Heat Transfer Enhancement in Solar Pond Using Modified Tube Inserts

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Abstract

Solar ponds are thermal energy storage systems containing pool of salt water. The availability of solar energy is intermittent and for utilizing this, Thermal Energy Storage systems (TES) are required. This stored thermal energy, is exchanged using a heat exchanger and used for various applications like process heating, power generation, and refrigeration. During this heat exchange process better ways of transferring the heat energy is an important aspect. For this purpose heat transfer augmentation techniques are adopted. In the present experimental investigation, helical twisted tapes (tube inserts) were placed in the flow passage of the heat exchanger of small scale solar ponds. Experiments were conducted by placing the solar ponds under direct sun. Results proved increased rate of heat transfer, heat exchanger of the solar pond fitted with twisted tape of 10.6 twist ratio resulted with maximum effectiveness of 0.43 and heat exchanger with twisted tape of 6.36 twist ratio resulted with maximum effectiveness 0f 0.60 whereas the heat exchanger without twisted tapes recorded a maximum effectiveness of 0.27.

1. Introduction

Salt Gradient Solar Pond (SGSP) is solar energy collector integrated with energy storage system. The salt-water of solar pond forms a vertical salinity gradient, also known as a "halocline", in which low-salinity water floats on top of high-salinity water. The layer of salt solutions increases in concentration with depth also the density of water increases with depth. The solar radiation falling on the solar pond reaches the bottom of the pond and gets absorbed. This absorption of solar energy increases the temperature, thereby causes thermal expansion and reduced density of water. If the water were fresh, the low-density warm water would float to the surface, causing convection current. The temperature gradient alone causes a density gradient that decreases with depth in an ordinary pond. However, in SGSP the salinity gradient forms a density gradient which increases with depth, and this acts against the temperature gradient and prevents heat in the bottom of the pond from moving upwards by convection. This means that, the solar energy reaching the bottom of the pond gets trapped at the bottom of the pond itself. Therefore the temperature at the bottom of the pond will increases as the solar radiation falls, while the temperature at the top of the pond remains at the surrounding temperature. Thus, the salt gradient solar pond is of non convective type and stores the thermal energy, which can be utilized for various applications like power generation, process heating and for achieving refrigeration. In SGSP there exist distinctly three different zones. The Upper Convective Zone (UCZ) is the top layer of the pond with less dense liquid. This zone is transparent and allows the solar radiation to pass through. Non Convective Zone (NCZ) is an intermediate zone which acts as a thermal insulator. The density of the water in the NCZ is higher than the UCZ but lower than Lower Convective Zone (LCZ). In this zone variation of density along the depth is predominant. LCZ is bottom layer of the solar pond, which contains highest salinity among other zones. The maximum storage of heat occurs in this zone and hence the temperature is higher compared to other zones. The exchange of heat from solar pond is achieved from this lower convective zone.

The conventional method adopted for exchanging the heat from the solar pond to any medium (usually water) is using a heat exchanger made of copper pipeline. In conventional method of heat exchange, the rate of heat transfer is less and this provides the scope for augmentation of heat transfer in the SGSP. Various methods are available to augment the heat transfer like, Active Methods and Passive Methods [1]. Active Method of heat transfer augmentation uses external power source, where as in passive methods, without external power, heat transfer is enhanced. The various active methods are stirring the fluid by mechanical means, surface vibration, applying electro static fluids, jet impingement etc. Some of the passive methods of heat transfer augmentation are metallic or non metallic coating of the surface, indentations in the surfaces, wire coil insert to disturb the boundary layer, extended surfaces, and swirl flow device like helical twisted-tape. The helical twisted tape inserts are described by their twist ratio (Y), which is the ratio of pitch length of the twist to the tape width. The thermal and hydraulic performance of helical twisted tape received attention in the literature [2,3,4,5,6], these twisted-tape inserts resulted in increased convective heat transfer coefficient. Providing twisted tape inserts in the flow passage will increase the rate of heat transfer and/or reduces the size of the heat exchanger.

