iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** IX **Month of publication:** September 2017

DOI: http://doi.org/10.22214/ijraset.2017.9046

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

Study on Selection of Salt for Solar Pond and Electricity Production through Salt Water

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Abstract*: Solar energy is the largest available energy on earth. The life on the earth is due to Sun, directly or indirectly. All the plants make their food through photo-synthesis in presence of Sunlight. In turn this food is eaten by humans and animals. For harnessing solar energy effectively and efficiently various methods have been proposed. Solar pond is one of the methods to absorb solar radiation by water. The special design of salt-gradient solar pond helps in storing the heat in lower layer of water, known as storage zone without loss through convection. In salt-gradient solar pond, salt is added to preserve the heat. In present investigation three salts sodium chloride, magnesium chloride and sodium sulphate have been added in water to study the temperature attained by water in solar pond at laboratory scale. High temperature of about 39 ^{0}C has been recorded in comparison to ambient temperature of 25 ^{0}C in one month. A comparison among different salts on the basis of attaining maximum temperature has the order, sodium chloride > magnesium chloride > sodium sulphate > fresh water. In next step the salt water has been used to produce electricity through simple electrochemical cell containing two electrodes made up of copper as anode & aluminium as cathode and salt water as electrolyte. The experiments have been performed by taking all the three above mentioned salts as electrrolyte one by one. The cell containing sodium chloride or magnesium chloride salt has shown more current in comparison to sodium sulphate salt.

Keywords*: Solar pond; Non-convective solar pond; Salt-gradient; storage zone; electrochemical cell; electrolyte Introduction

I. INTRODUCTION

Solar pond contains water or any other liquid, which absorbs solar radiation to heat the water/liquid present in the pond. The thermal energy stored in the pond in this manner is exchanged with heat exchanger to transfer heat energy to other place for specific application [1]. This thermal energy can be used for heating the space and building, in industries for specific reaction or for electricity production. The pond may be natural or artificial. The size of the pond ranges from few hundred sq metre to few thousand sq metre, depending on the requirement and application. The temperature of water/liquid rises in the pond after absorbing solar radiation. Due to convection currents and conduction process this heat reaches at the surface of pond. From there heat losses through evaporation by the surface. To prevent the thermal energy and thus to store heat inside the solar pond special mechanism is adopted. On this basis it can be broadly divided into two category; convective solar ponds and non-convective solar ponds.Convective Solar Pond is a normal pond containing water/liquid of homogeneous density. The surface is covered with transparent sheet to prevent the loss of heat through evaporation. The depth of such a pond is not large. It is a shallow pond with depth of 4 to 15 cm. Non-Convective Solar Pond is further divided into two category; Salt-gradient solar ponds and Viscosity stabilized solar ponds.

In Salt-Gradient Solar Pond, salt is dissolved in water, such that it divides the layers of ponds in three different zones (Fig.1) [2]. The density of salt water increases with depth. The upper zone is the layer of fresh water. Middle zone maintains the salt-gradient. The lowest layers form storage zone, which has saturated salt concentration. When solar radiation is absorbed, the temperature of water increases. As the density of water layer with high temperature is less, it rises up due to convection currents. In absence of salt gradient, this heat goes to the surface, and is lost because of evaporation. In the salt-gradient solar pond, the density of hot water is decreased, but it is still higher than the layer above it due to presence of salt. In storage zone the molecules are so heavy because of saturated solution that they cannot move in upward direction. Hence the heat is preserved in the storage zone. The temperature may rise up to 90° C to 100°C in the storage zone. As one moves towards the surface the temperature is decreased. If the surface is covered with transparent sheet, it will further prevent the heat loss and maintain the high temperature in solar pond. However, some of the heat losses due to conduction and salt&gradient is disturbed in the pond. To maintain the salt&gradient, salt is added and fresh water is replaced at the upper layer. Common salts which are utilised in the solar pond is sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Additional alternatives are potassium chloride (KCl), Calcium chloride ($CaCl_2$), Ammonium nitrate (NH_4NO_3), Potassium nitrate (KNO_3), Borax ($Na_2B_4O_7$) and Sodium sulphate (Na_2SO_4), which are widely available from the waste product of flue gases produced from coal-fired power plants. Few famous solar ponds around the globe and within India are being discussed here.

