International Journal of the Physical Sciences Vol. 7(18), pp. 2676-2686, 9 May, 2012
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS12.168
ISSN 1992 - 1950 © 2012 Academic Journals

Full Length Research Paper

The stored heat in a solar pond for salt production in Northeast Thailand

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Accepted 26 April, 2012

This research presents the experimental study of heat extraction from solar pond with thermosyphonic coils for salt production in Northeast Thailand. The solar pond has an area of 30 m^3. The thermophonic coil consisted of 15 U-shaped high density polyethylene (HDPE) tubes with a diameter of 25.4 mm. All 15 U-shaped HDPE tubes were connected to the upper side of each element and then connected to the upper header while the lower side of each element was also connected together with the lower header of the tanks that hold the saline water which are located nearby. As the saline water circulates through the warm coils, it was found that the temperature of saline water in the tank increased by 24.14°C during the daytime, while the night time temperature increased at an average of 22.10°C. This meant that rice husk, the conventional fuel in the northeastern region, consumption was reduced by 20.24 kg/day-m^3 (7.23%), and savings of 4,371.84 Baht/year-m^3 (145.73 \$/y-m^3) might be expected.

Key words: Solar pond, salt production, stored heat, energy conservation.

INTRODUCTION

Solar pond is basically a pool of saline water which acts as a low cost thermal energy storage system for collecting incident solar radiation and, at the same time, provides long term energy storage. Many research studies have been done on solar pond. Hüseyin et al. (2000) investigation showed that the salinity gradient solar pond is a low cost solar energy system which collects solar radiation and stores it as thermal energy in the same medium for a long period of time. Hsain et al. (2004) showed that a salinity gradient solar pond is a large body of saline water. Huanmin et al. (2004) study shows that heat storage allows solar ponds to power desalination during cloudy days and nighttime. Twenty-four hour a day operation allows desalination units of half the size to produce water relative to other solar desalination options. Hull et al. (1989) investigated that a solar pond can collect solar radiation and store it in the form of heat. Kumar and Kishore (1999) showed that solar ponds have recently become an important source of energy that is used in many different applications such as supplying processed heat for dairy plant, desalination and power production. Denius and Batton (1975) and Ahmed et al. (2001) integrated power, water and salt generation in their studies. Jaefarzadeh (2000) studied the performance of a salt gradient solar pond. It was found that the LCZ layer has a temperature which was between the ranges of 70-90°C and this correspond with the research result of Xiang et al. (2001) who verified the temperature in the LCZ layer to be between the ranges of 50-90°C.

In the northeastern part of Thailand where there are long hours of sunlight throughout the year, Pattanasethanon et al. (2007) showed that the annual mean of global illuminance on a horizontal plane is 446 W/m^2 and are much more able to be an energy source. Sompob (1986) investigated salinization in northeast Thailand, where is plenty of underground salt. The salt produced using 180 m underground saline water is pumped to the reservoir next to the salt pans having a

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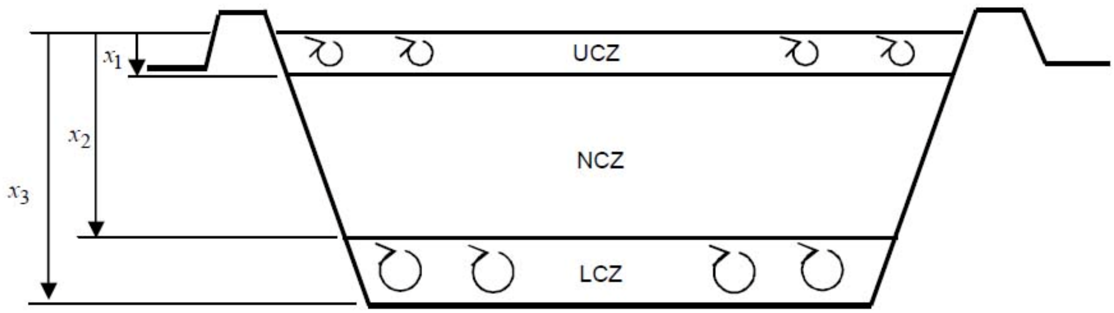

Figure 1. Schematic of a solar pond (Huanmin et al., 2004).

capacity of 5 m^3. Following this concentration using biomass fuel, especially rice husks, since it is very cheap when compared to other fuels, the operating period was divided into two parts: daytime 8.00 a.m. - 5.00 p.m. and night time 5.00 p.m.–5.00 a.m. The problems encountered in this process were increased energy and environmental costs. Usually, heat extraction from solar pond can be carried out in two ways. The first method uses a submerged heat exchanger in the pond. In the second method, brine is pumped from LCZ to an external heat exchanger. Both methods need external energy for the pumping system. In this study, the energy conservation in salt production was studied by using natural circulation (thermosyphonic flow) as heat extraction system to preheat saline water during the day time and the night time, suitable for rural area since this system needs no external energy.