Mazen M. Abu-Khader [7] listed the reasons for improved thermal performance of a flow passage conatining twisted tape inserts as (i) flow passage gets constricted resulting in increased axial velocity and wetted perimeter (ii) longer flow length in the helically twisting partitioned duct (iii) swirl or secondary fluid circulation and (iv) increased residence time of the flow medium. Sivashanmugam and Suresh [8] reported the heat transfer and friction factor characteristics of circular tube fitted with twisted tape inserts for laminar flow. Smithberg and Landis [3] reported friction and forced convection characteristics in tubes fitted with twisted tape swirl generators. Paisarn Naphon [9] reported about the effects of coil-wire insert on heat transfer enhancement and pressure drop of the horizontal concentric tubes. Agarwal et al. [10] experimentally studied the heat transfer enhancement by coiled wire inserts during the forced convection condensation of R-22 inside horizontal tubes. Wang and Sund [2] studied the heat transfer enhancement in the heat exchanger. Lokanath [6] reported experimental data on laminar flow of water through a horizontal tube under uniform heat flux conditions in the tube fitted with full and half-length twisted tapes. With Reference to the literature survey of solar pond, Mehmet Karakilcik et al [11] reported about the performance investigation of solar pond by conducting experiments and by developing a theoretical model. J Andrews and A Akbarzadeh [12] also studied about the enhancement of thermal efficiency of solar ponds by extracting heat from gradient layer. To increase the performance of solar pond N C Bezir et al [13] also analyzed about the performance of salt gradient solar pond with and without reflective covered surface. M Karakilcik et al [14] also presented the theoretical and experimental temperature distributions in a solar pond during day times and night times. M.R.Jaefarzadeh [15] studied about the extraction of heat from SGSP using in-pond heat exchanger in 4m2 area solar pond. Kumar A and Kishore [16] presented their experiences about construction and operation of 6000 m^2 solar pond at Kutch, India. Jaefarzadeh M.R [17] studied about the wall shadowing effect on thermal behavior of a small salinity gradient solar pond. Subhakar D and Murthy SS [18] published the simulation procedure for saturated solar ponds. Literature survey also showed the heat transfer enhancement techniques like twisted tape inserts were not used to study the characteristics and performance of in-pond heat exchanger of the SGSP. Huseyin Kurt et el [19] used an experimental set up to determine the suitability of sodium carbonate as a salt for solar ponds. The experimental set up and procedure are adopted in this investigation was similar to that adopted by Huseyin Kurt et al [19].

2. Experimental Setup

Three solar ponds were fabricated using GI sheet of 1.5 mm thick with the following dimensions 1200mm x 1000mm x 600mm (height). In-pond heat exchangers made of copper tube of 12mm diameter and 3.75m long, with three tube passes were installed in all the three fabricated ponds. In the first solar pond no twisted tape were inserted in the flow passage of the heat exchanger, where as in the second and third solar ponds twisted tapes of 10.6 twist ratio and 6.36 twist ratio were inserted respectively. These twisted tapes were of 11 mm twist diameter x 70 mm pitch (6.36 twist ratio) and 11mm twist diameter x 117 mm pitch. The twisted tape inserts were made of copper sheet metal and they were inserted only in the first and third tube pass of the heat exchanger. The four sides and the bottom of the ponds were insulated. The solar ponds were insulated with glass wool of 20 mm followed by Styrofoam of 25 mm. The inner surfaces of the solar ponds were black painted. The fabricated ponds were filled with salt water; Nacl was used as the salt in this experiment. Salt water of 16% salinity is filled for a depth of 250 mm; this region forms the Lower Convective Zone (LCZ). Above this zone salt water with 8% salinity is filled for a depth of 250mm.This zone forms the Non Convective Zone (NCZ). Finally 100 mm of depth is filled with ordinary water, to form the Upper Convective Zone (UCZ). For filling the ponds with salt-water, the following procedure was adopted. The LCZ was initially filled with 16% salinity water to a depth of 100mm; the remaining 400 mm of the LCZ was filled by slowly pouring the salt water using a floating plastic can. Similarly, the same procedure was adopted for filling the NCZ for a depth of 500 mm. Sampling vents (two vents in LCZ & in NCZ, and one vent in UCZ) were provided in all solar ponds to determine the density of water and to check the presence of halocline.

