Development of A Solar Paddy Drying by Fluidization Technique Using Energy from Solar Pond

Sura Tundee*, Manus Sirijun , Mongkon Laongoen and Kanchit Rongchai
Department of Mechanical Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khon Kaen Campus,Thailand.

Abstract

In this research a new approach for employing heat from solar pond as the main source of energy for paddy drying was introduced. The drying test rig was designed, fabricated and evaluated. The rig consists of paddy dryer and solar pond. The area of solar pond was 50 m^2 and a depth of 2.5 m was built at Khon Kaen in North-Eastern Thailand. Air mass flow rate was measured by an orifice plate, the temperatures were monitored by K type thermocouples, the solar insolation was recorded by a pyranometer. One of the objectives in this research was to evaluate the effect of mass flow rate and interval time of paddy discharging on the rate of paddy drying by the dryer and was conducted at temperatures of 40, 50, and 60 degrees Celsius at the flow rates of hot water of 0.56, 0.75, and 1.67 liters per minute respectively. The wind speed to be applied was 5 m/s. Heat in the experiment was obtained from the solar pond. The experiment was conducted at the flow rates of water of 2, 2.5, and 3 liters per minute respectively and was continuously run for 24 hours. In addition, the experiment took 3 days for each of the flow rates and data were recorded every 1 minute. The results showed that the flow rate of 2.5 liters per minute could take heat into application better than the flow rates of 2 and 3 liters per minute. At such the flow rate, moisture dropped from 23.4% to 15% for the first time of drying and for the second and third times, the moistures dropped to 13% and 11% respectively. Reduction in moisture content of the paddy met the criteria set which was 1% to 5% per round of drying.

Keywords: Solar Energy, Solar Pond, Paddy Dryer.

1. Introduction

Energy is one of the factors necessary for everyone. We use energy in various forms over the year, which causes a number of significant power sources in the World to decline by the amount of time spent. As a result, many countries start to realize and have already began to look for alternative renewable energy to replace those that are vanishing. There are many types of renewable energy such as wind power, hydro power, and biomass. There is also another type of renewable energy that is always available, inexhaustible, and not adversely affecting the environment. It is solar energy. To use such energy; however, there must be a device that can store heat energy from the sun so that the stored energy can be utilized later for various usages. Rice is one of Thailand's major commodities and the nation is the largest rice exporter in the world The rice generates the highest income in Thailand in 2015, exporting 9,795,763 million tons equivalent to 4,613 million US dollars. As opposed to using traditional manual harvest methods, more rice paddy is harvested using machinery resulting in high moisture content due to lack of drying. It is important that the grains are dried before storage. Drying methods can be done in many ways such as solar drying, hot wind drying or using a fluidised bed method. Each method has advantages and disadvantages. The fluidised bed method is appealing because relatively shorter drying time is required compared to other methods. Energy sources for fluidised-bed drying are important and concern.

Solar pond is another option that can be used to collect heat from the sun due to its lower cost per square meter than other types of solar energy equipment. This research has therefore used the solar pond as a storing source of thermal energy from the sun and uses the fluidized bed for paddy dryer.

Solar pond is a device to collect and store energy. It can operate continuously all year long. Solar ponds collect energy from solar radiation. The radiant heat is collected at the bottom side of the pond and this amount of heat would be used later.

The first recorded solar pond to a natural solar lake was that of Kalecsinsky who decribed the Lake Madoc (Medie Lagoon), located at $\left(42^{\circ}44'N, 28^{\circ}45'E\right)$ in Transylvania This lake showed temperatures increasing up to 70 °C. at a depth of 1.32 m at the end of the summer. The minimal temperatures were 26 °C.during early

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spring. Of which compare ambient temperature with higher than the others. The idea of solar energy collection was conduct by creating artificial solar pond hinted by Kalecsinsky.(Kalecsinsky, 1902)

The structure of solar pond is shown in Fig. 1**.** It is noted that the size of pond depends on the aim of energy use such as water heating, crop drying, desalination, and electrical power generation.

There is an amount of saline inside the pond. Generally, the saline solution is Sodium Chloride or Magnesium Chloride solution. The pond can be divided into three regions namely the upper convective zone (UCZ),the middle non-convective zone (NCZ), and the lower convective (LCZ).(Abhijit,et al. 2013.)

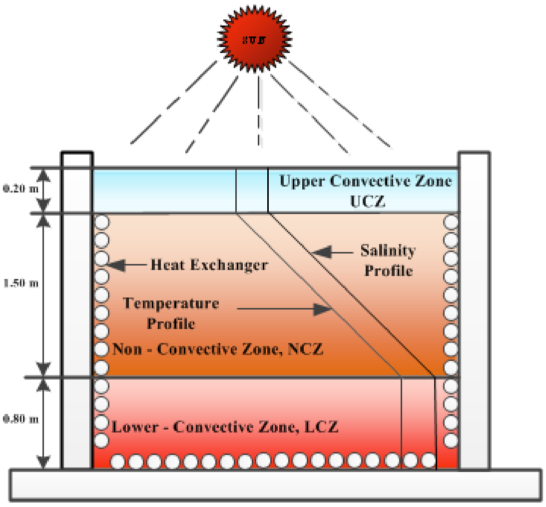


Fig.1: Schematic of the solar pond

The upper convective zone is located at the top of the pond. The temperature of this zone is nearly closed to the ambient temperature. The salt concentration is also near the clean water. Due to the contact between the top layer of this zone and the ambient, there is energy loss from convection and evaporation.

