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UTILIZATION OF HEAT EXCHANGERS IN DRYING OF FISH FARM WASTES FOR THE PRODUCTION OF FEED CONCENTRATES

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ABSTRACT

Due to increasing the prices of fish and animal feed, a big gap in feed nutrition is generated. Also the increment necessitates of the sources of animal protein creates and maximize this nutritional gap in Egypt. So the creation of local and alternative source of feed concentrates instead of import is needed. Huge quantities of small sizes of fish are thrown on land without any manipulation during fish ponds harvesting. It is necessary to process and recycle these wastes in order to be a useful component. Drying process was used in the present investigation for fish wastes treatment that adds to obtain feed concentrates with low costs (Fishmeal). Therefore, the objective of this research work is to dry a sample of the whole fish waste, by using the heat exchangers, at the experimental station of Rice Mechanization Center (RMC), Meet Eldeebah village, Kafr Elsheikh Governorate during September of the year 2015 by using a stream of hot air at different drying air velocities of 1.5, 2 and 3m/s. The manufactured heat exchanger has the cylindrical shape. Its dimensions were of 30.48cm in diameter internal, 50cm in diameter external and 150cm long. The heat exchanger is connected with a flat plate solar collector with the dimensions of 100 x 100cm. The working medium in the heat exchanger is the hot water output of flat plate solar collector. The extreme values of thermal energy stored in water and thermal efficiency of the solar system are of 50.284 and 53.549%, respectively.

Keywords: *drying rate, fishmeal, heat exchanger, flat plate solar collector, fish wastes*

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Maximum effectiveness of the parallel flow system was of 28.152% with the drying air velocity of 1.5m/s, whereas for the counter flow system was of 19.46% with the drying air velocity of 2m/s. Also, the highest values of heat energy transferred rate from water to air were of 2.21kW and 2.81kW with the drying air velocity of 3m/s for the parallel and counter flow heat exchangers, respectively. In general the counter is better than the parallel system with the maximum drying rate of 0.42kg water/(kg dry matter. min) at drying air velocity of 1.5m/s. Maximum internal energy of water tank was of 6.09kJ at 5.00PM, temperature of water was of 40.6 ℃ and less radiation was of 77.43W/m^2. In addition, maximum exergy rate of the parallel flow system was of 2.49kW with drying air velocity of 2m/s, whereas for the counter flow system was of 0.433kW with the drying air velocity of 3m/s. Maximum specific enthalpy of the parallel and counter drier units of drying air are of 214.56 and 180kJ/kg at drying air velocity of 2m/s, respectively. While specific enthalpy of drying air of counter drier unit is higher than that of parallel one at drying air velocities of 1.5 and 3m/s while lower at drying air velocity of 2m/s.

NOMENCLATURE

a_1, a_2	Coefficients in the heat loss terms of the efficiency, W/m^{2}K
A	Total hot side or cold side heat transfer area, m^2
C_p	Specific heat, J/kg K
C_{max}	Maximum heat capacity rate of two fluids, W/K
C_{min}	Minimum heat capacity rate of two fluids, W/K
C^*	Ratio of heat capacity rate of C_{max} and C_{min}
dM	Amount of change of fish waste, g
dt	Time interval for sampling, h
DR	Drying rate, kg water/(kg dry matter. min)
h_i , h_o	Heat transfer coefficient for inside and outside flows, W/m^{2}K
I_b	Solar radiation falling on the heater surface, W/m^2
K	Thermal conductivity, W/mK
L	Length, m
LMTD	Logarithmic mean temperature difference, K
$\dot{m}$	Mass airflow rate, kg/s

M	Mass of product to be dried, kg
M_o	Initial moisture content, %wb
M_t	Moisture content at time t, %wb
M_{ds}	Mass of dry solids, kg
M_w	Mass of evaporated water from the product during drying day, kg
W_o	Initial mass of the dried product, kg
W_t	Mass of product to be dried at any time, kg
U	Overall heat transfer coefficient, W/m^2K
NTU	Number of transfer units = UA/C_{min}
P	Thermal effectiveness of heat exchanger, decimal
Q	Total heat transferred rate , W
Q_u	Amount of useful energy, W
Q_{abs}	Amount of absorbed energy, W
r	Radius of the cylinder heat exchanger, m
R	Thermal resistance, m^2K/W
$\sum R$	Total thermal resistance of tube to heat flow, m^2K/W
t	Total time, h
T_{amb}	Ambient air temperature, °C
$T_{iw.Exg}$	Inlet water temperature of heat exchanger, °C
$T_{ow.Exg}$	Outlet water temperature of heat exchanger, °C
T_o	Water temperature in the tubes, °C
ΔT_M	True mean temperature difference between two fluids of heat exchanger, K
UA	Thermal resistance of a heat exchanger, m^2K/W
η	Thermal efficiency of flat plate solar collector, %
η_o	Optical efficiency of the water in glass collector, %
η_s	Storage efficiency of flat plate solar collector, %

Subscripts

c	Cold fluid	i, o	Inlet and outlet
CDU	Counter drier unit	PDU	Parallel drier unit
CFHE	Counter flow heat exchanger	PFHE	Parallel flow heat exchanger

INTRODUCTION

Dried fish as a fishmeal, is one of the most important exported marine products in many countries such as Turkey, Iran, India wherever the fish powders containing about 55-72% crude protein and fat content of 5%. Fishmeal production peaked in 1994 at 30.2 million tonnes, in 2010 it was dropped to 14.8 million tonnes owing to the reduced catches of anchoveta, increased in 2011 to 19.4 million tonnes and then declined to 16.3 million tonnes in 2012. Owing to the growing demand for fishmeal and fish oil and rising prices, more fishmeals are being produced from by-products of fish, which previously were often discarded. This can affect the composition and quality of the fishmeal. According to the recent estimates, about 35 percent of world fishmeal production was obtained from fish wastes in 2012 **(FAO, 2014).** Fish is an important source of protein for both humans and animals where small fish and other by-products are used in the production of feed (Fishmeal) or direct feeding for aquaculture and livestock. In 2014, fishmeal production was of 15.8 million tonnes due to reduced catches of small fish. Non-official estimates of the contribution of by-products to the total volume of fishmeal and fish oil produced indicate that it is about 25-35% **(FAO, 2016)**. The province of Kafr Elsheikh represents 40% of the fish production in Egypt **(FWA, 2010).** Total fish production in Egypt is about 1.06763 million tonnes and Kafr Elsheikh governorate represents almost 442000 tonnes per year of fish farms **(WFC, 2011).** The wasted quantities of small fish are forming low-value of fish ponds harvesting. These wastes can be used as a source of protein for animal and fish feed "Fishmeal". The international trend towards fishmeal production is noticeable in a lot of countries such as Vietnam **(RIMF, 2001)**, but it is still not considered in Egypt. There are two types of fishmeal in Vietnam: "fish powder" produced in a traditional, artisanal way by sun drying and grinding; and fishmeal produced using an industrial process in which raw materials are cooked before being dried. Fish powder is mainly used to feed livestock **(Edwards *et al*., 2004).** Alaska produces about 1-2% of the world fishmeal through processing fish by-products **(Knapp, 2008).**