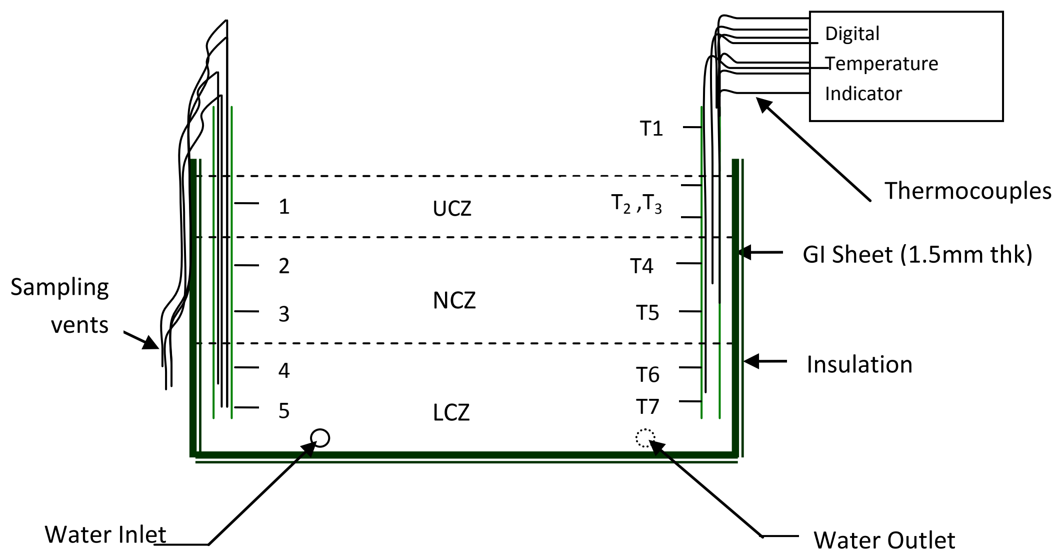

Fig 1. Cross section of experimental solar pond

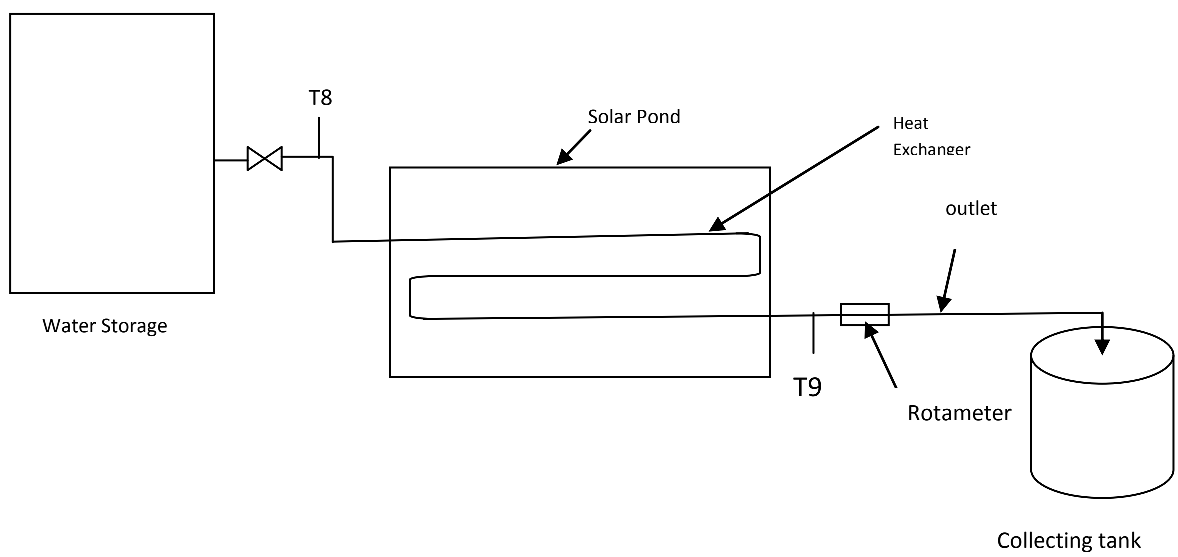

Fig 2. Experimental set up indicating the tube pass of heat exchanger

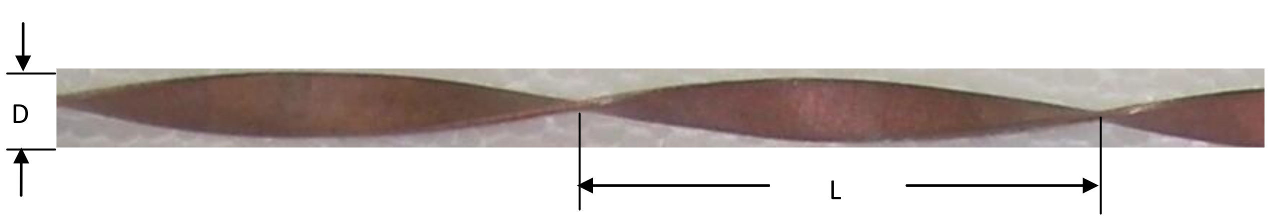

Fig.3 Twisted- tape insert in the flow passage

The Six numbers of thermocouples of 'T' type (two thermocouples for each zone) were placed in all the three zones of the solar ponds to determine the temperatures of the zones. Three more 'T' type thermocouples were used to determine the temperature of inlet & outlet water of heat exchanger and the ambient temperature. The thermocouples of each pond were connected to a 12 channel digital temperature indicator with an accuracy of 0.3ºC. The density of all the zones of the pond was checked regularly for every two days. The density was measured by measuring the mass of the sample using a digital balance of ±10-4 g accuracy, and the volume was measured with 10 ml pycnometer with an accuracy of ±0.2ml. The small scale solar ponds after filling with salt-water were covered by transparent plastic sheet and left for three days, this was done to allow molecular diffusion of salt and to achieve linear salt gradient. Halogen lamps were used as solar simulators for determining the performance of the solar pond under simulated mode. In the simulated solar ponds, to hold the halogen lamps a hood was fabricated and the inner side of the hood was nickel plated. The intensity of solar radiation was measured using a pyranometer of Solar-130 type with an accuracy of ±1.5 W/m^2.