Solar ponds

Duffie and Beckman (1991) investigated salinity gradient solar pond as a shallow body of saline water with several meters deep, set up so that there is increasing salinity with depth. Solar radiation entering the pond penetrates through to the lower layer, which contains concentrated salt solution. The temperature in this layer rises since the heat is unable to move upwards to the surface by convection. Solar heat is thus stored in the lower layer of the pond. Zhen et al. (2011) studied a salinity gradient solar pond which consists of three different concentrations of salt solution usually sodium or magnesium chloride as shown in Figure 1. The upper convective zone (UCZ) varies in thickness between 0.15 - 0.30 m which has a low and almost uniform salt content. Beneath the UCZ is the non-convective zone (NCZ) which varies in thickness between 1.0 - 1.5 m and has a salt content increasing with depth. The bottom layer is the lower convective zone (LCZ) also called the storage zone, which has thickness varying between 1.0 - 2.0 m and has a nearly uniform high salt concentration. Dark coloured absorbing material is often used to line the pool to enhance the absorption of solar radiation and to prevent groundwater contamination. The pond is also made as transparent as possible by periodically treating it for algae and dust control. Heat is extracted from this layer by pumping the salt solution from the bottom layer through an external heat exchanger. Alternatively, a heat transfer fluid may be pumped through a heat exchanger placed on the bottom of the pond. The solar pond will takes 2-3 months after establishing the salinity gradient to heat up. Huanmin et al. (2001) investigated daily variations in the storage zone temperatures are 2-3°C and the annual variation is of the order of 10°C. The solar ponds have a low capital cost owing to the fact that they are based on low-cost materials such as clay, plastic and salt. Matthias et al. (1998) showed advantage of low initial cost which means that it is cheaper to produce hot water or hot air in the temperature range of 60-80°C. The requirements of land, salt and water suggest that solar ponds are better constructed on wasteland or in desert land close to salt works. The schematic drawing of an ideal solar pond is shown in Figure 1 and consists of three zones. The UCZ, of thickness x_1, is thin and has a uniform salt content and a constant temperature, which is close to the air temperature. The UCZ is followed by the NCZ, of thickness $x_2 - x_1$, in which the salt content increases with depth. The NCZ is followed by the LCZ, of thickness $x_3 - x_2$, in which the salt content and temperature are nearly constant. The bottom of the pond is assumed to be a black body.

The design of solar ponds

To explore the thermal energy saving performance of the solar pond, the same method of flat plate solar collector performance can be considered using its equations so that it would be convenient to calculate for the appropriate size and the operational parameters of the pond. The equation mentioned is then used to find the relationship between the sizes, the layer's thicknesses,

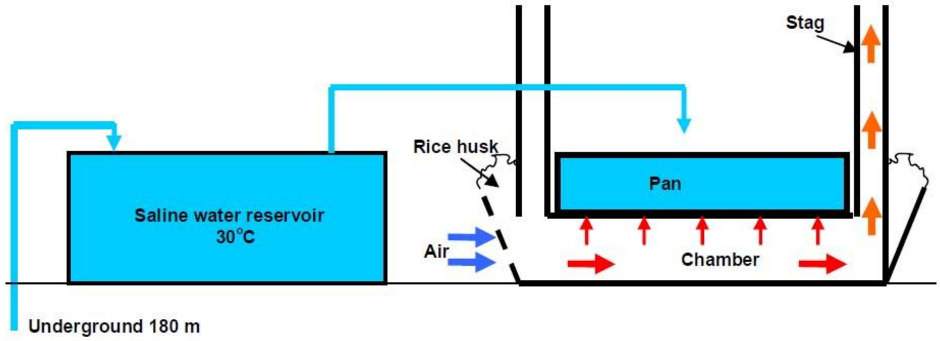

Figure 2. Conventional salt production.

and the heat loads desired. In designing the solar ponds there is needs to realize the optimum convenience for usage as well as the duration, by dividing into 2 stages as follows:

Solar pond location

Since the solar pond needs energy from the sun, the most suitable location would be a place with wide open space, no shade from any trees or buildings, deep or no underground water and situated close to water and salt supplies so that the materials would be more easily accessible.

The thermal utilization coefficient of the solar pond

A mathematical model of the thermal utilization coefficient of the solar pond is proposed, based on similar methods to analyze and calculate flat plate solar collector performance. It can be used to optimize the size and operational parameters of the ponds and to find the optimal relationship between the ponds and the loads. The thermal utilization coefficient of a solar pond is the ratio of the useful heat provided by the pond to the practical heat received by the pond. The thermal utilization coefficient depends, for example, on solar radiation, air temperature, thickness of the UCZ and the NCZ, depth of the underground water etc. However, most of these parameters are calculable in a nearly ideal solar pond. If the thermal utilization coefficient of a solar pond is a known quantity, the useful heat output can be simply given as follows:

$$Q_{up} = A_c F_R (\tau\alpha)_p \overline{H}_0 \varphi \qquad (1)$$

where F_R, A_c, and $\overline{H}_0$ are known parameters. When the operating conditions of the pond are changeless, $(\tau\alpha)_p$ is also a changeless quantity.

The NCZ of the solar pond serves mainly as the insulating layer. The bigger the thickness of the NCZ, the better is the insulating performance of the NCZ, but the less the sunlight that transmits through it. Conversely, when the NCZ is thin, although more sunlight can penetrate it, its insulating performance is worse. Therefore, the NCZ has an optimum thickness. The heat output of the solar pond is related to the thickness of the UCZ and NCZ. If the thickness of the UCZ does not change, the heat output of the solar pond is able to reach the maximum value by selecting x_2 by setting $\partial Q_{up}/\partial x_2 = 0$, the optimum thickness x_{2opt} of the NCZ follow as with Zheng et al. (2009).

$$x_{2opt} + x_1\left(\ln x_1 - \ln x_{2opt} - 1\right) = \frac{K\left(T_2 - T_1\right)}{\overline{H}_0 \bar{p} b} \qquad (2)$$

The thermal utilization coefficient of a solar pond is the ratio of the useful heat provided by the pond to the practical heat received by the pond. If the bottom of the pond is insulated perfectly, the thermal conductivity of the insulation layer can be considered to be very small then the thermal utilization coefficient of a solar pond can be simplified as follows.