Production of fish stock is about 10 thousand tonnes; the main producers are being Iceland and Norway. The biggest producers of the other dried products are countries in Asia and Africa. The annual export of dried heads from Iceland is about 15 thousand tonnes, mainly to Nigeria, where they are used for human consumption **(Arason, 2001).** The fishmeal industry is likely to use geothermal steam in the processing and hopefully within a few years, geothermal steam will be transported through pipes. It can be expected that the price of oil will increase more than the local energy in the future and, therefore, it is worth paying attention to the use of locally available energy sources in the fishing industry. It was recommended that further work on optimizing the technique and a feasibility study for a freeze drying production have been done **(Gudlaugsson, 1998)**. The fishing sector produces a huge amount of waste in fish farms and processing industries. These by-products are mainly used in the manufacture of fishmeal. However, there are other potentially valuable uses. One low investment possibility is the elaboration of agricultural products by composting the fish remains with other marine materials such as seaweed. The main purpose of their research work is to obtain a fertilizer suitable for use in organic agriculture, by composting a mix of seaweed and fish wastes **(López-Mosquera *et al.*, 2011).** The Arabian Gulf has an abundant source of animal protein in the form of surplus fish according to the report **(MAF, 1995)**. Small pelagic landings in Oman, for example, were of 41496 tonnes, (80%) of which were sardines (*Sardinella longiceps*) (33054 tonnes). Waste disposal and by-products management in food processing industry pose problems towards the environmental protection and sustainability **(Russ and Pittroff, 2004).** There is a gap between the available quantity of green forage and the required amount of animal feed. This gap between the availability and requirement of feed is wide and the estimated shortage is 3.1 million tonnes of total digestible nutrients per year. The forage gap or the feed shortage has been partially narrowed to become 2.42 million tonnes because of using new forage resources. The drying rate is another important factor in describing the characteristics of the drying process. Double layer covered plastic greenhouse of 4cm dead air space was the best to be used as a solar drier because of increasing temperature and humidity reduction inside the solar greenhouse drier **(Abdallah, 2010)**. A solar drying system of a cylindrical section which consists of a flat plate solar collector, drying chamber cylindrical section and a fan was built and designed for the purpose of drying 70kg of bean crop **(Gatea, 2011)**. Temperature is being a very important factor accelerating the process of spoilage where the spoilage reactions connecting on the death of the fish proceed at a very rapid rate where solar drying produced better quality dried fish compared to that of sun drying due to reduction in insect infestation and other contaminants **(Sablani *et al.*, 2003).** Fresh fish contains up to 80% of water, fish weight loss in solar driers differs in the ecological zones of Nigeria with the North-East recording the highest value while the value of weight loss was least in South; this was attributed to the influence of relative humidity on drying **(Olokor *et al.*, 2009)**. The problem of the shortage of animal feed in Egypt is well recognized. Several efforts had been done to improve the nutritive value of agricultural byproducts. Rice straw, wheat straw, corn stalk, sugarcane, basse vine of broad bean, squash vine and other vegetable wastes were used for increasing the available feed **(Ali, 1996).** This fact reduces the wastes to be used as animal feed to fruit–vegetable and fish wastes. One of the main drawbacks of using fruit–vegetable and fish wastes in the formulation of animal diets is that their composition may be extremely variable depending on the area of production and the period of the year and reports of FAO also indicated that the quantity and quality of these wastes vary from country to country **(Westendorf, 2000).** Nowadays there are a lot of engineering techniques used for drying purposes of agricultural production wastes. The trend towards the exploitation of solar energy as an alternative source of energy was considered by a lot of investigators such as greenhouses as a solar energy collector for drying agricultural wastes **(E1-Sahrigi *et al.*, 1993; Abdallah, 1999; El-Keway, 2003; Eldreeny, 2015** and **Elbadawy, 2016),** solar tunnel and flat plate solar drier (**Bala and Mondol 2001; Bala *et al.*, 2001; Goddard and Perret, 2005; Dhiwahar, 2010; Montero *et al.*, 2010; Basunia *et al.*, 2011; Gatea, 2011; Bala and Debnath, 2012),** Solar cabinet and chimney drier "mixed-mode" **(Mumba, 1996; Ekechukwu and Norton 1999;**

Pangavhane *et al*., 2002; Vlachos *et al*., 2002; Sablani *et al*., 2003; Sankat and Mujaffar, 2004; **Gbaha *et al*., 2007; Forson *et al*., 2007**; **Bukola and Ayoola, 2008**; **Afriyie *et al*., 2009**; **Jairaj *et al*., 2009**; **Ramana Murthy, 2009; Sharma *et al*., 2009; Fudholi *et al*., 2010; Banout *et al*., 2011; Mujaffar and Sankat, 2011; Vijaya Venkata Raman *et al*., 2012).** On the other hand, there are limits literatures that investigate the utilization potential of the heat exchangers for drying air heating processes by solar energy. Therefore the main aim of the present research work is investigate the thermal performance of heat exchangers operated by solar energy in the drying process of fish farm wastes for the production of feed concentrates.

MATERIALS AND METHODS

Experimentation

The solar drying system is consisted of drying chamber, flat plate solar collector supplemented with parallel and counter flow heat exchangers.

1. Drying chamber

Drying chamber consists of greenhouse with dimensions of 2m long, 1m wide and 0.9m height and covered all sides by polyethylene plastic, placed under shadow to avoid the effect of direct heating by solar rays in drying chamber on heat exchanger performance analysis. The drying chambers are equipped with load cells (type S, Model YZC-516C, China) with an accuracy of 50g and measuring up to 500kg_f, to acknowledge the whole weight of the drying chamber and loaded fish wastes to be dried. In this investigation, the drying air was supplemented by a solar heat exchanger unit to the drying chamber through an isolated steel duct located at the top of the drying chamber greenhouse type. A suction fan powered AC (Future, Motore Asincrono Trifase; 50Hz- 0.37kW-2850RPM, Italy) fixed on the opposite side at the bottom of the air chamber. Exit air velocities were adjusted by valves and calibrated by the anemometer (microprocessor digital meter with vane probe, AM 4838, Taiwan).

2. Flat plate solar collector

Flat plate solar collector with a wooden frame of 1 x 1m, consists of cover plate of ordinary transparent glass 6mm in thick and inside there is a heat absorbent dark colored plate to absorb the sun's rays and inner copper pipes (seven pipes with the dimensions of 0.9m length and a diameter of 0.6cm) through which the water to be heated and the distance between each tube is 15cm. The product of heated water was stored in a thermally insulated tank (150 litres in capacity).