3. Experimental Procedure

The three solar ponds were left for three days after filling with salt water and covering them with transparent plastic cover. The presence of halocline was ensured by taking the samples from sampling vents for every two days. In the set of experiments conducted, all the three ponds were placed under sun, from 6:00 am to 6:00 pm, and the temperature readings like ambient, inlet water, outlet water, LCZ, NCZ, UCZ were measured using thermocouples connected to digital temperature indicator. The temperatures were measured for every 30 minutes, these readings were taken for one month and the average readings were used to plot the characteristic curves of the solar ponds. The flow rate of water through the heat exchanger was maintained constant as 0.0182 kg/s and the flow rate was measured using a rotameter. The performance curves of the solar pond obtained for both the set of experiments conducted are indicated in the fig 4 to fig.10.

4. Data Reduction

(i) The actual rate of heat extraction from the solar pond is

$$Q_{act} = \dot{m}\, c\, (T_9 - T_8)$$

where $\dot{m}$ is mass flow rate, C is specific heat of flowing water, T9 is water outlet temperature from the heat exchanger, T8 is water inlet temperature to the heat exchanger.

(ii) The maximum possible rate of heat extraction from the heat exchange of the solar pond is

$$Q_{max} = \dot{m}\, c\, (T_{LCZ} - T_8)$$

where, T_{LCZ} is the temperature of the LCZ.