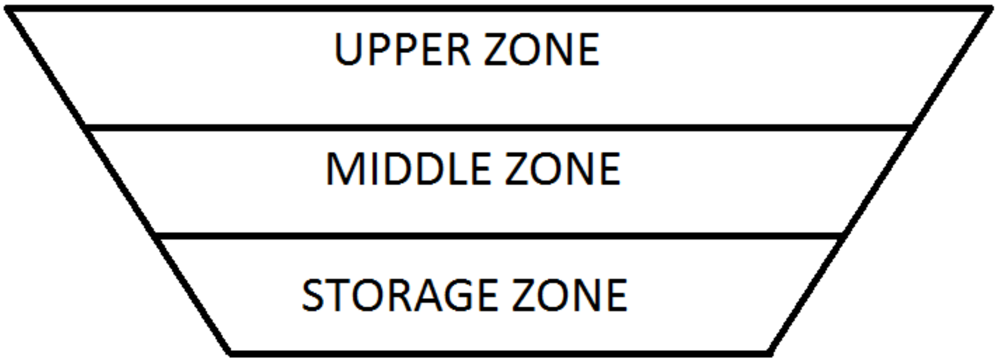

Fig.1 Schematic diagram of different layers in solar pond.

A. El paso solar pond

The El Paso Solar Pond project is a research, development, and demonstration project initiated by the University of Texas at El Paso in 1983. It has operated since May 1986 and has successfully shown that heat, electricity, and fresh water can be produced in the southwestern United States using solar pond technology [3].

B. Pyramıd hıll solar pond

A consortium of RMIT University, Geo-Eng Australia Pvt. Ltd. and Pyramid Salt Pvt. Ltd. has completed a project using a 3000 square metre solar pond located at the Pyramid Hill salt works in northern Victoria to capture and store solar energy using pond water which can reach up to 80°C [4]. At the local level this will be a significant boost in an area with high unemployment and a depressed economy.

In India, the first solar pond with an area of 1200 m^2 was built at the Central Salt Research Institute, Bhavnagar in 1973 [5]. Since then several solar ponds have been built and are in operation.The latest pond with an area of 6000 $m^{2,}$ built at Bhuj (Gujarat) is the second largest in the world. The 6000 m^2 solar pond in Bhuj, the first large-scale pond in industrial environment to cater to actual user demand, supplied totally about 15 million litres of hot water to the dairy at an average temperature of 75°C between September 1993 and April 1995 [6]. The Bhuj solar pond was conceived as a research and development project of TERI, which took over nine years to establish, to demonstrate the feasibility of using a salt-gradient pond for industrial heating [7].The solar pond is 100 m long and 60 m wide and has a depth of 3.5 m. The pond was then filled with water and 4000 tonnes of common salt was dissolved in it to make dense brine [8].

In context to above description, it is obvious that heat stored in the storage zone depends on the salt dissolved in it. In the present investigation solar pond has been constructed at laboratory scale. The temperature of three different zones (upper zone, middle zone and storage zone) of water column has been measured by dissolving different salts like, sodium chloride (ordinary salt), magnesium chloride and sodium sulphate. The effect of three different salts on the temperature achieved by three zones is studied. The salt water has been also used as electrolyte to produce electricity through a simple electrochemical cell. In present investigation, cell has been fabricated using aluminum and copper electrodes with electrolyte made up of above mentioned salts.