3. Heat exchanger

The investigated heat exchanger has two flow patterns: parallel and counter flow. Both of them consist of two parts: an internal galvanized iron conduict with a diameter of 0.3048m, 1.5m in length and 0.0009m in thickness, which is overlapped with an outer galvanized iron conduict of 0.5m in diameter used for solar heated water paths. The internal conduict is filled with commercial micro-wires which stand against fresh air passage. Micro-wires of iron generate airflow resistances on the fresh air that adds heat to be transferred from the hot surface to fresh air bulk. The heat exchanger is isolated from the outside with glasswool, **Figure 1**.

Experimental procedure

Fourteen kilograms of the small fish sizes were collected from fish ponds with the average dimensions of 3.6±1.4cm length, 2±0.7cm thick and weight of 19±2.88 grams, **Figure 2** from Damro village, Sedi Salim district, Kafr Elsheikh Governorate during September of 2015. They were divided into two halves, the first half for the parallel flow heat exchanger and the second half for the counter one. After that they were conveyed to the experimental station of Rice Mechanization Center (RMC) at Meet Eldeebah village, Kafr Elsheikh Governorate located at 31^{o} 07'N Latitude, 30^{o} 57'E Longitude and 20m Altitude **(Abou- Zaher, 1998).** The oven drying method was used for determining fish wastes moisture content at 105°C for 24h **(AOAC, 2005 and Sultana *et al.*, 2009).** The initial moisture content of the experimented sample was of 76.9±1%wb. Solar drying experiments were conducted at an averaged ambient air temperature of 31.3±4.5°C, averaged air relative humidity of 61.8±1% (Chino Digital Humidity Meter HN-K & HN-L18 Sensor, Japan) and intensity of solar radiation incident ranged between 560.48 and 949.78W/m^2 per hour. Fish wastes were spread on the drying tray for a drying bed depth of 2cm as a thin layer, inside greenhouse solar drier. The solar drier was positioned in a shaded place to avoid any additions of thermal energy from the direct solar radiation. A centrifugal suction fan was adjusted to provide with three levels of drying air velocities of 1.5, 2 and 3m/s. The effect of the investigated variables on relative humidity, moisture content loss, ambient air temperature, drying rate of fish wastes, heat exchanger performance analysis and drying air temperatures inlet and outlet of the drying chamber was investigated. The readings of weight loss in the sample were recorded at an interval of 2 hours during the drying experiment by using a load cell connected with a digital screen, **Figures 3** and **4.**

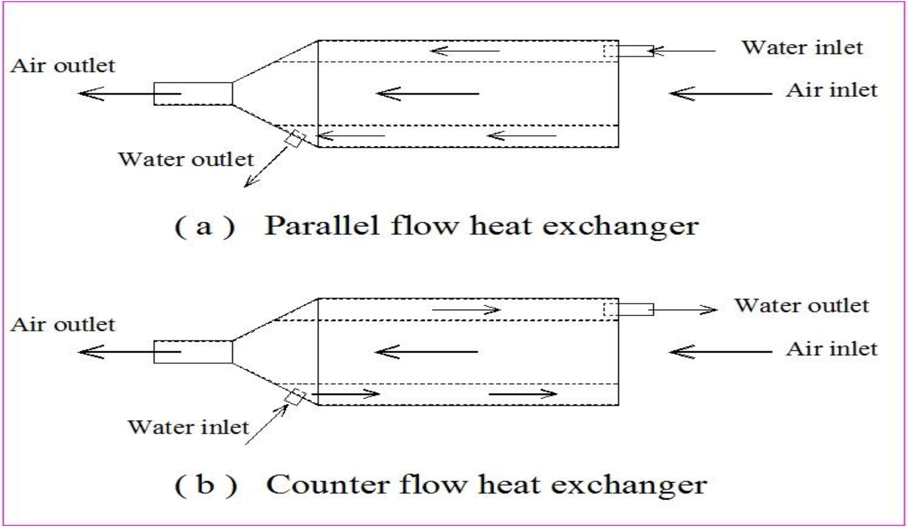

Figure 1. Fluid flow direction for both parallel (a) and counter (b) flow heat exchangers

Figure 2. A photograph of fish pond wastes (fry) used in the drying experiment

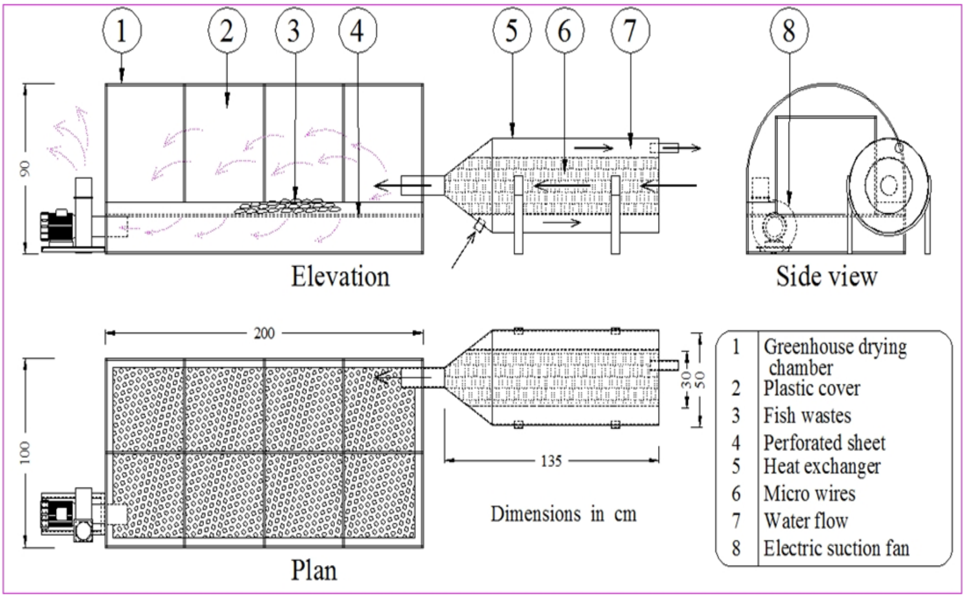

Figure 3. Perspective view of the drying chamber supplemented with the parallel and counter flow heat exchangers