(iii) The effectiveness (ε) of the heat exchanger is given as

$$\varepsilon = \frac{Q_{act}}{Q_{max}}$$

(iv) The efficiency (η)of the solar pond is

$$\eta = \frac{Q_{act}}{A_p I_i}$$

where, A_p is surface area of the solar pond, and Ii is intensity of solar radiation incident.

(v) Twist ratio of tape insert (Y)

$$Y = \frac{L}{D}$$

where, L is the pitch of the twist and D is the width of the tape.

5. Results and Discussion

In the graphs, fig 4, 5, & 6 the temperature of the LCZ is higher compared to other zones, this is obvious because the solar radiation incident on the pond heats the bottom of the pond and the heat gets trapped at the LCZ. It is also understood that the maximum temperature occurs during 1:00 pm, even though the solar radiation is maximum during 12:00 noon. This is because the response of the salt water is slow which is due to low thermal diffusivity.

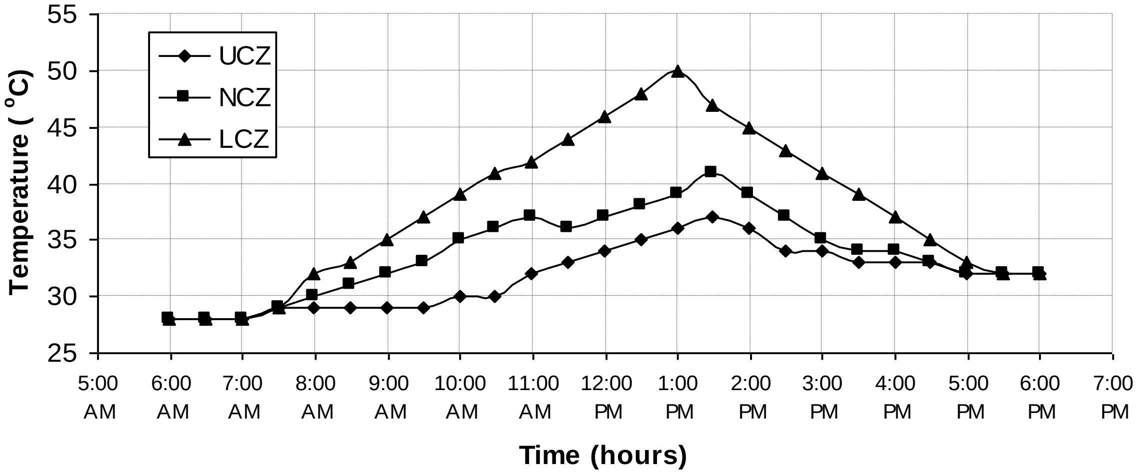

Fig.4. Temperature variation in various zones (without twisted tapes)