II. EXPERIMENTAL DETAILS

A. Construction of solar pond

In present investigation solar pond was constructed at laboratory scale by taking four measuring cylinders of diameter 4 cm and height 30 cm. Each cylinder acted like a solar pond. One cylinder contained fresh water only. In all the other three cylinders salt-gradient solar pond was created by taking three different salts sodium chloride NaCl (ordinary salt), magnesium chloride $MgCl_2$ and sodium sulphate Na_2So_4 . One salt was used to construct one solar pond in a cylinder. For constructing solar pond, saturated solution of salt was prepared in water. About one-third portion of the cylinder was filled with this saturated salt solution. Another solution was prepared by the same salt of the concentration half of the saturated solution. This half-saturated solution was poured gently in previous cylinder (filled with one-third portion by saturated solution), upto two-third level. The upper one third portion of cylinder was filled with fresh water. In this manner, three zones were created in the solar pond prepared in a cylinder. Care was taken during filling the cylinder with different solutions to avoid intermixing of different zones. In this way four solar ponds were created; one completely filled with fresh water and other three with three salts, NaCl (ordinary salt), $MgCl_2$ and Na_2So_4, taken one salt for each solar pond. After constructing the solar ponds described by above method, the set up was kept in an area where the maximum amount of sunlight was recieved (Fig. 2). Temperature of three different zones (upper, middle and storage) was measured by thermometer at alternate days. In the present investigation the whole experiments were carried out in the month of February 2017, in Rishikesh city, Dehradun, India.

Fig. 2. Experimental Set-up to study solar pond at laboratory scale.

B. Fabrication of electrochemical cell

In a separate experiment, the same salt was used as electrolyte to produce electricity by simple electrochemical cell. The cell was fabricated by two electrodes made up of copper (Cu) as anode & aluminum (Al) as cathode. Cylindrical arrangement of the copper and aluminium electrodes were taken as shown in Fig.3. The diameter of Cu electrode was 9 cm and height was 18 cm. Similarly, the diameter and height of Al electrode was 4 cm and 15 cm respectively. The gap between two cylindrical electrodes were 5 cm. Electrolyte was prepared by four salts NaCl, $MgCl_2$ and Na_2So_4 and ordinary salt taken one salt for each electrochemical cell. The voltage between two electrodes was 0.5 volt. The current was measured for short duration, by changing the parameters. A multimeter was used for measuring the values of current & voltage. Two resistances $R_1 = 1.4\Omega$ and

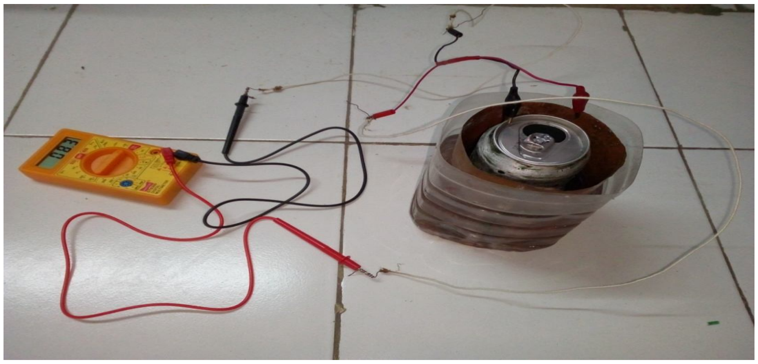

Fig. 3 Experimental set-up of ecectochemical cell.

$R_2 = 1.1\Omega$ were inserted in series with anode and cathode respectively for current measurement. In the present investigation variation in current was observed by taking different salt solution as electrolyte at the concentration of 60 g/l. In another experiment the effect of electrolyte concentration on current was observed by taking ordinary salt solution at concentrations of 12 g/l, 24 g/l, 48 g/l and 60 g/l.