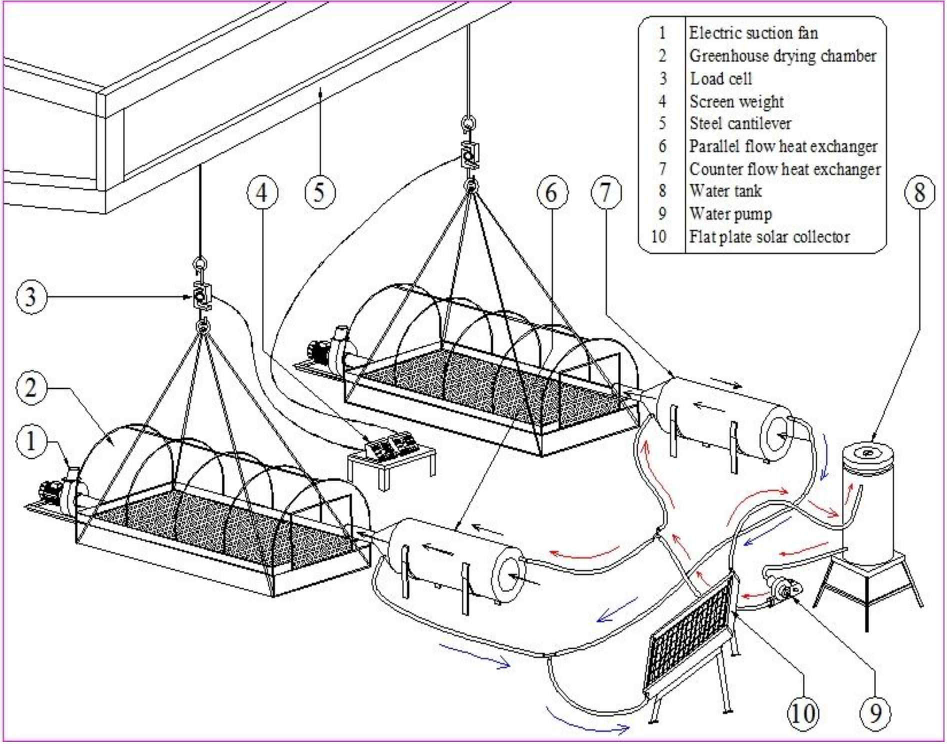

Figure 4. Schematic drawing of the whole solar drying system

Heat exchanger manufacture calculations

Specific surface area calculations of the filling material of internal tube (drying air path):

Micro-wire was identified by a digital vernier (Digital Caliper, 0-150mm, Germany) which has a thickness of 100µm, width of 290µm and a length of 0.65m and the weight of it is 19.6 grams measured by a digital balance (Citizen, Model CX 220, Max.capacity 220g, Accuracy of 0.1mg, China). The specific surface area per weight unit is 5.228m^2/kg. Thermal conductivity of micro-wires is of 80W/mK **(Incropera and DeWitt, 2002).** Heat exchanger design criteria are considered by assuming that the air temperature at heat exchanger inlet is 26°C (average weather temperature during the experiment of period) and the required drying air temperature is 56°C, therefore the amount of heat transferred rate is 2.7kW. This value requires a temperature gradient of 1.77K/m on heat transfer surfaces (between micro-wires and internal surface of the heat exchanger). Assuming 10% of heat transferred from water to the drying air is dissipated in the transfer path. The tube of heat exchanger obtained is 1.34m in length, given by **Equations 1 and 2** as follows:

$$Q = m^{\cdot} * C_p * \Delta T \qquad \text{Eqn 1}$$

$$Q = k * A * \Delta T \qquad \text{Eqn 2}$$

Bulk density of micro-wire was calculated by the actual volume of the wire at Rice Mechanization Center Lab, which is equal to the volume of an internal conduict then, getting on the length of conduict. Overall heat transfer coefficient of heat exchanger was calculated by heat transfer total resistance, given by **Equation 3** as follows:

$$U = \frac{1}{A * \sum R} \qquad \text{Eqn 3}$$

The LMTD method for heat exchanger performance analysis

In heat transfer analysis of heat exchangers, the total heat transferred rate, Q through heat exchanger is the quantity of primary interest. Let us consider a simple counter flow or Parallel flow heat exchanger **(Kakac and Liu, 2002).** The form in **Equation 4** may be applied to determine an energy balance for a different area element in the hot and cold fluids.

$$Q = UA\ \Delta T_m \qquad \text{Eqn 4}$$

Thermal effectiveness of heat exchanger

Heat exchanger effectiveness is defined as the ratio of the actual amount of heat transferred to the maximum possible amount of heat that could be transferred with an infinite area **(Fakheri, 2006 and Guo *et al.*, 2010)** using **Equations 5 and 6 as follows:**

$$P_{PFHE} = \frac{1-\exp[-NTU(1+C^{*})]}{1+C^{*}} \qquad \text{Eqn 5}$$

$$P_{CFHE} = \frac{1-\exp[-NTU(1-C^{*})]}{1-C^{*}\exp[-NTU(1-C^{*})]} \qquad \text{Eqn 6}$$

Thermal resistance of heat exchanger

Thermal resistance of heat exchanger is commonly defined as the ratio of the temperature difference of the heat flux or the reciprocal of (UA), can be calculated by **Agarwal *et al.*, 2014** using **Equation 7** as follows:

$$UA = \frac{1}{\frac{\ln\left(\frac{r_o}{r_i}\right)}{\frac{1}{h_i A_i}+\frac{1}{2\pi L k}+\frac{1}{h_o A_o}}} \qquad \text{Eqn 7}$$

Thermal and storage efficiency of flat plate solar collector

The optical efficiency of the water in glass collector under experiment is assumed to be 0.536 **(Budihardjo and Morrison 2009),** determined from energy gain measurements at solar noon when the radiation level and incidence angle are approximately steady. The heat loss coefficient varies with the temperature, the coefficients in the heat loss terms of the efficiency equation were determined by testing individual tubes **(Marco *et al.*, 2015)**, given by **Equation 8.** The storage efficiency of flat plate solar collector is the ratio between the amount of useful energy and the amount of absorbed energy is given by **Equation 9**.

$$\eta = \eta_o - a_1 \frac{T_o - T_{amb}}{I_b} - a_2 \frac{(T_o - T_{amb})^2}{I_b} \qquad \text{Eqn 8}$$

$$\eta_s = \frac{Q_u}{Q_{abs}} \qquad \text{Eqn 9}$$

Instantaneous moisture content (Mt)

To evaluate the performance of each drying unit, a methodology proposed by **Leon *et al.*, 2002** was used in this study. The instantaneous moisture content on wet basis at any time can be calculated by the following equation:

$$M_t = \left[(M_o + 1)\ \frac{W_t}{W_o}\right] - 1 \qquad \text{Eqn 10}$$

Drying rate

Drying rate (DR) was calculated according to **Banout *et al.*, 2011; Michael Ayodele and Adesoji Matthew, 2012 and Darvishi *et al.*, 2013** using **Equation 11** as follows**:**

$$\mathrm{DR} = \left(\frac{\mathrm{dM}}{\mathrm{dt}}\right) = \left(\frac{\mathrm{M_w}}{\mathrm{M}_{ds}.t}\right) \qquad \text{Eqn 11}$$

RESULTS AND DISCUSSION

The incident solar radiation on a horizontal surface of the drying chamber and ambient air temperatures were recorded, **Figure 5.** The drying process starts from 9:00AM to 9:00PM for all the investigated variables. Solar radiation rises up to a maximum value of 743.843, 783.7833 and 895.1W/m^2 at 11:00AM during the experimentation for 1.5, 2 and 3m/s drying air velocity, respectively. **Figure 6** shows the inverse relationship between the ambient air relative humidity and ambient air temperature. As the temperature increases from 30.06 to 34°C, the air relative humidity decreases from 63.43 to 53.27% during the period from 9.00AM to 3.00PM at drying air velocity of 1.5m/s. The same behavior was noticed at the other drying air velocities of 2 and 3m/s.