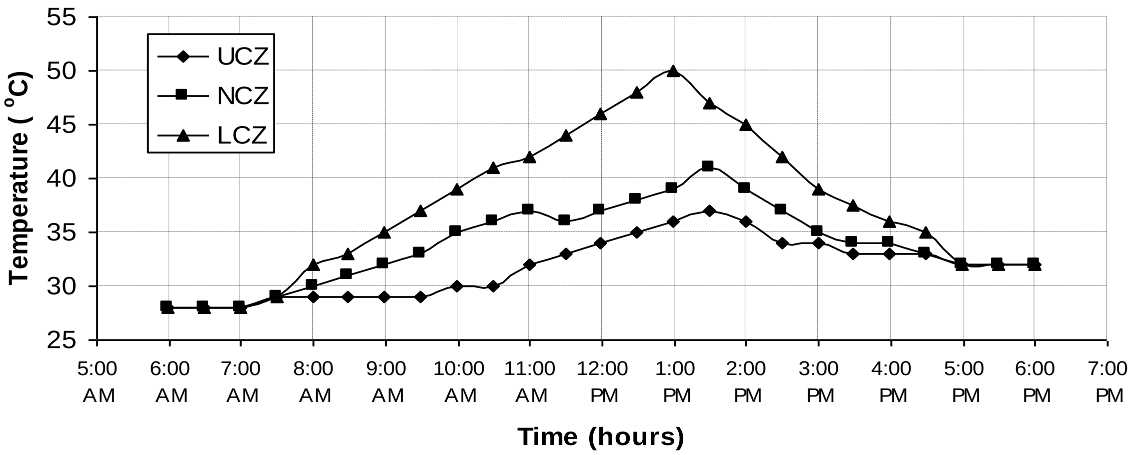

Fig.5. Temperature variation in various zones (Y=10.6)

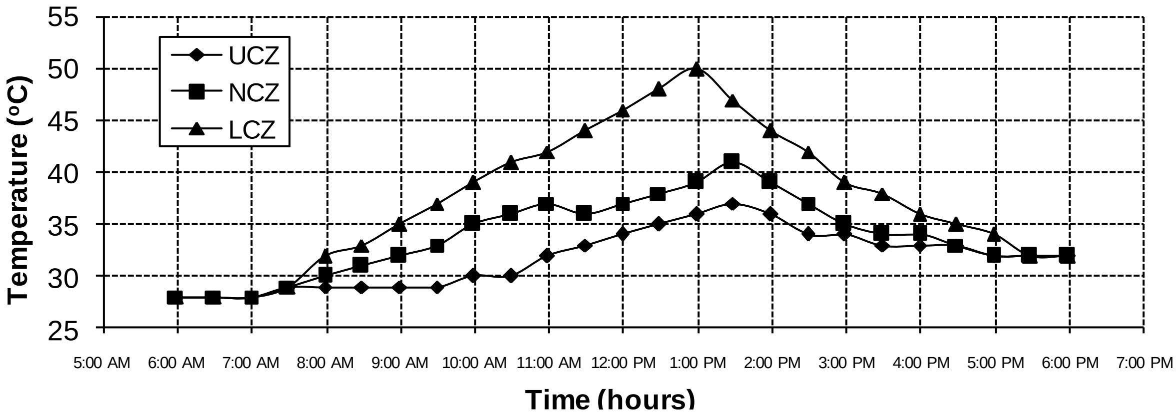

Fig.6. Temperature variation in various zones (Y=6.36)

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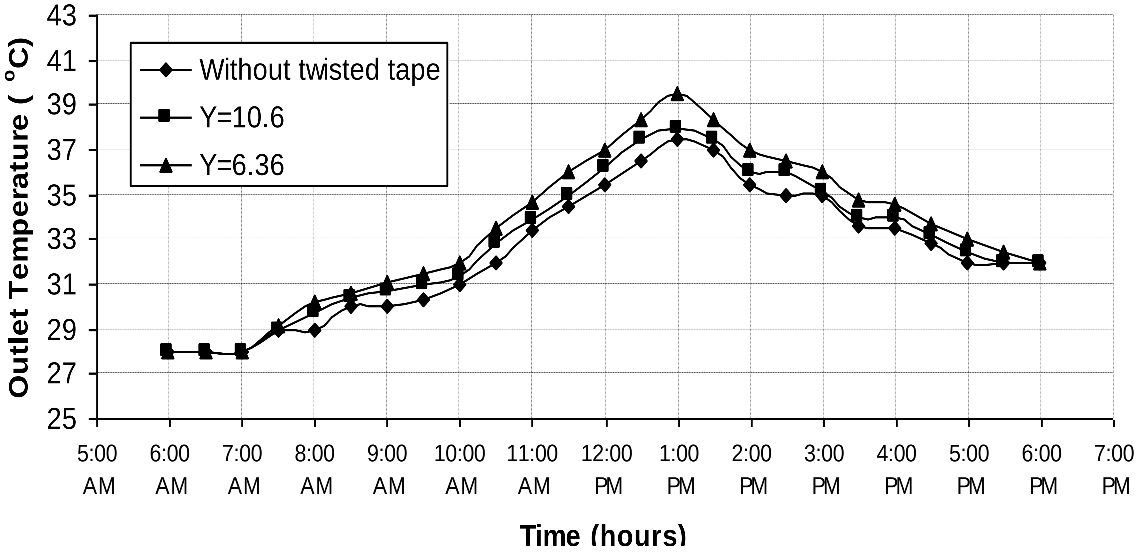