The next zone, non-convection zone, is below the upper convection zone. In this zone, the salt concentration is changed with the depth measured from the interface of the upper convective zone and non-convection zone. The increasing of depth from this interface results in the increasing of salt concentration. The function of this zone is to protect the heat convection from the optimum thickness of this zone yielding the high efficiency of energy storing inside the pond.(Andrew and Akbarzadeh 2005; Ha, 1984; Tabor and Doron,1986)

The last zone, lower convection zone, is the most salt-concentrated zone. The concentration in this zone is uniform. When the pond receives heat from solar radiation, the heat penetrates through the upper and non-convection zone to be stored at the bottom side.

Investigations on heat extraction systems have been conducted by a number of researchers generally performed by means of single-phase heat transfer using sensible heat gain by the liquid working fluid which is mostly water. The current method of heat extraction suffers from two main limitations. Firstly, the active circulation of the working fluid inside the in-pond heat exchanger requires pumping power which is unsuitable in the remote areas where solar ponds are most viable. Secondly, single phase heat exchangers are bulky in size and are required to handle large mass flow rates of heat transfer fluid in order to transfer kilowatt range heat provided by the solar ponds.

A crucial aspect of solar pond technology is the heat extraction from the LCZ (Sherman, 1989; John and Walton, 2001; Kumar and Kishore, 1999). Presently it is carried out in one of the following two ways: by using a submerged heat exchanger located on the bottom of the pond, or by pumping brine from the lower convective zone to an external heat exchanger and then returning it to the pond. The first method implies high costs for the maintenance of the heat exchanger, as it is fully submerged in the hot brine, which is a highly corrosive medium. The second method generates local temperature differences of which final effect is to destabilise the salinity gradient layer, because this brine extraction injection process is performed at a specific point of the solar pond, generally close to the centre of a circular solar pond.

Aboul-Enein et al.,(2004) investigated the thermal performance of a shallow solar-pond under the batch mode of heat extraction. They proved that the pond could provide 361 K of hot water at a maximum temperature of 60 °C. at sunset. Also the pond can retain hot water until 7.00AM next day at a temperature of 47 °C.

(Ramadan et al., 2004) studied the thermal performance of solar pond under continuous mode of heat extraction. They proved that the continuous mode of heat extraction is more efficient than the batch mode of heat extraction. (Jaefarzadeh, 2006) studied the heat extraction from the solar pond with an area of 4 m^2 and a depth of 1.1 m by using in-pond heat exchangers with water as the working fluid. In this investigation, a system of internal and external heat exchangers was used. The internal heat exchanger was installed in the LCZ that helps to extract heat from the bottom of the pond by using circulating fresh water and transfer it to the water to air heat exchanger placed externally to the pond. It was concluded that the solar pond can deliver heat either continuously with low efficiency or intermittently with relatively high thermal efficiency (Chyng, Lee, and Huang, 2003; Wang, Akbarzadeh, 1982; Andrews and Akbarzadeh, 2005; Leblanc et al., 2011; Tundee et al., 2010; Valderrama et al., 2011).