$$\varphi = 1 - \frac{K\left(T_2 - T_1\right)}{\overline{H}_0 \bar{p} b\left[x_1 \ln x_1 - x_2 \ln x_2 + \left(x_2 - x_1\right)\left(1 + \ln x_o \cos\gamma\right)\right]} \qquad (3)$$

SALT PRODUCTION

Conventional salt production at the Kantharawichai site used 180 m underground saline water pumped to the reservoir and adjacent to salt pans with a capacity of 5 m^3 (Figure 2). Following this concentration, by using biomass fuel, especially rice husks since it is more economical when compared to the other fuels, the operating period was divided into two parts: daytime; 8.00 a.m. - 5.00 p.m., night time 5.00 p.m. – 5.00 a.m. This study involved a solar pond being used to supply process heat for salt production,

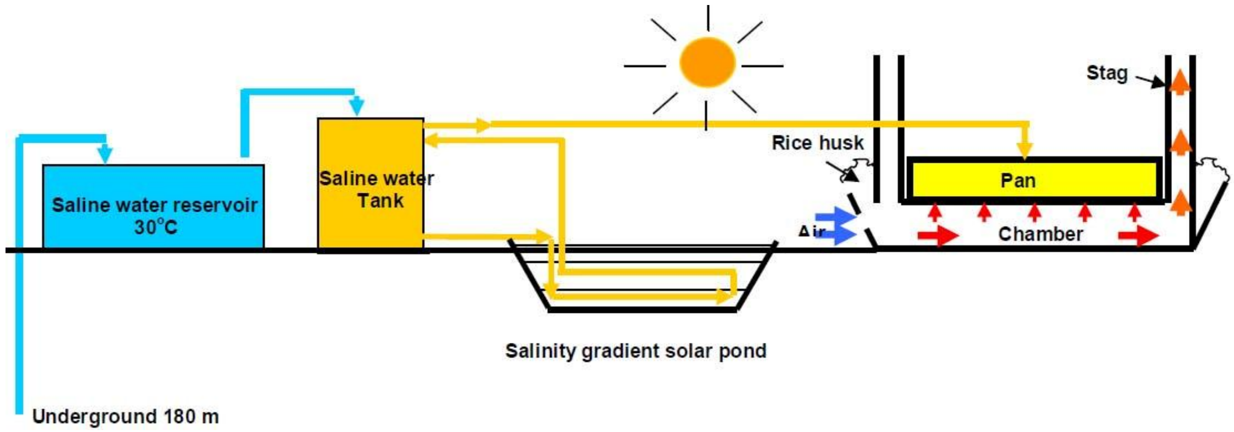

Figure 3. Lining scheme of saline water preheating system.

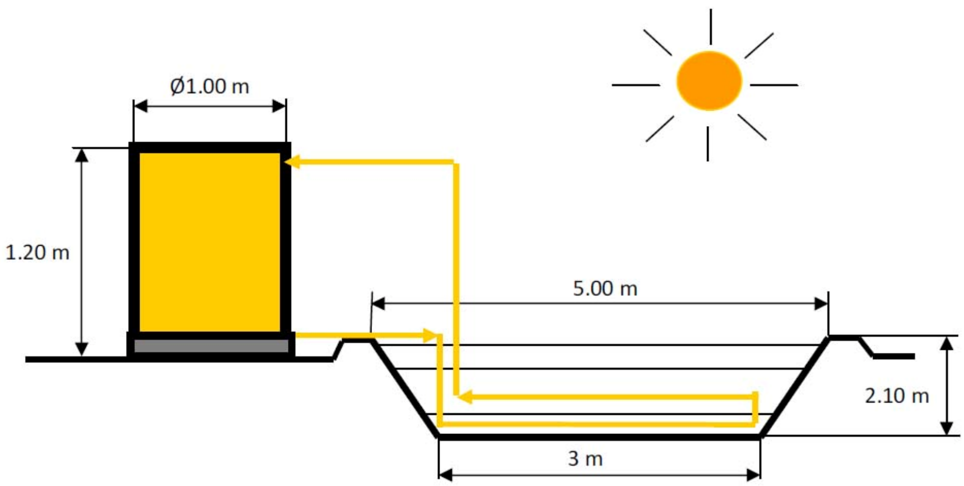

Figure 4. The saline water preheating system.

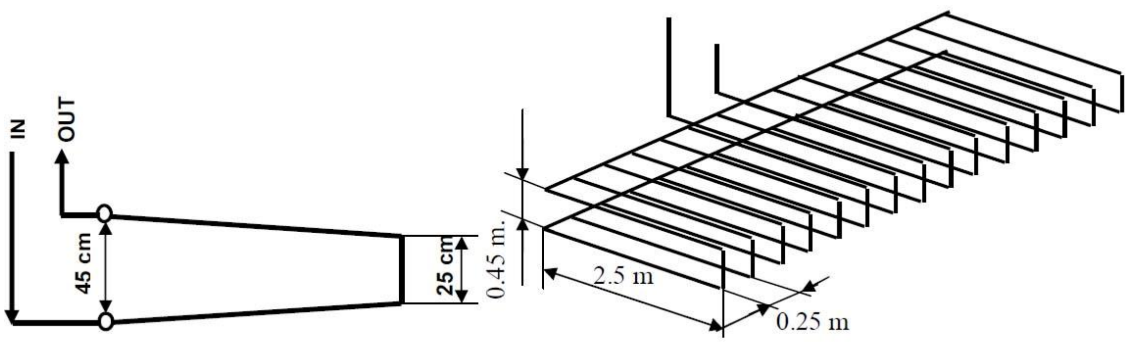

Figure 5. The thermos phonic coil.

the stored heat in LCZ heating saline water in the tank up to 70°C in the day time and the night time before feeding it to the process (Figure 3). The thermosyphonic coils had been used for the heat extraction system as shown in Figures 4 and 5, as the heated saline water is less dense, it rises to the top and cold saline water flows through the bottom layer heating up and then returning to the tank. The circulation need no external energy as it can operate independently.