Fig.7. Outlet water temperature

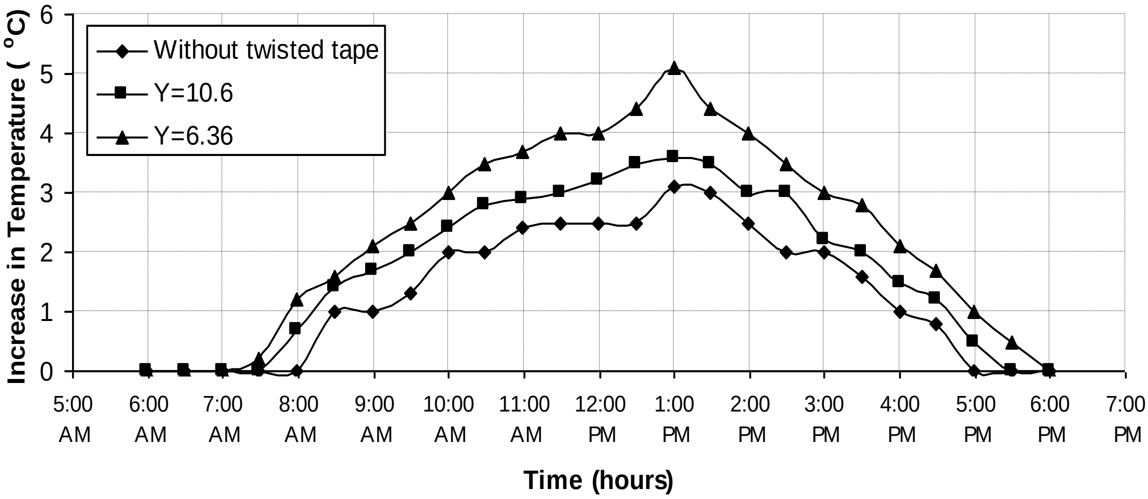
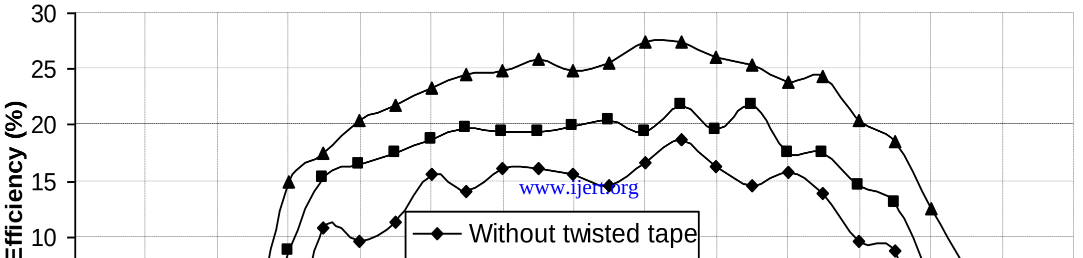


Fig.8. Increase in outlet water temperature (ºC)

From graphs fig.7&8, it is evident that the outlet temperature and gain in temperature for the flowing medium are higher for the solar pond possessing twisted tape inserts and more predominant for the heat exchanger having tape inserts with higher number of twists, i.e. the less twist ratio, indicating the augmented rate of heat transfer. This enhanced heat transfer in solar ponds with twisted tapes, is due to more swirls being generated in the flow passage and also due to the increased residence time of the flowing medium through the heat exchanger. The twisted-tape inserts also increases the turbulence in the flow, thereby augments the convective heat transfer coefficient and thus resulting in the enhanced heat transfer. The presence of helical twisted tapes in the flow passage also breaks the boundary layer, normally boundary layer is considered as a barrier for heat transfer. Thus, because of the above mentioned reasons, there is a phenomenal increase in rate of heat transfer, for the solar ponds provided with helical twisted-tape inserts.