Bansal, Hrishikesan, and Garg 1984) studied the effect of the heat extraction on the performance of solar pond at the flow rate of 0.1- 0.2 kg/s. The solar pond efficiency was found to be 60% when calculated from the calorific value from the radiation of the sun at the surface of the pond. (Sabetta, Pacetti and Principi, 1985) built a heat exchanger which is made from poly ethylene tube, installed inside the solar pond at the lower convective zone. Throughout the experiment, the heat exchanger showed no corrosion in the brine. (Prakash,Garg, and Hrishikesan, 1989; Taga, Fujimoto, and Ochi, 1996) designed and tested a solar pond with a cover made from a transparent double film (González, Pérez, and Benítez, 1992) studied theoretically and experimentally the effect of water depth on the pond performance throughout daytime hours in order to find the optimal water depth. (Ali, 1987; Ali, Akhlaghi, 1987) developed a theoretical model, which was validated experimentally, to predict the performance of a solar pond. Transient analysis of the SSP water heaters integrated with baffle plates has been presented by (Dutt1, Rai1 and Tiwari, 1987; Madhuri and Tiwari,1986). It is concluded that better performance of the solar pond can be achieved with the use of baffle plates. (Parkash, Garg and Hrishikesan, 1989) have investigated the effect of using a movable insulation cover on the performance of a collector-cum-storage water-heating system. (Abhijit et al. 2013) studied heat extraction from non-convective and lower convective zone of the solar pond. it is found that temperature of the LCZ and the average annual solar pond efficiency is very sensitive to the mass flux of the heat transfer fluid that flows through the in-pond heat exchangers.(Sharma and Tiwari, 2010) proposed system modifications to enhance the performance of shallow solar pond. It is found that use of glass glazing along with the P.V.C., the final temperature rises to 79°C. (Wang et al., 2015) studied experimentally the effectiveness of using the thermal and porosity properties of cleaned and screened coal cinders to achieve higher temperature in the lower convective zone (LCZ) of a salt-gradient solar pond. It is concluded that adding porous medium in lower convective zone may cause the increase of the temperature of this layer, and it can be deduced that the effect of porous medium on salt diffusion will be also influenced with the increase of the temperature. Zomorodian et al.(2007) Introduced a new approach for employing solar radiation as the main source of energy for paddy drying. The drying test rig was designed, fabricated and evaluated. The rough rice solar dryer was a cross-flow and an active mixed mode type with a new and an efficient timer assisted semi continuous discharging system. The maximum overall efficiency of drying system was 21.24% (with average drying air temperature of 55 °C) and the fraction of energy consumed by the auxiliary heating channel during the drying process compared with solar energy was only 6–8%. The maximum capacity of the dryer was about 132 kg of rough rice with initially 27% d.b. down to 13% d.b. final moisture content in 3 h of drying period Sutherland and Ghaly (1982) were probably the first research group who investigated feasibility of using fluidization technique for paddy drying. They were reported showed that head yield was 58-61% when paddy was dried from 28.2 to 20.5% but was 15-24 % when the final moisture content was 19%. Tumambing and Driscol (1991) found that drying temperature and bed thickness affected on the drying rate of paddy. Drying conditions were as follows: drying air temperature of 40 –100 °C, bed thickness of 5–20 cm and air velocity of 1.5–2.5 m/s in their experiments. Soponronnarit, Yapha, and Prachayawarakorn (1995) designed and tested a prototype of 0.82 ton/h capacity fluidized bed paddy dryer for high moisture paddy. Results showed that the unit operated efficiently and yielded high product quality in terms of head yield and whiteness. The moisture content was reduced from 45% to 24% d.b. by using air temperature of 100–120 °C, fraction of air recycled of 0.66, specific air flow rate of 0.05 kg/s kg dry matter, superficial air velocity of 3.2 m/s, bed depth of 0.1 m. Reid and Siebenmorgen (1998) explored the relationships between rough rice surface temperature, amount of moisture removed and harvest moisture content and head rice yield reduction (HRYR) and developed a model describing HRYR as a function of these variables Queiroz, Couto, and Haghighi (2000) developed a model to simulate the moisture diffusion during the drying process of rough rice by using finite element analysis. The simulated model could predict the temperature of the air and grain and the moisture movement inside the rough rice kernel. Soponronnarit, Wetchacama, Trutassanawin, and Jariyatontivait (2001) designed, constructed and tested a prototype of vibro-fluidized bed paddy dryer with a capacity of 2.5–5.0 ton/h and developed a mathematical model that determines optimum operating parameters. Comparison between the experimental and simulated results showed that the mathematical model could predict fairly well. From the survey of previous works, there have been no reports of an investigation into paddy drying using a fluidised bed that incorporates an alternative energy source from a solar pond.

2. Theory

2.1 Energy balance on solar pond

The system being considered is the one dimensional heat transfer problem through a parallel piped whose base is a unit surface area of the pond, and its height is the depth of the pond. To obtain better results from the model developed, it is more convenient to address each zone in respect to the boundary conditions. For this purpose, the pond is considered to have three zone, as in Fig 2. The UCZ and LCZ are considered as single grid points which have a thickness of Z_0 and Z_A, respectively. The total depth of the pond is Z. Conservation of energy is then applied on each zone. For NCZ, the energy equation can be written as follow;

$$\rho C \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z} \right) + q - q_{loss} \tag{1}$$

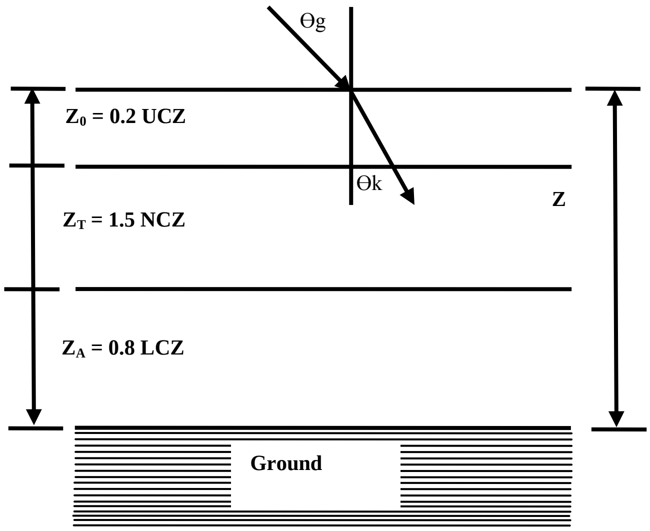


Fig. 2: The physical structure of the coordinate system of the solar pond model

For LCZ, the energy equation is also written as follow;

$$\rho c_p A D_L \frac{\partial T_L}{\partial t} = Q_R - Q_{up} - Q_s - Q_G - Q_L \tag{2}$$

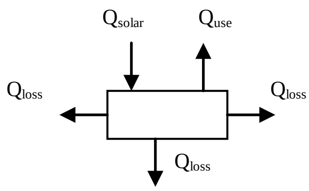


Fig. 3: Diagram of control volume

By assuming that the pond is well insulted, heat loss around the pond is small comparative with amount of heat extraction. The equation (2), thus, can be written as follow;

$$Q_{solar} = Q_s + mc_p \frac{\Delta T}{\Delta t} \tag{3}$$

From the fact that extracted heat from the solar pond is equal to the heat extracted by thermosyphon. Substitute (3) into (2), we got;

2.2 Fluidization

Fluidization is a process in which solids are caused to behave like a fluid by blowing gas or liquid upwards through the solid-filled reactor. Fluidization is widely used in commercial operations; the applications can be roughly divided into two categories.