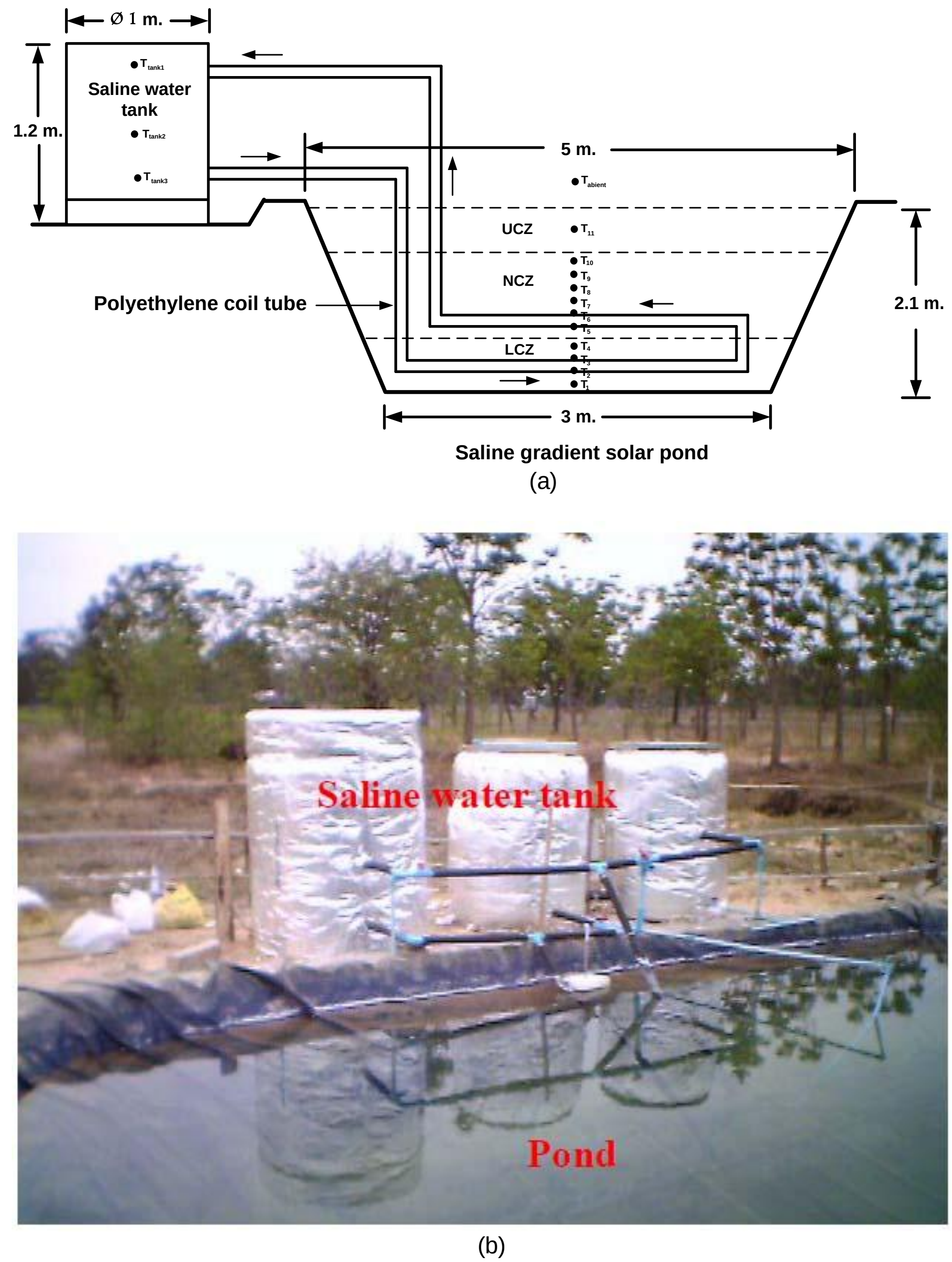

Figure 6. The construction and dimensions of the Kantrarawichai pond.

Construction of the pond and experiments

In the present experimental work, solar pond with an area of 30 m^2 and a depth of 2.1 m was studied. A solar pond collects the sunlight and stores energy in the bottom layer. Solar energy is absorbed by a solar pond from its surroundings during the daytime and stored in the form of heat energy in it. The thermosyphonic coils were installed at the bottom convective zone. All 15 U-shaped HDPE tubes diameter of 25.4 mm were connected to the upper side of each element and then connected to the upper header, the lower side of each element was also connected together with the lower header as shown in Figure 5 and then the unit was fixed to the bottom of the solar pond. As the saline water circulates through the warm coils, it becomes heated and less dense, and upon its return, rises to the top of the tank. The cold saline water at the bottom of the tank flows through the coils in the solar pond where it once again gets heated and returns to the top of the tanks. The temperature measurements were taken at different locations of the pond and saline water tank by using K-type thermocouples with an uncertainty of $\pm 0.58°C$. Also, the researchers recorded the temperature value every hour. The construction and dimensions of the Kantrarawichai pond are shown in Figures 6(a) and (b).