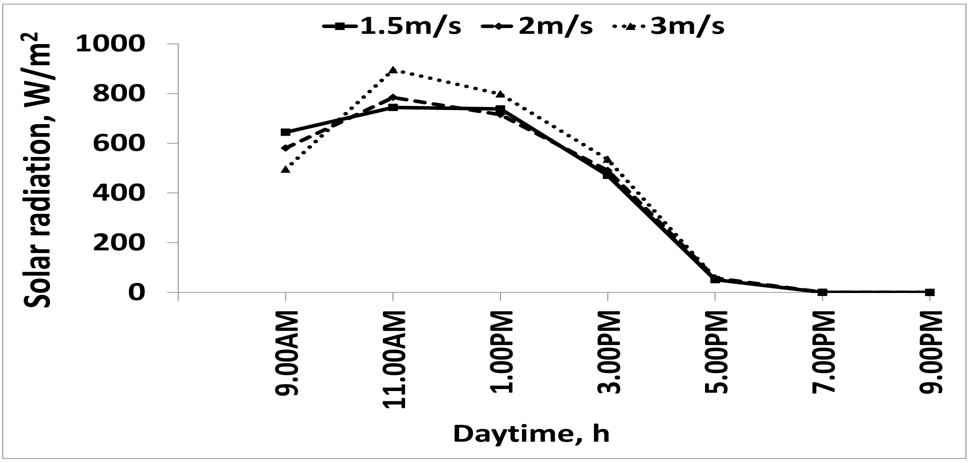

Figure 5. Variations of solar radiation incident throughout the whole drying experiment

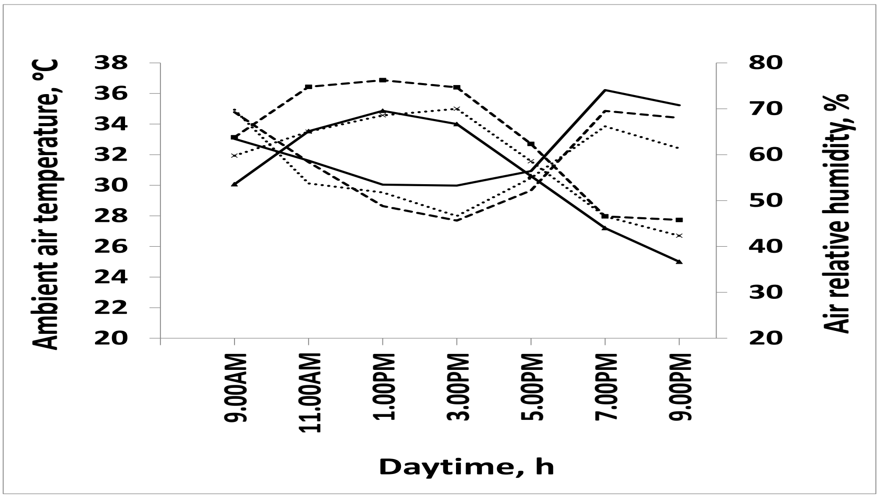

Figure 6. Ambient air temperature and air relative humidity as related to daytime during the experimental work

Figure 7 shows that the temperature of water entering the heat exchanger increased gradually during the period from 5.00PM to 7.00PM, after that the temperature decreases gradually to be stable until reached 9.00PM. The water temperature decreases dramatically due to the high consumption of the stored energy by water reservoir tank. The temperature of the water outlet of the counter flow heat exchanger is lower than that in the parallel system during the period from 9:00AM to 9:00PM due to thermal energy loss of hot water and gaining of the drying air with the drying air velocity of 1.5m/s, The same behavior was found at the other drying air velocities of 2 and 3m/s, during the period of drying. **Figure 8** shows that, at drying air velocity of 1.5m/s, the drying air temperature reached its highest values for both parallel and counter flow heat exchangers of 39.1 and 42.5°C, respectively. The same behavior was found at drying air velocities of 2 and 3m/s. The drying chamber temperature increases with the increase of drying air temperature and this leads to decrease the air relative humidity and reduces the moisture content of fish on the drying tray that can be noticed on the digital panel of the load cell as weight reduction. The counter flow heat exchanger achieved the highest values of moisture content reduction if compared to the parallel one for all the investigated drying air velocities.