III. RESULTS AND DISCUSSIONS

A. Study on solar pond

The main objective of the present study is to see the effect of salt on the temperature attained in different zones of salt-gradient solar pond. For this, temperature was recorded in each zone of solar pond prepared by different salt. The variation of temperature with days in upper, middle and storage zone are shown in Figs. 4, 5, 6 and 7 corresponding to the salt $MgCl_2$, Na_2SO_4, NaCl and fresh water. In Figs 4, 5 and 6 the temperature attained by different zones in 27 days varies in the order storage zone > middle zone > upper zone. As the upper layer is in direct contact to atmosphere, it losses heat. The density of water increases with depth due to concentration-gradient. Hence the vapour attaining higher temperature in storage zone can not rise to the surface because of its high density. Thus the heat is stored in the storage zone, imparting highest temperature to the storage zone. The maximum temperature attained by storage zone in different solar pond prepared with different salt is in order of NaCl > $MgCl_2$ > Na_2SO_4. The maximum temperature of the storage zone corresponds to 39 °C, 38 °C and 33 °C for NaCl, $MgCl_2$ and Na_2SO_4 in comparison to 25 °C of upper zone temperature. Fig. 7 shows the variation of temperature in different zones in fresh water. In this case, the temperature is almost same in each zone. As the fresh water without concentration –gradient does not form a solar pond, it has no storaze zone and heat is lost in the atmosphere due to evaporation.

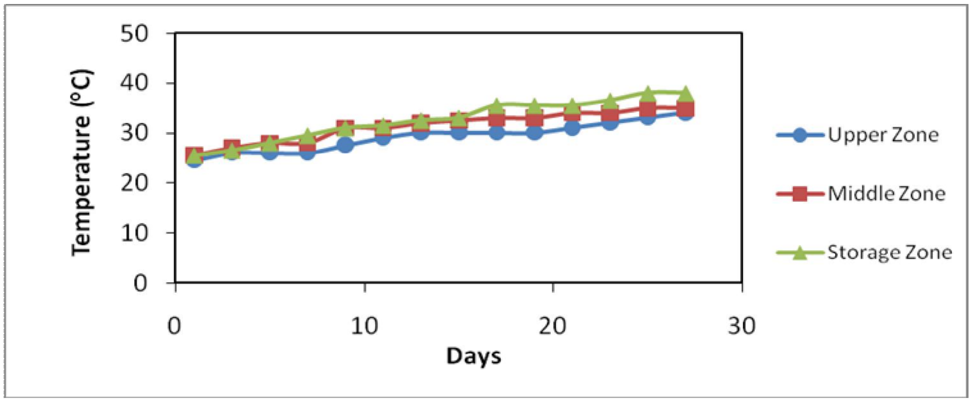

Fig.4 Variation in temperature of different zone with days for salt $MgCl_2$.

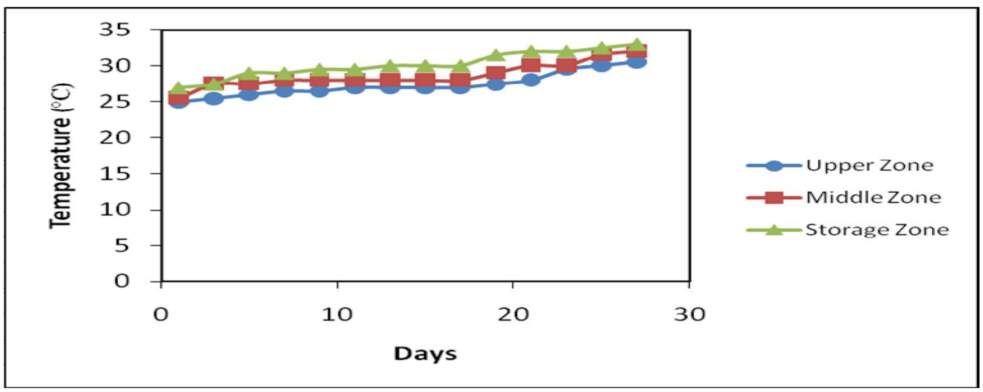

Fig. 5. Variation in temperature of different zone with days for salt Na_2SO_4.