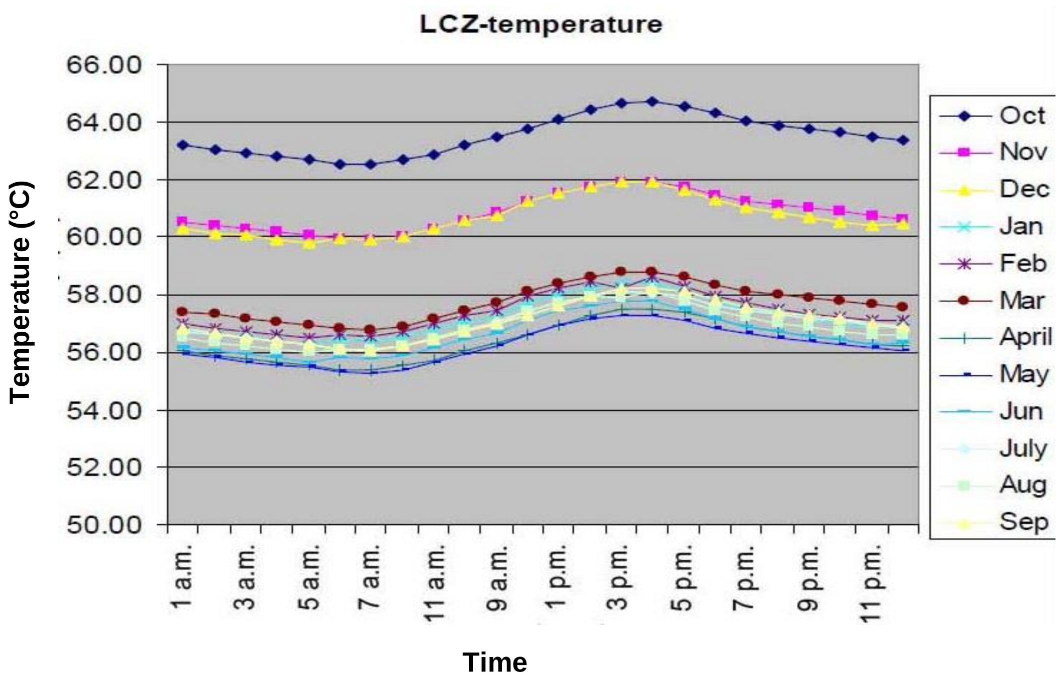

Figure 7. The variation of daily mean temperature of the LCZ.

RESULTS AND DISCUSSION

Daily average temperature of UCZ in the solar pond

The solar energy that penetrated through the saline water was stored as thermal energy at LCZ. According to Figure 7, which shows the daily average temperature alteration during October 2008 to September 2009, it was found that the highest temperature was in October 2008 because no heat was extracted from the LCZ layer. The heat was accumulated after 7 a.m. in the morning and started increasing up to the highest temperature during 3-4 p.m., then started decreasing little by little down to the lowest temperature in a day at 7 a.m. the following day. The daily temperature difference between daytime and night time was approximately 2-3°C. From the chart, the average maximum temperature was 64.69°C in October, 61.92°C in November, and 61.92°C in December; whereas, the highest solar energy from 12 p.m. - 1 p.m. was 720.40, 717.65, and 712.30 W/m^2 respectively.

Temperature of the heat storage zone (LCZ)

According to the temperature of LCZ measured at a depth of 10, 20, 30, and 40 cm, respectively from the bottom of the pond in October 2008, it was found that the maximum temperature difference between daytime and nighttime occurred at the nearest depth of 10 cm from the bottom at 2.9°C. Since the nearest spot transferred heat into the ground easily, the lowest temperature was thus reached at 6-7 a.m. The minimum temperature difference between daytime and nighttime occurred at the depth of 40 cm from bottom of 1.1°C which is the furthest distance. The LCZ's mean maximum temperature was 64.69°C at 3-4 p.m. as shown in Figure 8.

Temperature of the solar pond at different depths

In the study, temperature at different depths of the pond was measured at distances of 10, 20, 30, 40, 50, 70, 90, 130, 150, 170, and 190 cm from the bottom and then compared to the temperature of the atmosphere in October, 2008. The results revealed that the temperature of LCZ at a depth of 10-50 cm was almost exactly the same. At a depth of 70-170 cm, the deepest point of the NCZ, the lowest temperature shown was from 60.66°C below to 32.99°C; while there was only a slight variation in daily temperature. At the topmost, the daily mean temperature showed a greater change as its temperature was between 25-35°C harmonized with the environment's temperature which varied between the range 22 - 34°C, as shown in Figures 9 and 10.

Maximum mean temperature of LCZ and the temperature of saline water in the storage tanks