- physical operations, such as transportation, heating, absorption, mixing of fine powder, etc. and
- chemical operations, such as reactions of gases on solid catalysts and reactions of solids with gases.

When the solid particles are fluidized, the fluidized bed behaves differently as velocity, gas and solid properties are varied. It has become evident that there are number of regimes of fluidization, as shown in Figure 4. When the flow of a gas passed through a bed of particles is increased continually, a few vibrate, but still within the same height as the bed at rest. This is called a fixed bed (Figure 4.A). With increasing gas velocity, a point is reached where the drag force imparted by the upward moving gas equals the weight of the particles, and the voidage of the bed increases slightly: this is the onset of fluidization and is called minimum fluidization (Figure 4.B) with a corresponding minimum fluidization velocity, U_{mf}. Increasing the gas flow further, the formation of fluidization bubbles sets in. At this point, a bubbling fluidized bed occurs as shown in Figure 4C. As the velocity is increased further still, the bubbles in a bubbling fluidized bed will coalesce and grow as they rise. If the ratio of the height to the diameter of the bed is high enough, the size of bubbles may become almost the same as diameter of the bed. This is called slugging (Figure 4D). If the particles are fluidized at a high enough gas flow rate, the velocity exceeds the terminal velocity of the particles. The upper surface of the bed disappears and, instead of bubbles, one observes a turbulent motion of solid clusters and voids of gas of various sizes and shapes. Beds under these conditions are called turbulent beds as shown in Figure 4E. With further increases of gas velocity, eventually the fluidized bed becomes an entrained bed in which we have disperse, dilute or lean phase fluidized bed, which amounts to pneumatic transport of solids

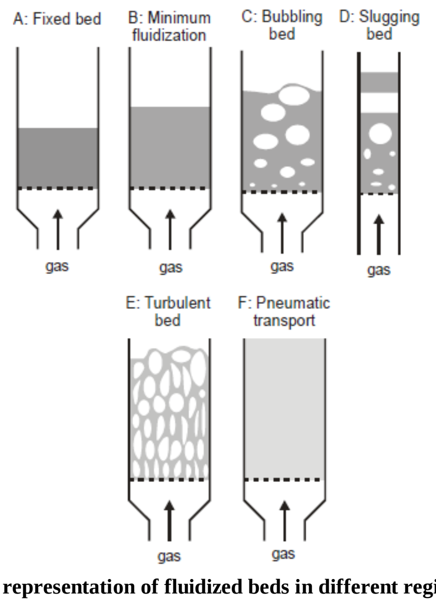


Fig.4: Schematic representation of fluidized beds in different regime (kunii and Levenspiel,1991)

Under a fluidised condition, solid particles are suspended freely in a fluid. The particles are in equilibrium between two forces: the weight of the particle and the resultant force exerted by the fluid including frictional forces. The relationship can be written as equations (4) and (5).

$$\Delta PA = W = (AL_{mf})(1 - \varepsilon_{mf})\frac{g}{g_c}(\rho_p - \rho_g) \tag{4}$$

$$\frac{P}{L_{mf}} = (1 - \varepsilon_{mf})\frac{g}{g_c}(\rho_p - \rho_g) \tag{5}$$

When

ΔP = The pressure drop across the bed, (N/m^2)

L_{mf} = The length of the bed (m)

A = Cross section area of bed(m^2)

W = Weight of bed (Kg)

g = Gravitational acceleration (m/s^2)

ρ_p = The density of fluid (kg/m^3)

ρ_p = The density of solid kg/m^3)

ε_{mf} =Void fraction

g_c = Gravitational constant

Ergun's equation (6) shows the pressure drop caused by the fluid passing through the bed at the beginning of the fluidized bed.

$$\frac{\Delta P g_c}{L_{mf}} = \frac{150(1-\varepsilon_{mf})\mu U_{mf}}{\varepsilon_{mf}^3(\emptyset_s\, d_p)^2} + \frac{1.75(1-\varepsilon_{mf})}{\varepsilon_{mf}^3 \emptyset_s d_p} \tag{6}$$

Equation (5) and (6)

$$\frac{1.75}{\emptyset_s}\left[\frac{d_p\, U_{mf}\, \rho_g}{\mu}\right]^2 + \left[\frac{150-(1-\varepsilon_{mf})}{\emptyset_s^2 \varepsilon_{mf}^3}\right]\left[\frac{d_p\, U_{mf}\, \rho_g}{\mu}\right] = \frac{d_p^3\, \rho_g(\rho_p-\rho_g)\, g_c}{\mu^2} \tag{7}$$

When

U_{mf} = Lowest speed of Fluidized bed, (m/s)

μ = The dynamic viscosity of the fluid, (kg/m.s)

d_p = Diameter of particle, (m)