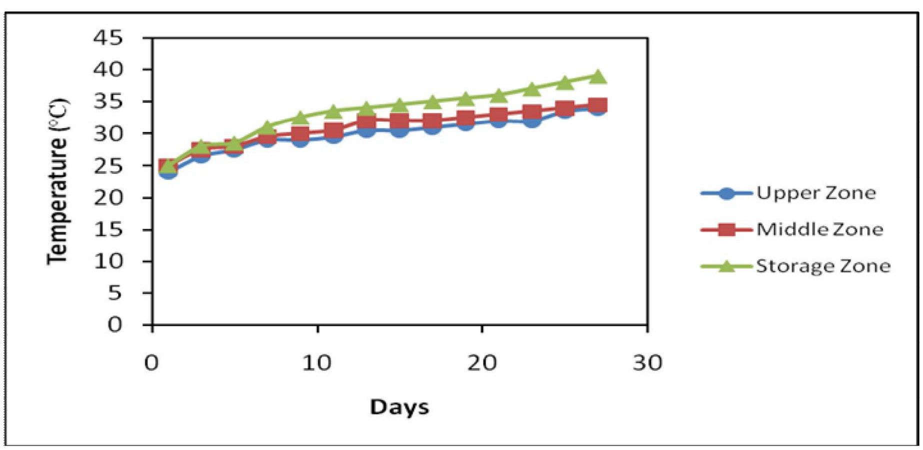

Fig. 6. Variation in temperature of different zone with days for salt NaCl.

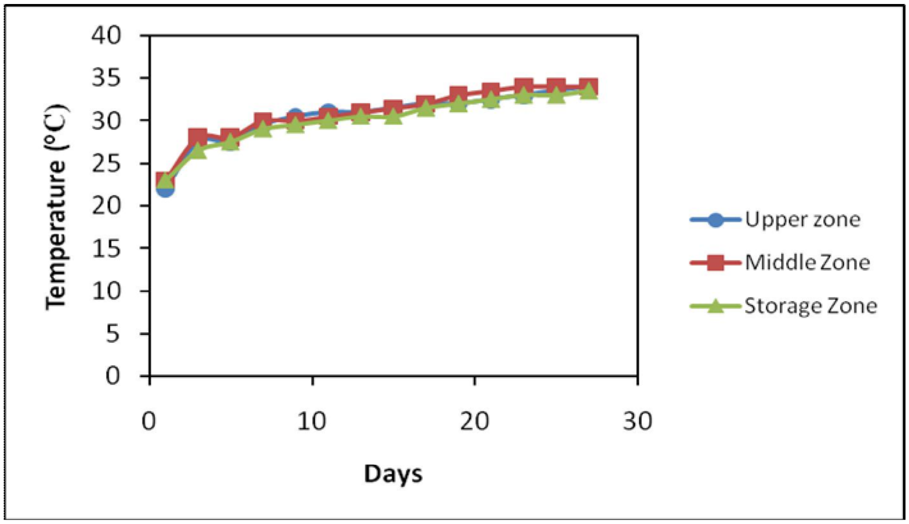

Fig. 7 Variation in temperature of different zone with days for fresh water.

A comparison of the temperature of particular zone with salt is given in Figs. 8, 9 and 10. These curves reflect that, there is not much differences in temperature of upper and middle zone, but remarkable differences can be noticed in storage zone. The solar pond prepared by Na_2SO_4 salt attains minimum temperature in all the zones in comparison to other salts.

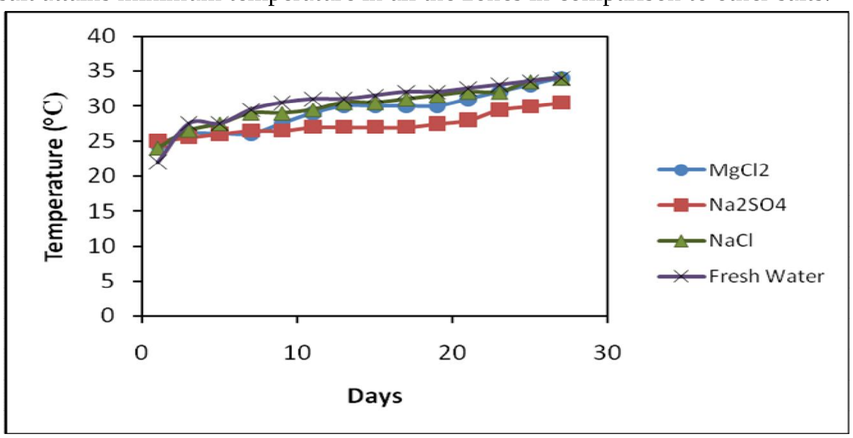

Fig. 8. Variation in temperature of upper zone with days for different salt.