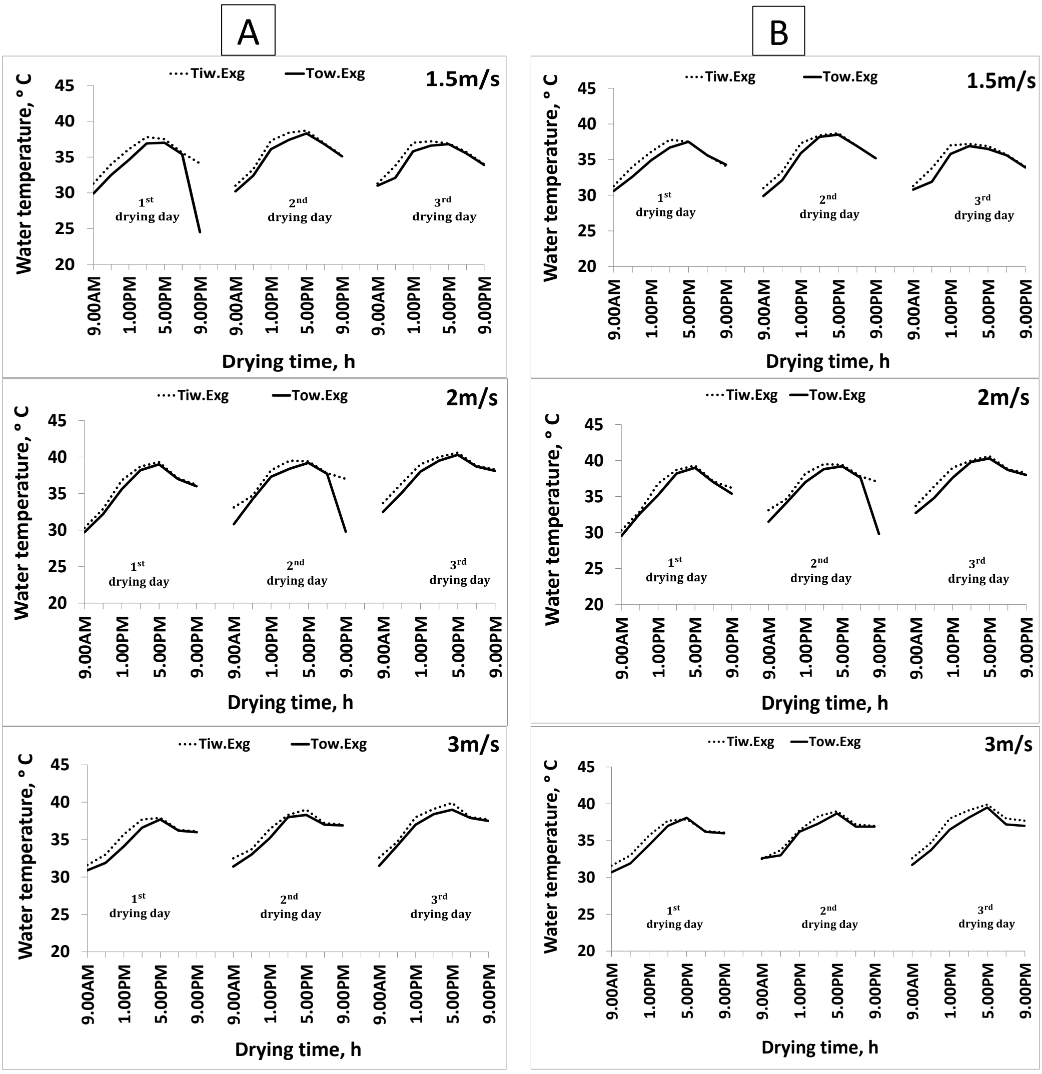

Figure 7. The influence of water temperature on the drying air temperature for both the parallel (A) and counter (B) flow heat exchangers at different drying air velocities

Figure 9 shows the evolution of fish wastes drying rate versus drying time. Drying rate of fish wastes was decreased continuously with the progress of drying time due to the reduction in fish wastes moisture content. There are different drying curve profiles; the drying rate for the first drying day is higher than that of the second drying day due to the cohesion strength of the water molecules with fish dried and increases with the drying time until the equilibrium moisture content of 9±1.74%wb is reached.

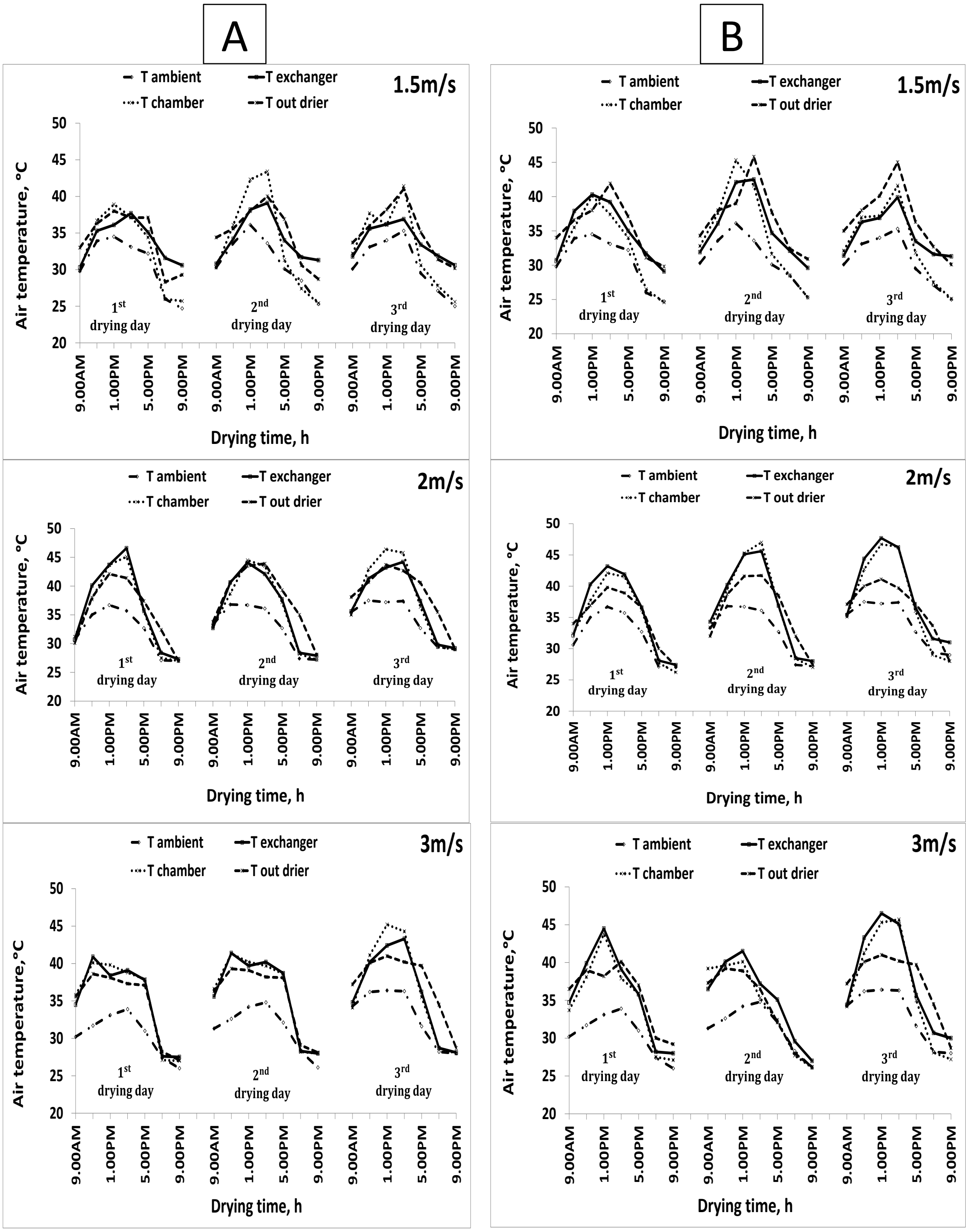

Figure 8. Hourly variations of air temperature inside and outside solar drying system for both parallel (A) and counter (B) flow heat exchangers at different drying air velocities