$\emptyset_s$ = Particle size, (Surface area of the sphere Surface area of particles) (m/s)

3. Experimental setup and data processing

3.1 Solar pond

In the present experimental work, solar pond with an area of 50 m^2 and a depth of 2.5 m was built at Rajamangala University of Technology in north east of Thailand (16.479312N102.958760E). The built solar pond was used to characterize the daily temperature variations and possible heat extraction rate from the salinity-gradient solar ponds. Fig. 5 illustrates various zones in the solar pond and their thicknesses. In this case, the pond was built above ground with concrete walls 25 cm thick. The temperature measurements were taken at different locations along the inner concrete wall of the pond, as indicated in the Fig. 6, by using K-type thermocouples with an accuracy of ± 0.5°C. These thermocouples were equally spaced at 0.05 m interval with the starting point at 0.05 m and end point at 2.45 m from the bottom surface of the pond.

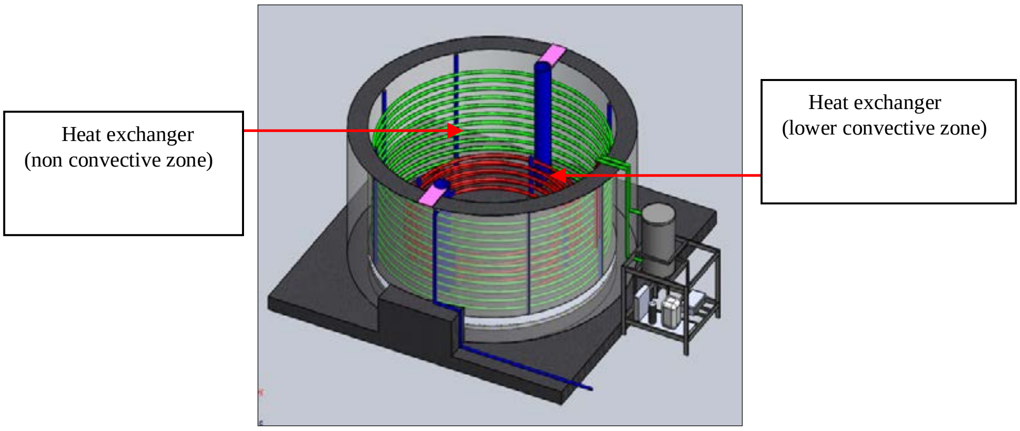


Fig.5: Schematic view of the solar pond and the system of heat extraction.

The temperature distributions at these regions were recorded at 5 min time interval by using the data acquisition system connected to these thermocouples. For monitoring and processing the output data, the data acquisition unit was connected to a computer system. The solar radiation intensity (in W/m^2) incident on the horizontal surface was measured at an interval of 10 min by using a 105HP type pyranometer with an uncertainty of ± 5% of the output reading. In order to record the density profile for the solar pond, samples of the saline water was extracted from different depths of the pond using simple gravity assisted siphoning technique. Density was measured using DMA 35N Density meter from Anton Paar which has an accuracy of ±1 kg/m^3. Within the solar pond, it installed the heat exchanger for 2 sets. Set 1 installed within lower convective zone, there is the heat exchange area of 7.85 square meters and set 2 installed at the inner wall of the solar pond 50 mm away from the wall and there is the heat exchange area of 7.85 square meters.

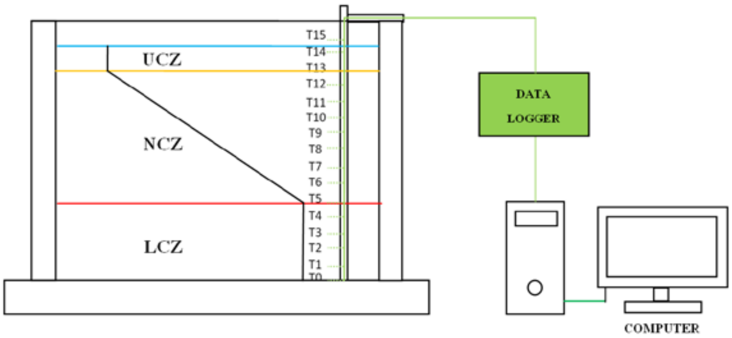
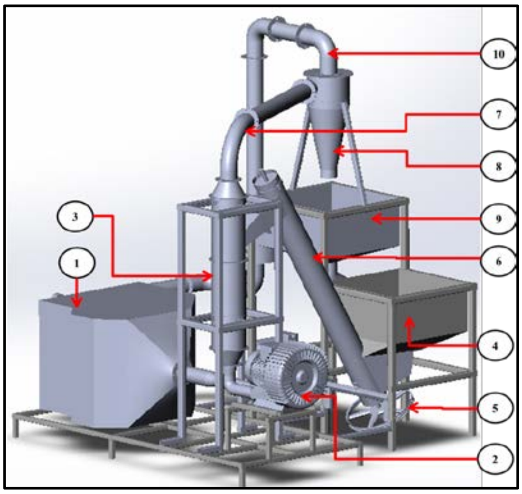


Fig.6: Experimental setup, pond heat extraction system and associated data acquisition facilities

The water is used as the receiver of the heat in the heat extraction from the lower convective zone and the non convective zone to control the incoming water temperature at 25 – 30 °C. It is installed the Thermocouple; T_0 is in the bottom next to the pond ground, T_1 is 5 cm away from the pond ground, and T_1 to T_{14} are away from each in 10 cm, and T_{15} took the atmospheric temperature, the Data Logger were used to collect the data in every 1 minute. When observing the heat extraction experiment, they will additional install the Thermocouple for 4 points which is to take the inlet water temperature for 2 points and the outlet water temperature for 2 points and collected the data in every 1 minute.