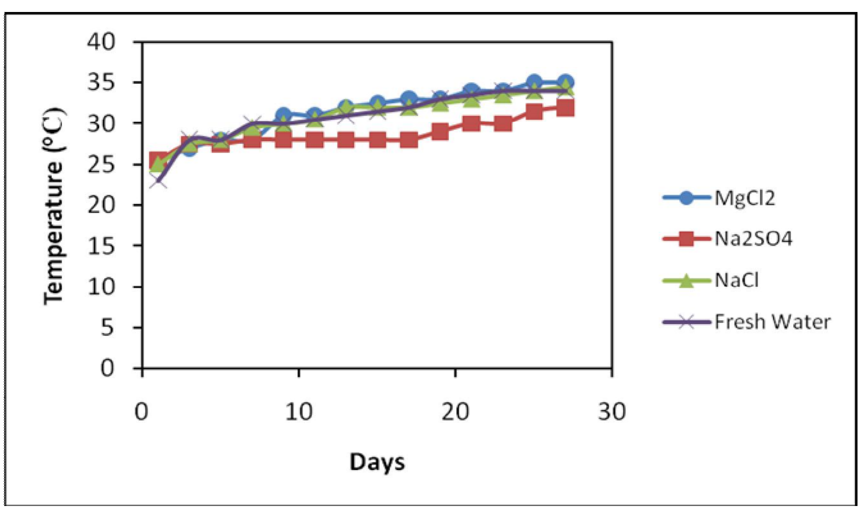

Fig. 9 Variation in temperature of middle zone with days for different salt.

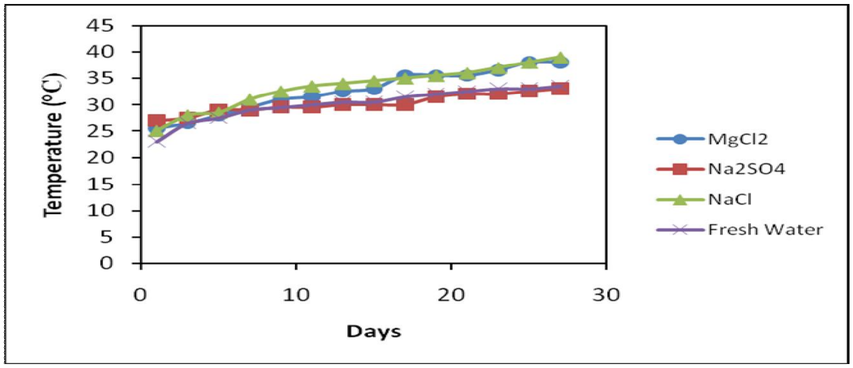

Fig. 10. Variation in temperature of storage zone with days for different salt.

B. Study of electrochemical cell using electrolyte made up of salts

After a long period the temperature attained by solar pond may rise upto 80 - 100 °C. This high temperature may be utilized in producing steam to run the turbine for electricity production. The other use is in space heating or for industrial heat energy. The salt water of solar pond may be used as electrolyte in electrochemical cell to generate current. To see the applicability of the salts as electrolyte, the variation of current is recorded as time. The salts used in electrolyte are same as used in preparing solar pond. In all the cases the potential difference between anode (Cu) and cathode (Al) is found to be constant at the value of 0.5 V. The variation in current with time for different salt as electrolyte is shown in Fig. 11. Here again, large amount of current is recorded for NaCl and $MgCl_2$ salt in comparison to Na_2SO_4 salt. The value of Maximum current is 54 mA, 13 mA, 58 mA