Extracting the heat from LCZ into the heat storage tanks

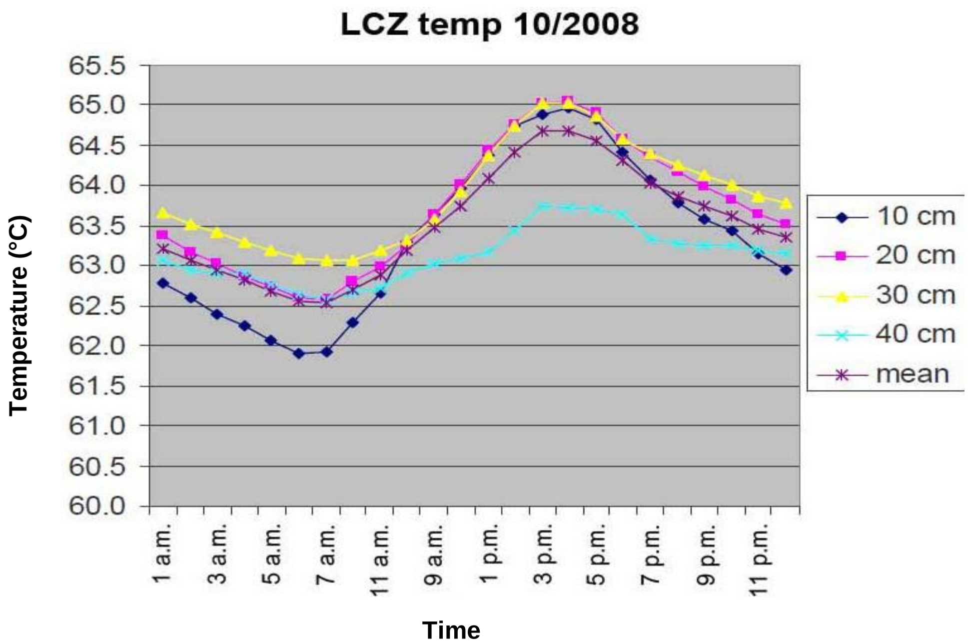

Figure 8. The temperature profile of the pond.

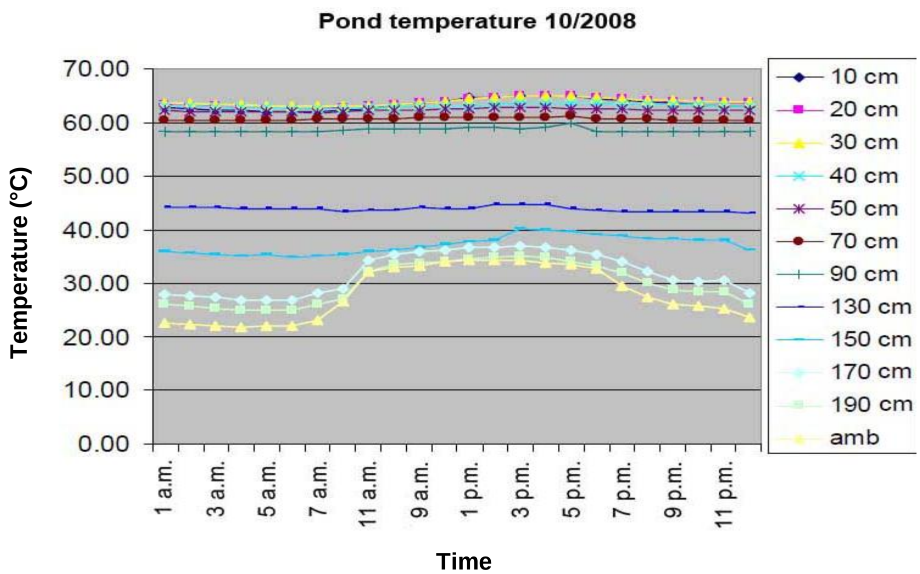

Figure 9. The temperature profile of the pond.

via the thermosyphonic flow system had the capacity of transferring heat to the tanks. Throughout the daytime period, the temperature of saline water in the tank increased to 24.14°C on average as demonstrated in Figure 11. Meanwhile, the temperature in the tank increased to 22.10°C at night as shown in Figure 12, yet it was even lower than that in the daytime by 2-3°C throughout the year.

Temperature of LCZ and solar energy

In the first month of the study, October 2008, the solar pond began storing energy with all its capacity, yet there was no heat extracted from LCZ of the pond. According to Figure 13, it can be seen that the temperature of LCZ could reach a maximum of 64.69°C. When the thermal extraction process was generated in LCZ, the

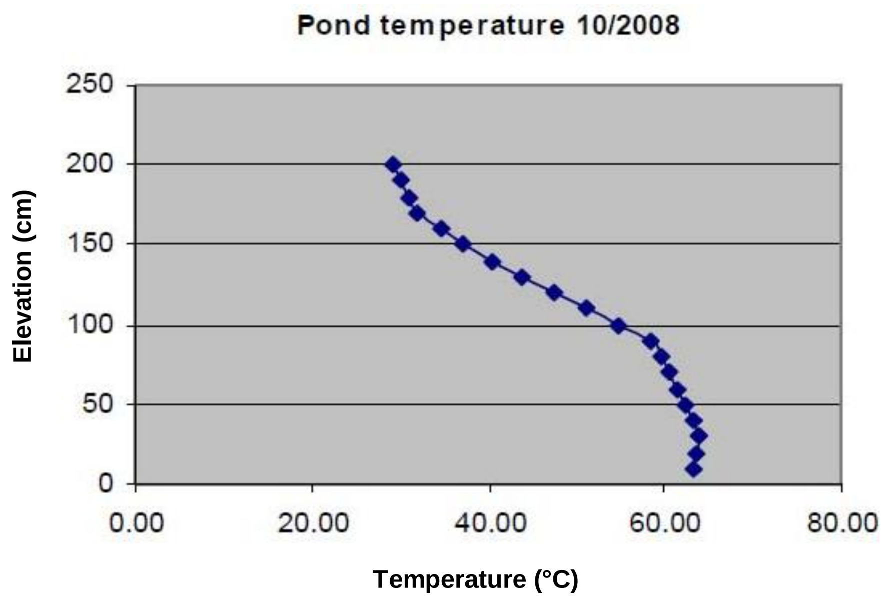

Figure 10. The temperature profile of the pond.