3.2 Fluidized bed dryer

1.Heat exchanger



2.Blower
3.Drying chamber
4.Paddy inlet container
5.Feeder pulley
6.Rotary Feeder inlet
7.Paddy outlet
8.Cyclone
9.Paddy outlet container
10.Air recycled

Fig. 7 : Schematic view fluidized bed paddy dryer

The main components of the fluidised-bed paddy dryer with a solar pond are shown in Fig 9. The system consists of a counter-flow heat exchanger (1) which receives heat from the solar pond via 3 heat radiators. Heat in the water is transferred to the air which is blown over the radiators by a blower (2). Hot air is then channelled to the drying chamber (3). The paddy which is stored in the paddy inlet container (4) is transferred by a rotary feeder inlet (6). The volume of rice intake to the drying chamber is controlled by a feeder pulley (5). When hot air has entered the paddy drying chamber, the fluidised-bed drying operation will begin. Starting from hot air travelling at a speed which causes fluidisation travels through the air diffuser to the bed where paddy is stored. The paddy grains are lifted and become suspended in hot air. Heat from the hot air transfers to the grains. Dry grains exit through the paddy outlet (7) into the cyclonic chamber (8) to remove impurities from the grains. The clean paddy grains will be stored in the paddy outlet container (9). Some of the hot air will be recirculated into the heat exchanger through the air recirculation duct (10) to receive heat in (1) and re-enter the cycle.

Fig. 8: Photos experiment fluidized – bed paddy dryer and solar pond

Fig 8 illustrates the solar pond and the fluidised-bed paddy dryer. The solar pond receives and store solar energy. It acts as a heat source to the system. The stored heat is the extracted to the dryer. The renewable source of energy does not have negative impacts on the environment.

4. Results and discussions

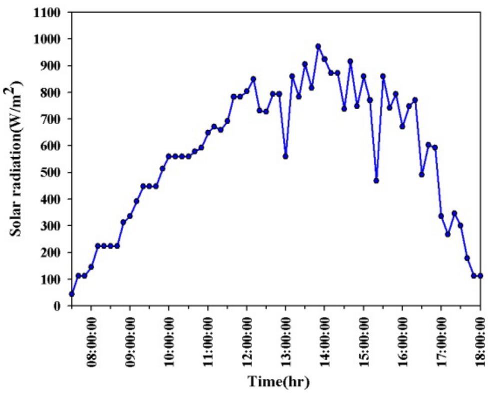


Fig. 9: Change of the solar radiation with time

The experiments were performed in July 1017, in Khon Kaen Province, Thailand. Fig. 9 shows the solar radiation rate compared to the time. It can be seen that in the morning, it will be low due to the low impinging amount of solar light intensity and it will be increased according to the intensity of the radiation from the sun. The highest solar rate is found in the duration around 12:30 to 13:30 pm and when the intensity of radiation is high, the solar radiation rate also increased with the time as well. When the solar radiation rate begins to decline until it cannot be measured in the evening at approximately18:30 am. The change starts from low to high and highest and then began to decline. Because the characteristic of increasing, decreasing and then going up again, because the trial will be experimenting with solar, the experimental sets will be installed outdoors, according to the weather conditions of the experiment day, such as sun, rain, heat, humidity, and so on. Because it is during the rainy season, it results in an increase and decrease of the rate change according to environmental conditions as shown in Fig 9.

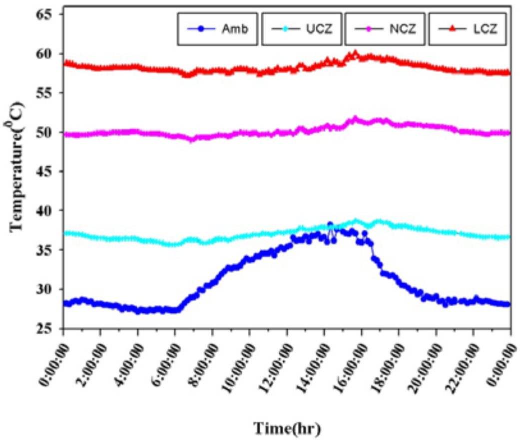


Fig. 10: Average temperature in the solar pond at the UCZ, NCZ LCZ and Ambient

Fig. 10 shows average temperature in the solar pond at the UCZ, NCZ LCZ and Ambient. Thermocouples were installed in the solar pond with a distance of 5 cm from the bottom of the solar pond up to the upper layer. The average values were calculated from five measure points in the 20-cm-thick UCZ. . The temperature in the UCZ was similar to the ambient value. It can be seen that during daytime, when the temperature of the atmosphere was high, the three average temperatures increased accordingly. At night, when the atmospheric temperature dropped, the temperature in the UCZ dropped as a result. By contrast, the average temperature of the NCZ exhibited small reduction or increase during the night and daytime respectively.

