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