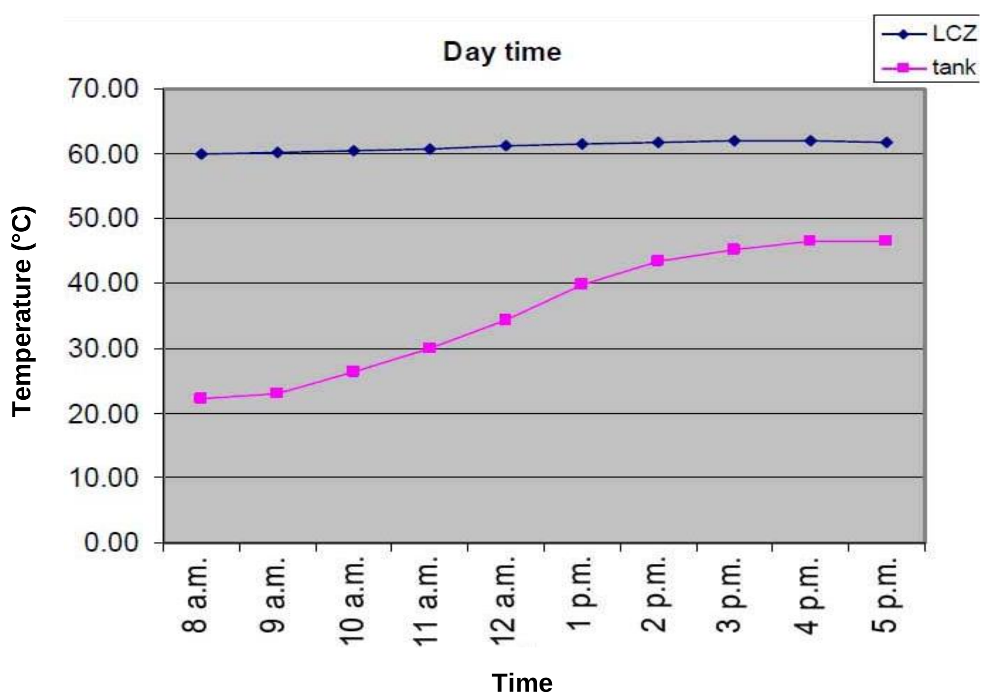

Figure 11. The temperature variation of LCZ and the saline water in the storage tank during the daytime period.

temperature in November to December decrease to 61.92 and 61.73°C respectively, and kept decreasing in the month after until it reached the lowest temperature of 57.3°C in May. Looking at the results of annual experiment, it was found that the temperature of LCZ had not been influenced by the solar energy shined through the surface only, there were many other factors including rain storm and strong wind, which could not be controlled

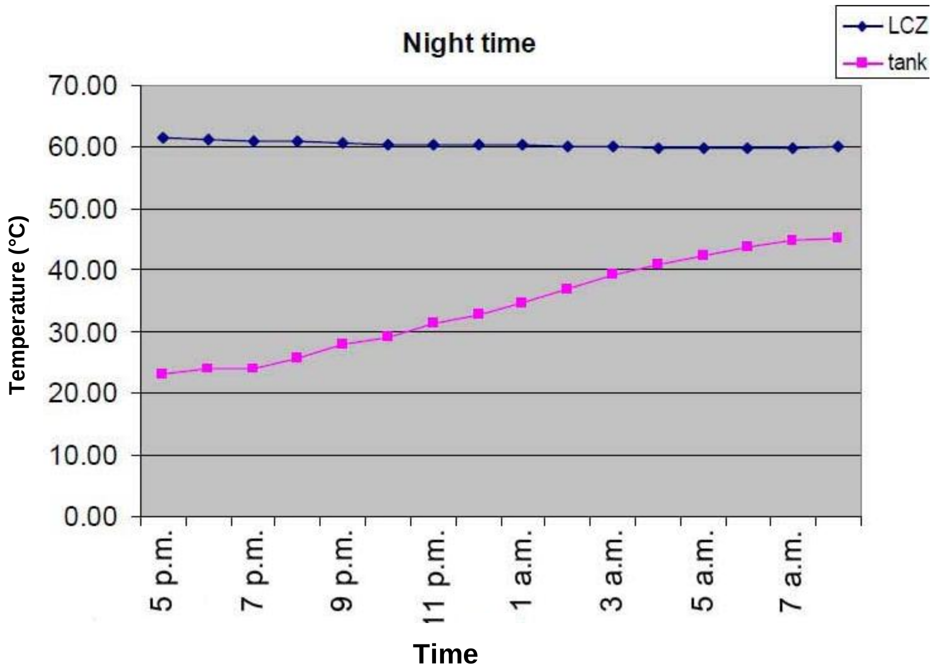

Figure 12. The temperature variation of LCZ and the saline water in the storage tank during the nighttime period.