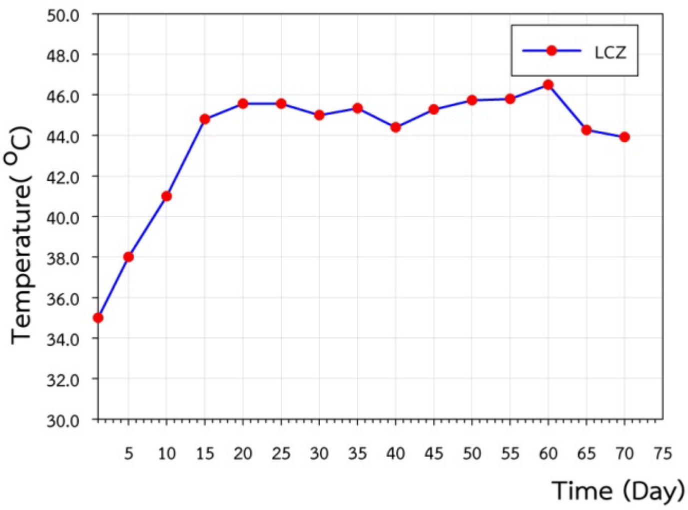


Fig. 11: shows the average temperature of the lower convection zone (LCZ)

Fig 11 shows the average temperature of the lower convection zone (LCZ) of the solar pond over the course of 70 days of experiment. It can be seen that during the first 15 days of the test, the temperature rose relatively rapidly because the pond could receive and store a high amount of heat due its low initial temperature. When the amount of heat received by the solar pond is similar to the amount of heat dissipated to the atmosphere, the rise in temperature of the solar pond became slower and depends on daily solar irradiation. The temperature increased on a sunny day and decreased on a cloudy day. It was observed that the highest temperature that the solar pond could store was 47°C after the pond had 60 days.

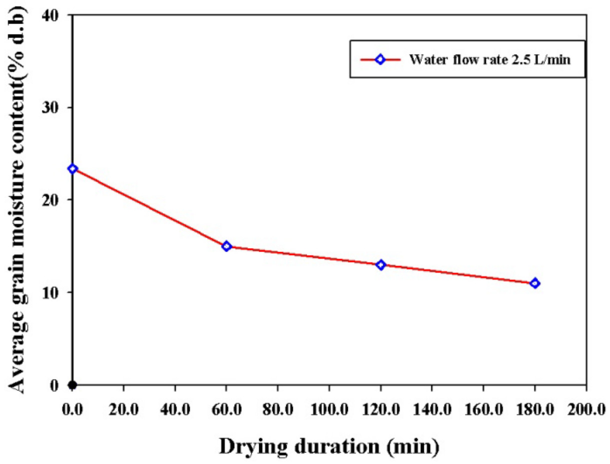


Fig .12: Evolution of moisture content

Drying curves of paddy are presented in Fig. 12. It is apparent that moisture ratio decreases continuously with drying time. As indicated in these curves, there was no constant rate period in drying of paddy. All the drying process occurred in the falling rate period, starting from the initial moisture content (23 ± 0.5%, wet basis) to final moisture content (11 ± 0.5%, wet basis).

5. Conclusions

In order to shine some light on the subject, our research aims to study the application of this novel renewable and environmentally-friendly technique to rice paddy drying that could benefit many farmers and the economy not just nationally but globally. The results showed that the flow rate of 2.5 liters per minute could take heat into application better than the flow rates of 2 and 3 liters per minute. At such the flow rate, moisture dropped from 23.4% to 15% for the first time of drying and for the second and third times, the moistures dropped to 13% and 11% respectively. Reduction in moisture content of the paddy met the criteria set which was 1% to 5% per round of drying.

Acknowledgments

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References

Abhijit, D.,Yusli, Y., Ashwin, D., Shankar, K., Akbarzadeh, A., 2013. Heat extraction from non-convective and lower convective zones of the solar pond: A transient study. Solar Energy 97, 517–528.

Aboul-Enein, S., El-Sebaii, A.A., Ramadan, M.R., Khallaf, A.M., 2004. Parametric study of a shallow solar pond under the batch mode of heat extraction. Applied Energy 78 (2), 159 -177.

Andrew, j., Akbarzadeh, A., 2005. Enhancing the thermal efficiency of solar ponds by extracting heat from the gradient layer. Solar Energy 78, 704-716.

Ali, H. M., 1987. Study on shallow solar pond applications at Tehran. Energy Conversion and Management 27(1), 33 - 38.

Ali, H.M., Akhlaghi, M., 1987. Experimental study in a shallow solar pond. Solar & Wind Technology 4 (4), 425 - 430.

Bansal, P. K., Hrishikesan, D.S.,Garg, H.P., 1984. Effect of heat exchange on the performance of a shallow solar pond water heater. Energy Conversion and Management 24 (4), 259 - 63.

Chyng, J. P., Lee, C.P., Huang,B.J., 2003. Performance analysis of a solar-assisted heat pump water heater. Solar Energy 74 (1), 33 - 44.

Dutt, D.K., Rai, S.N., Tiwari, G. N., 1987. Transient analysis of a shallow solar pond water heater integrated with a baffle plate. Energy Conversion and Management 27 (3), 303 - 307.