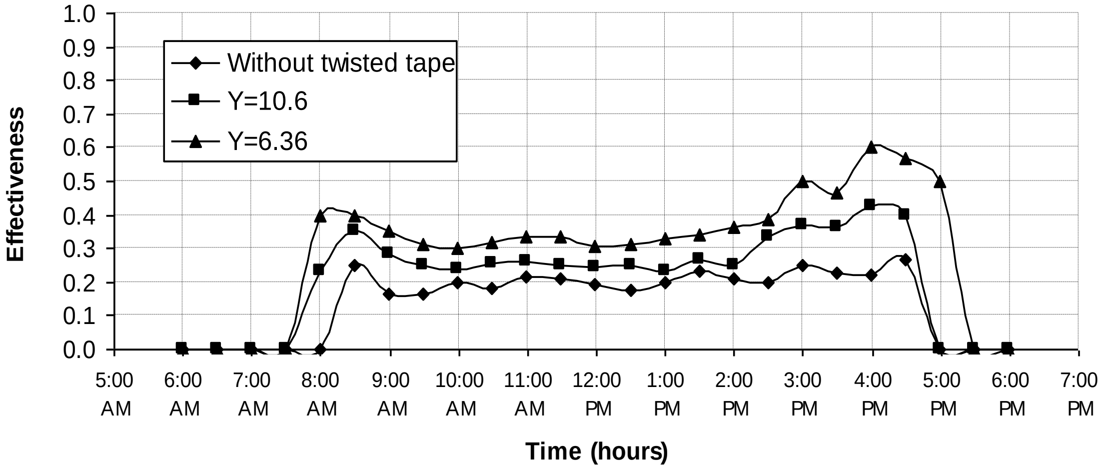


Fig.10. Effectiveness of heat exchanger

From the fig.9, there is an increase in efficiency for the pond having less twist ratio. Similarly from the fig.10 the effectiveness of the in-pond heat exchanger is more for pond with more number of twists in the tube insert. The effectiveness of the heat exchanger varies mostly between 0.3 to 0.5 and this for the solar pond having tape insert of 6.36 twist ratio. From fig.8, 9, and 10 it is observed that the solar pond thermal performance is better due to tube insert, which is distinct during 11:00 am to 2:00 pm, because the incident energy is more during this period.

6. Conclusion

From the above experiments conducted, it is inferred that providing tube inserts in the flow passage will augment the rate of heat transfer. Under solar irradiated mode, for solar pond with tube inserts of 10.6 twist ratio the increase in efficiency is 1.6% to 8.7% and for solar pond with tube insert of 6.36 twist ratio the increase in efficiency is 2.9% to 14.9%.

Solar ponds are thermal energy storage devices where, augmenting the rate of heat transfer will increase the performance of the system. This is also being proved, from determining the effectiveness of the in-pond heat exchanger. The heat exchanger of the solar pond fitted with tube insert of 10.6 twist ratio resulted with maximum effectiveness of

0.43 and heat exchanger with tube insert of 6.36 twist ratio resulted with maximum effectiveness 0f 0.6 whereas the heat exchanger without twisted tapes recorded a maximum effectiveness of 0.27. It is important to consider that, for augmenting the heat transfer the pressure drop in the flow passage is being sacrificed due to the presence of tube inserts. In future, the experiments can also be carried out for various flow rates by incorporating twisted tapes of various twist ratios. The parameters like flow rate, Reynolds number (Re), pressure drop, twist ratio (Y) can also be optimized for a particular real time solar pond. There is also scope to have nano – fluids in the flow passage and providing phase change materials in the solar pond, to increase the performance of the solar gradient solar pond.

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