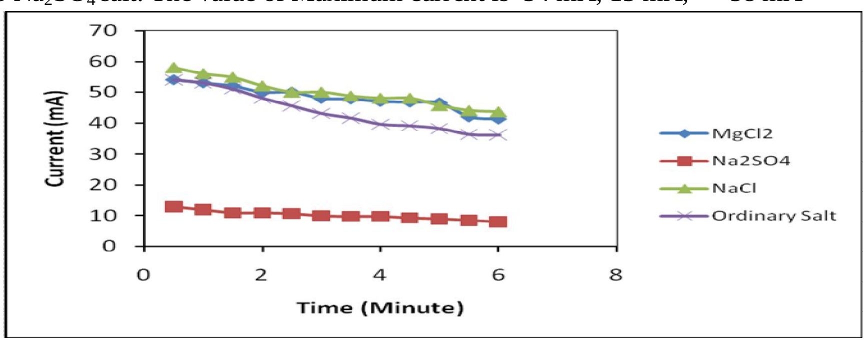

Fig. 11. Variation of current with time for different electrolyte at concentration of 60 g/l.

and 54 mA corresponding to $MgCl_2$, Na_2SO_4, NaCl and ordinary salt respectively. The time taken to reduce the current to 75% of maximum level is large in $MgCl_2$ and NaCl salt in comparison to Na_2SO_4. After 6 min the level of current is recorded as 76.4, 75.1 and 66.6% of the maximum value for $MgCl_2$, NaCl and Na_2SO_4 respectively . The better performance of $MgCl_2$ and NaCl salt is due to its high ionizing capacity in comparison to Na_2SO_4 salt. Similarly the variation in current with electrolyte concentration in the electrochemical cell prepared by common salt is presented in Fig. 12. It is obvious that at higher concentration more ions are available to give more current.

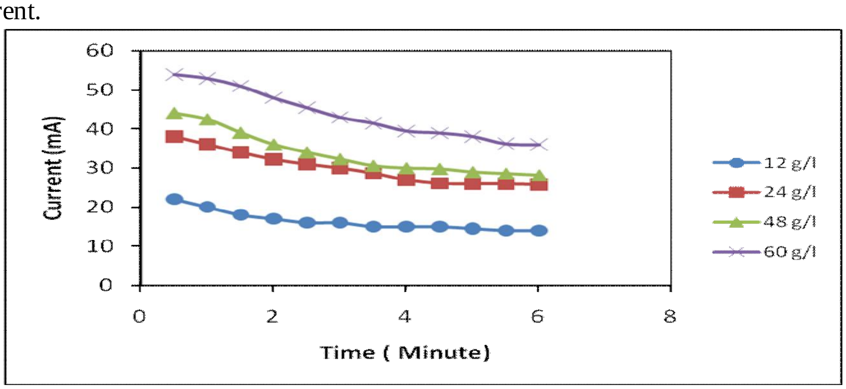

Fig. 12. Variation of current with time for electrolyte made up of ordinary salt at different concentration.

IV. CONCLUSIONS

It can be concluded that the temperature attained by storage zone in solar pond depends on the salt dissolved in it to maintain the concentration-gradient. A comparison among different salts to attain maximum temperature is in order, sodium chloride > magnesium chloride > sodium sulphate > fresh water. Salt having more value of temperature is considered as better option for solar pond.In present investigation a temperature of about 39 ^{0}c has been attained in comparison to ambient temperature of 25 ^{0}C in 27 days. In electrochemical cell prepared by electrolyte of salt water, the large current is recorded for NaCl and $MgCl_2$ salt in comparison to Na_2SO_4 salt. Hence in the present investigation the suitability of salt is in order of sodium chloride > magnesium chloride > sodium sulphate.

V. ACKNOWLEDGMENT

This study is undertaken for dissertation during Post Graduate Course in Physics. Authors are grateful to Head of the Department Dr.D.P.Bhatt for helpful discussions.