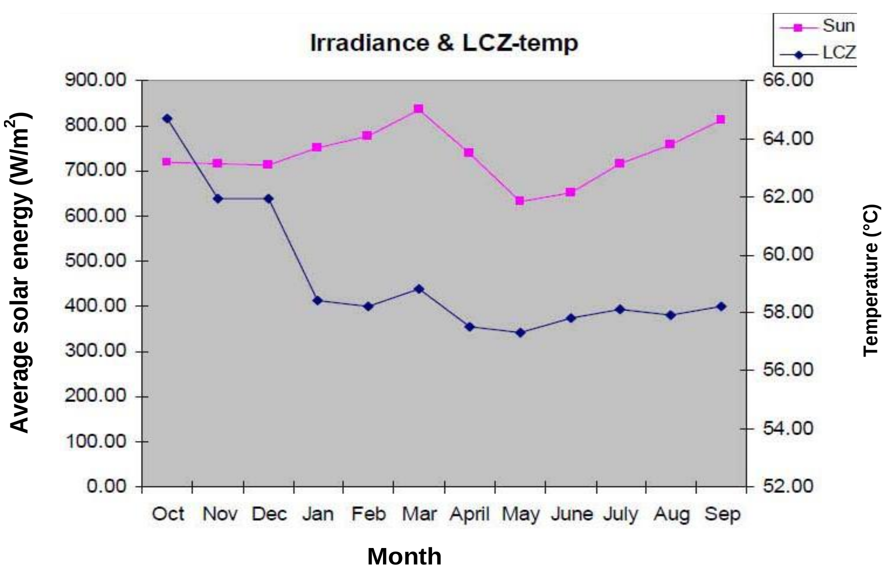

Figure 13. The temperature variation of LCZ and the monthly average solar energy.

since the solar pond's location must be in the open-air.

Overall efficiency of the system

The overall efficiency of the system is the ratio of the practical heat received by saline water in the tanks to the solar energy. The overall efficiency of the system includes the thermal utilization coefficient of a solar pond and the efficiency of the heat extraction system. The overall efficiency of the system can be simply given as $\eta_{all} = (Q_t / A_c)/\overline{H}_0$ where Q_t is the heat collected of

Table 1. Saving cost in daytime and nighttime 1 m^3.

Item	Daytime saving		Nighttime saving	
	Detail	Value	Detail	Value
Saline water	1 m^3	1,217 kg	1 m^3	1,217 kg
Heat collected (Q=mc$_p\Delta$T)	1,217x3.993x22.10	107,394 kJ	1,217x3.993x22.24.14	117,307 kJ
Rice husks weight	107,394/(14,232.4/0.78)	9.67 kg	117,307/(14,232.4/0.78)	10.57 kg
Saving cost (6 months)	1.20x9.67x(30X6)	2,088.72 ฿/y	1.20x10.57x(30X6)	2282.12 ฿/y

Table 2. Saving cost per saline water 1 m^3 (30 ฿/$).

Item	Cost	
Daytime saving	2,088.72 ฿/y	69.63 $/y
Nighttime saving	2,283.12 ฿/y	76.10 $/y
Total	4,371.84 ฿/y	145.73 $/y
Investment	29,000.00 ฿	966.67 $
Payback period (29,000.00/4,371.84)	6.53 y	

daytime and nighttime (w/m^2) and $\overline{H}_0$ is average daily solar irradiance ($\overline{H}_0$ = 446 w/m^2 in Northeast Thailand; (Pattansethanon, 2007). In this study, it was found that the overall efficiency of the system was 39%.

Economic evaluation

In the case of salt production, due to Environmental Law, the process can be operated over 6 months per year for saving and recovery of the environment since it will takes a significant amount of time for recovery to be achieved. In the salt production, the solar pond utilizing thermosyphonic coils could be used for preheating the saline water. The economic evaluation of daytime and nighttime values of saline water is shown in Table 1. The data from this table are base on density of saline water ρ = 1,217 kg/m^3, specific heat C_p = 3.99 kJ/kg.K, heat value of rice husks = 14,232.4 kJ/kg, and price of 1.20 ฿/kg, kiln efficiency = 0.78, and economic evaluation of system is shown in Table 2.

Conclusions

In this study, thermophonic flow can be used for the heat extraction system of the solar pond. It is interesting since this system runs independently without any external energy, so it is suitable for use in rural areas. From the results, it is demonstrated that the stored heat in solar pond can be used for 24 h by preheating the saline water in the storage tanks and gaining higher temperatures up to 24.14°C on average in the daytime; while, it can be increased up to 22.10°C at night. Due to the higher temperature of saline water in the tanks, the rice husks can be saved around 20.24 kg/day-m^3 or 7.23%. This is to say that there will be some money saved - 4,371.84 Baht/year-m^3 (145.73 $/y-m^3). Besides, the maximum temperature of the LCZ can reach 64.69°C during October, 2009, which is quite similar to the planned temperature of 70°C. At the saturation point, there is not much variation on the temperature of LCZ. Its temperature stored in the daytime becomes higher than that in the night time period by only 2-3°C; even if it does not get any sunlight at all at night. This significantly indicates that the soil around the solar pond's site provides good quality heat storage.

ACKNOWLEDGEMENTS

The authors would like to express their great appreciation to the Faculty of Engineering, Mahasarakham University and Thailand Research Fund (TRF) for providing financial support of this study.

Nomenclature

A_c	Surface area of the solar pond	m^2
F_R	heat removal factor	-
$\overline{H}_0$	average daily solar irradiance	kJ
K	thermal conductivity of solution	W/m^0C
$(\tau\alpha)_p$	equivalent absorptivity-transmissivity product	-

φ thermal utilization coefficient of solar pond -

x_1 downward co-ordinate of depth at point 1 m

x_2 downward co-ordinate of depth at point 2 m

x_2 downward co-ordinate of depth at point 2 m

Q_{up} useful heat collected from pond kJ

$\bar{p}$ weighted average coefficient of diffusion and beam fraction of solar radiation on surface of pond -

T_1 temperature of UCZ at point 1 °C

T_2 temperature of NCZ at point 2 °C

γ average reflection angle of sun light in pond -

LCZ lower convective zone

NCZ non-convective zone

UCZ upper convective zone

η_{all} overall efficiency of the system

Q_t heat storage of solar pond W

x_o, b two constance's connect with sun light in pond -

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