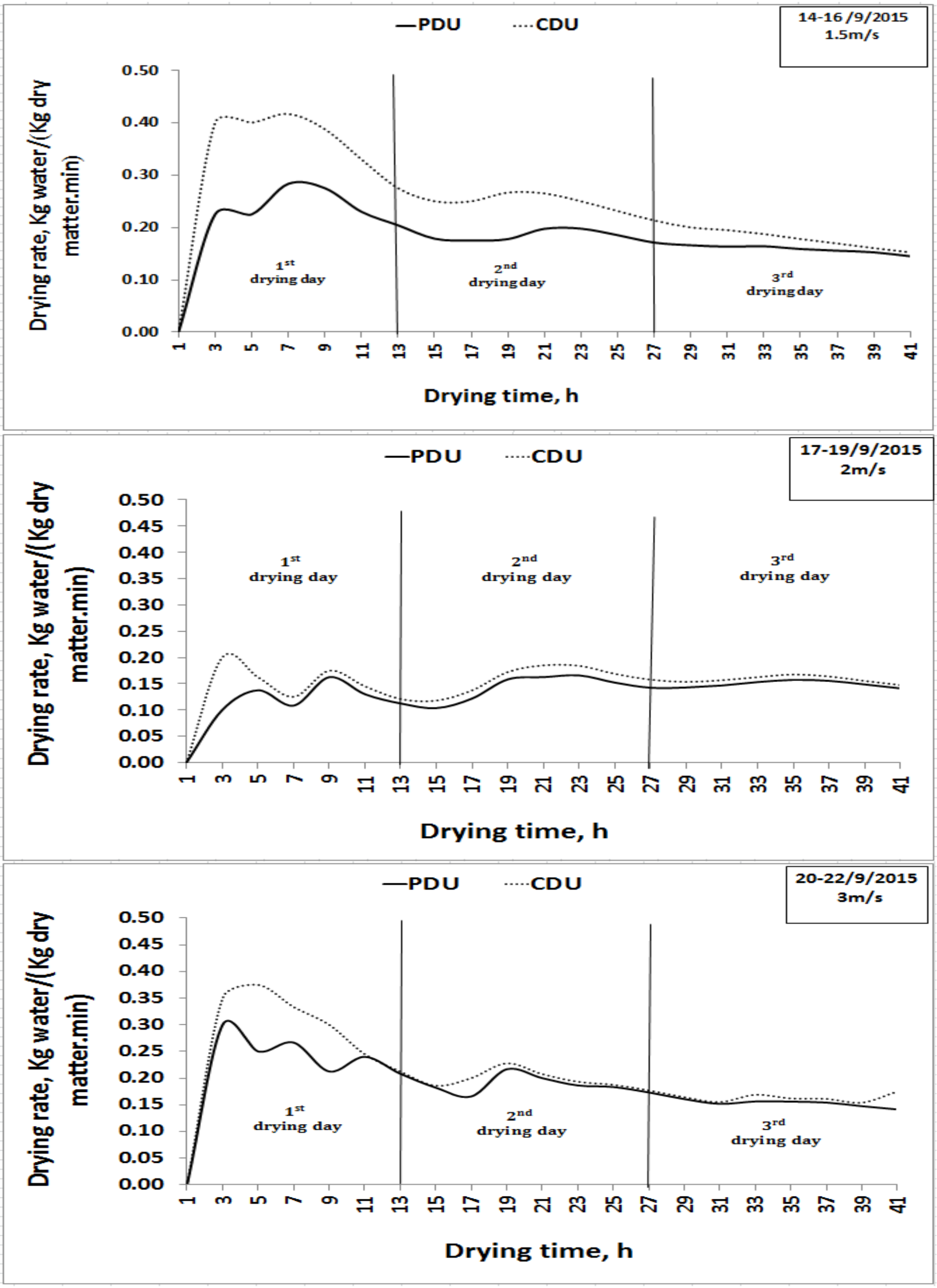

Figure 9. Drying rate as a function of drying time at different drying air velocities for both the parallel and counter drier units

In addition, the drying rate of counter drier unit (CDU) is higher than that of the parallel drier unit (PDU) at all drying air velocities because drying air temperature of counter system is higher than that of parallel system. From the drying curves, it is evident that the highest drying rates occurred in case of CDU. Since the drying rates at drying air velocity of 1.5m/s in PDU and CDU are of 0.28 and 0.42kg water/(kg dry matter. min) respectively. Whereas the final moisture content of 11.43 and 6.43%wb is reached after three days of drying for the PDU and the CDU respectively. The same trend was observed at drying air velocities of 2 and 3m/s. These results are corresponded to the observations reported by **Elbadawy, 2016**. **Figures 10** shows the variations of moisture content of fish wastes over drying process time at different levels of drying air velocities. It is observed that, the moisture content decreases tremendously with the drying time. The reduction rate of fish wastes moisture content was increased as the drying air velocity rises. There is a significant difference between the parallel and counter flow systems at drying air velocity of 1.5m/s and this difference begins to be less with the increase of drying air velocity. Moreover, the reduction rates of fish wastes moisture content of counter drier unit were higher than that of the parallel drier unit throughout the period of drying experiment.

The maximum averaged value of energy stored efficiency of the water is 50.284% at useful energy of 240W during the drying process**.** A significant reduction of the storage efficiency was noticed due to continuous consumption of energy stored during the drying process at 7:00PM**, Figure 11.** The maximum average value thermal efficiency of flat plate solar collector obtained is 53.549% at ambient air temperature of 33.9°C and solar radiation of 743.843W/m^2 at 11.00AM, **Figure 12**. The internal energy of water stored at the three experimented drying air velocities is depicted in **Figure 13**. For the second drying day and drying air velocity of 1.5m/s, the internal energy of the water reached its maxima of 5.85kJ at 3.00PM, water temperature was of 39°C and solar radiation of 609.3W/m^2. Moreover, for the third drying day and at drying air velocity of 2m/s, its value was of 6.09kJ at 5:00PM, water temperature of 40.6°C and solar radiation of 77.43W/m^2. While for drying air velocity of 3m/s it was of 6kJ at 5:00PM, water temperature of 40°C and 63.7W/m^2 solar radiation.