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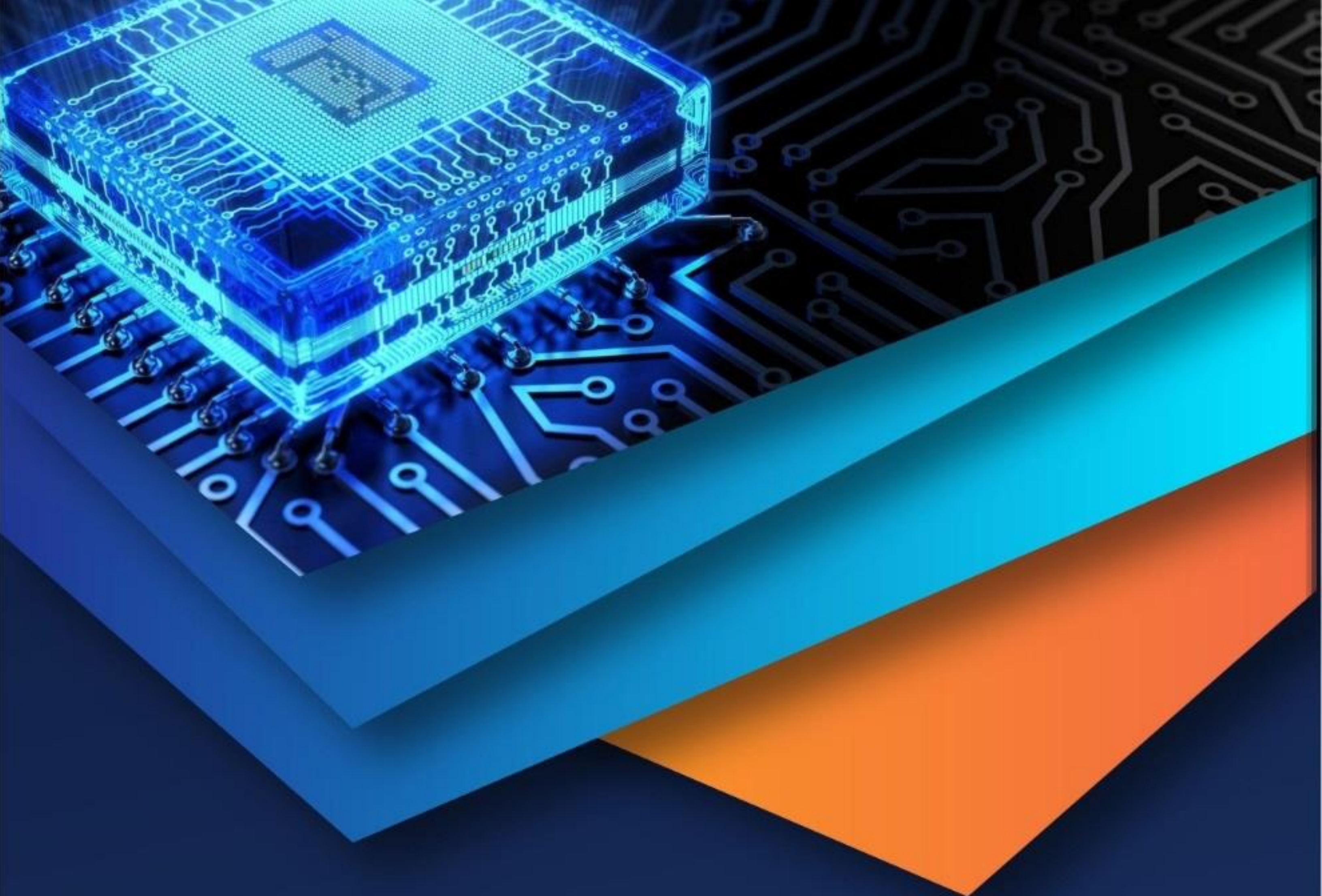

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