Ergun, S., 1952. Fluid flow through packed columns. Chemical Engineering Progress 48(2), 89 - 94.

González, J., Pérez, L.R., Benítez, J., 1992. Modeling the thermal process in a shallow solar pond water heater. Solar Energy 48 (4), 261 - 265.

Ha, B., 1984. Ormat Turbines, Arava Solar Pond Inaugurated, Sunworld.8(1) 18.

Jaefarzadeh, M. R., 2006. Heat extraction from a salinity-gradient solar pond using in pond heat exchanger. Applied Thermal Engineering 26 (16),1858 - 1865.

John, H. L.,Walton, C., 2001. Desalination coupled to salinity gradient solar ponds. Desalination 136,13-23.

Kalecsinsky, A. V., 1902. Ueber die ngarischen natuerlich waermeaccumulatoren. Annalen der Physik IV 7,408 - 416.

Kumar, A., Kishore,V.V.N., 1999. Constuction and operational experience of A 6000 m^2 solar pond at Kutch,India. Solar Energy 65(4), 237 - 249.

Leblanc, J., Aliakbar, A., Andrews, J., Lu, H., Golding,P., 2011. Heat extraction methods from salinity-gradient solar ponds and introduction of a novel system of heat extraction for improved efficiency. Solar Energy 85(12), 3103 - 3142.

Madhuri.,Tiwari,G.N., 1986. The effect of a baffle plate on the transient performance of a shallow solar pond water heater. Energy Conversion and Management 26(7), 217 - 220.

Prakash, J., Garg., H.P., Hrishikesan, D., Ranjana ,J., 1989. Performance studies of an integrated solar collector-cum-storage water heating system with transparent insulation cover. Solar & Wind Technology 6 (2),171 - 176.

Queiroz, D. M., Couto, S. M., & Haghighi, K.,2000. Parametric finite element analysis of rice drying. Presented at the 2000-ASAEAnnual- International-Meeting, Milwaukee, WI, USA, 9 - 12.

Ramadan, M. R. I., El-Sebaii, A.A., Aboul-Enein, S., Khallaf,A.M., 2004. Experimental testing of a shallow solar pond with continuous heat extraction. Energy and Buildings 36 (9), 955–964.

Reid, J. D., & Siebenmorgen, T. J., 1998. Using surface temperature and moisture content to describe head rice yield reduction during thin-layer drying of rough rice. ASAE-Annual- International-Meeting,

Sabetta, F., Pacetti, M., Principi, P., 1985. Aninternal heat extraction system for solar. 34 (4), 297 - 302.

Sharma, S. C. and Ashesh Tiwari. 2010. Performance Enhancement of Shallow Solar Pond by System Modification. International Journal on Emerging Techonologies 1(1), 92 - 96.

Sherman, B. S., 1989. Modelling and Control of a Solar Pond. The University of Westen Australia.

Soponronnarit, S., Wetchacama, S., Trutassanawin, S., & Jariyatontivait,W.,2001. Design,testing, and optimization of vibro-fluidized bed paddy dryer. Drying Technology, 19(8), 1891 -1908.

Soponronnarit, S., Yapha, M., & Prachayawarakorn, S.,1995. Crossflow fluidized bed paddy dryer: prototype and commercialization. Drying Technology, 13(8 & 9), 2207 - 2216.

Sutherland,J.W.and Ghaly,T.F., 1982.Heated - Air Drying of Oilseeds.Stored products Research.18(2), 43-54.

Tabor, H., and Doron, B., 1986. Solar Ponds- Lessons learned from the 150 kW power plant at Ein Boqek, Proc. of the ASME Solar Energy Div., Anaheim, California.

Taga, M., K. Fujimoto, and T. Ochi., 1996. Field Testing on Non -Salt Solar Ponds. Solar Energy 56(3), 267 - 277.

Tumambing, J. A., & Driscol, R. H., 1991. Modeling the performance of continuous fluidized bed dryer for pre-drying of paddy. In Presented at the Proceedings of the 14th ASEAN seminar on grain postharvest technology, Philippines.

Tundee, Sura, Pradit Terdtoon, Phrut Sakulchangsatjatai, Randeep Singh, and Aliakbar Akbarzadeh. 2010. Heat Extraction from Salinity-Gradient Solar Ponds Using Heat Pipe Heat Exchangers. Solar Energy 84(9),1706 - 16.

Valderrama, Cesar et al., 2011. Solar Energy Storage by Salinity Gradient Solar Pond: Pilot Plant Construction and Gradient Control. Desalination 279(1-3),445 - 450.

Wang, Hua, Xiaolei Yu, Feiling Shen, and Liugang Zhang. 2015. A Laboratory Experimental Study on Effect of Porous Medium on Salt Diffusion of Salt Gradient Solar Pond. Solar Energy

Wang Y.F, Akbarzadeh, A. 1982. A Study on the Transient Behavior of Solar Ponds. Solar Energy 7(12),1005 - 1017.

Zomorodian A, Zare D, Ghasemkhani H., 2007. Optimization and evaluation of a semicontinuous solar dryer for cereals (Rice, etc.). Desalination,209,129 - 135.