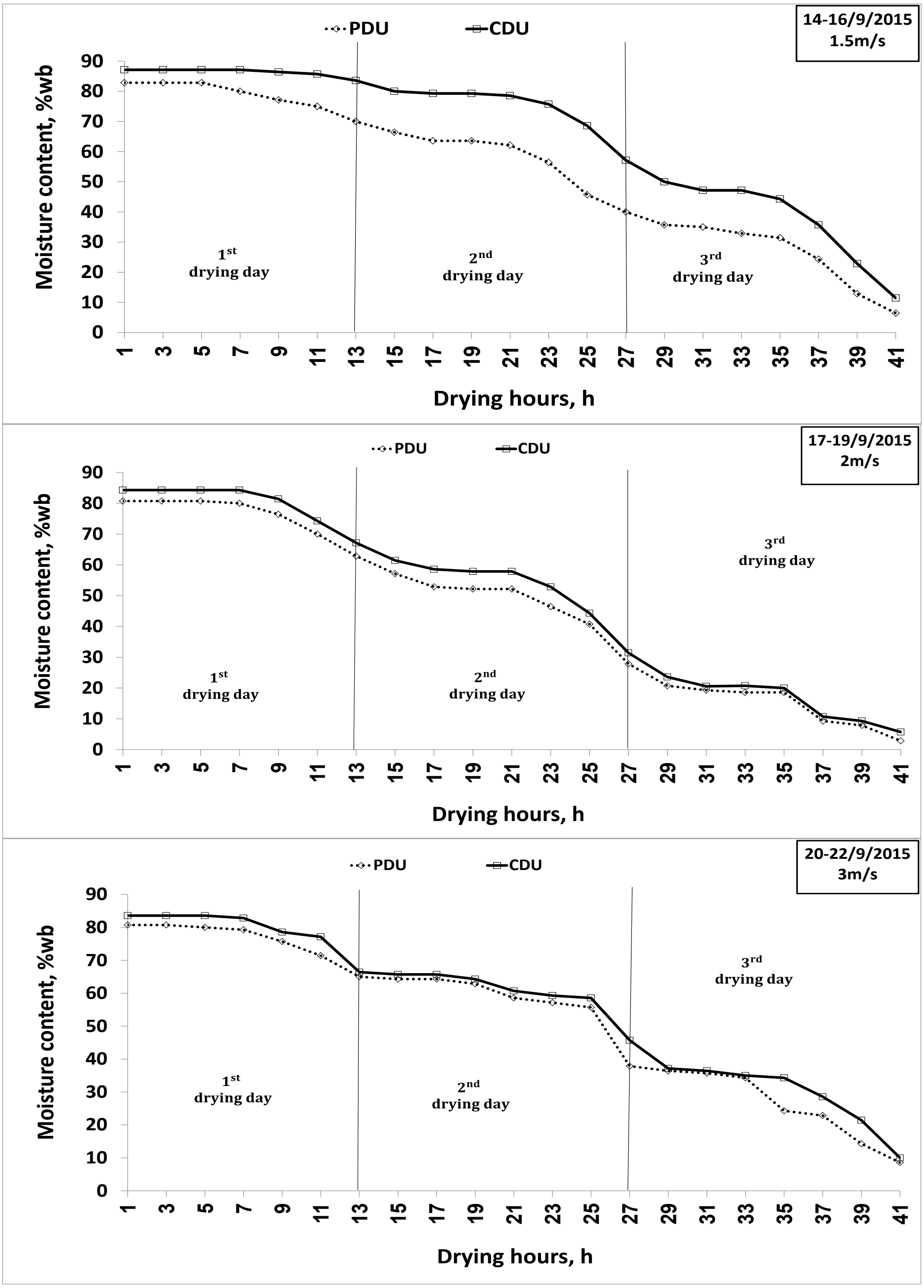

Figure 10. Evolution of fish wastes moisture content as affected by drying hours for both the parallel and counter drier units at different drying air velocities

It can be concluded that the highest internal energy was obtained at the end of drying day at 5.00PM. Exergy summation is the exergy gained by drying chamber greenhouse. It is observed from **Figure 14** that the maximum exergy rate at drying air velocity of 1.5m/s was of 0.08314 and 0.1356kW for parallel and counter drier units, respectively. Moreover, at drying air velocity of 2m/s, its value was of 2.497 and 0.225kW. While at drying air velocity of 3m/s, its value was of 0.303 and 0.433kW. The specific enthalpy inside the drying chamber has higher values than that of the ambient specific enthalpy at all drying air velocities. **Figure 15** shows the maximum values of specific enthalpy of 86.32, 214.56 and 121.06kJ/kg inside the solar drier at drying air velocities of 1.5, 2 and 3m/s, respectively, for the parallel drier unit. While for the counter drier unit, its values were of 115.69, 180 and 135.14kJ/kg.

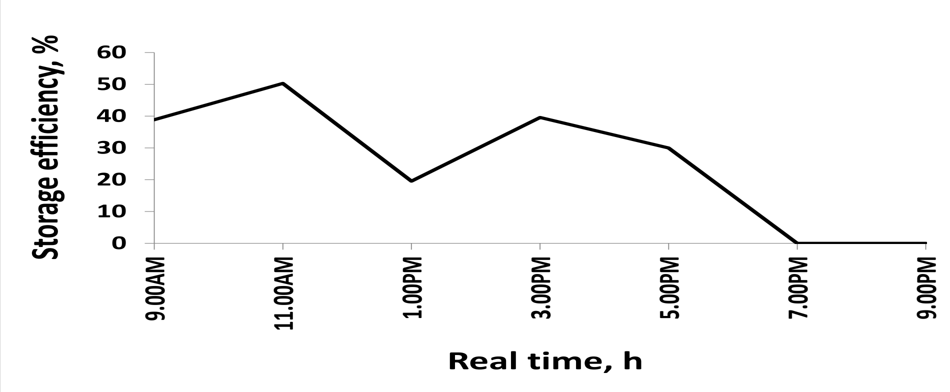

Figure 11. The averaged storage efficiency of flat plate solar collector during the experiment at real time

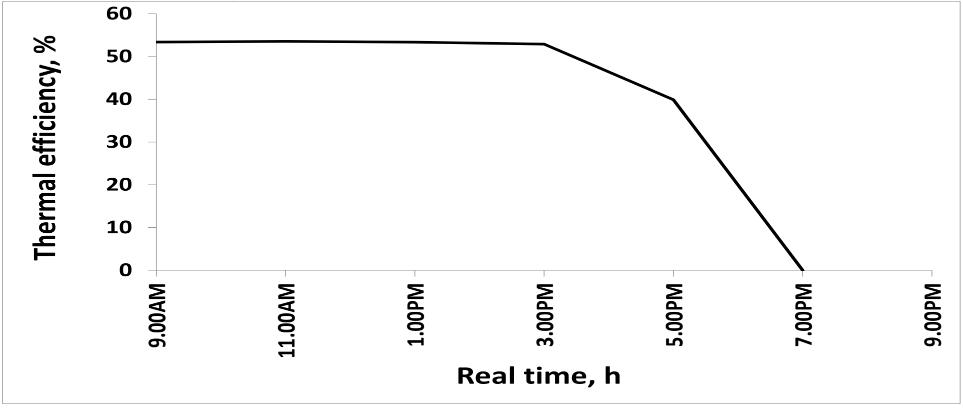

Figure 12. Thermal efficiency of flat plate solar collector during the experiment at real time

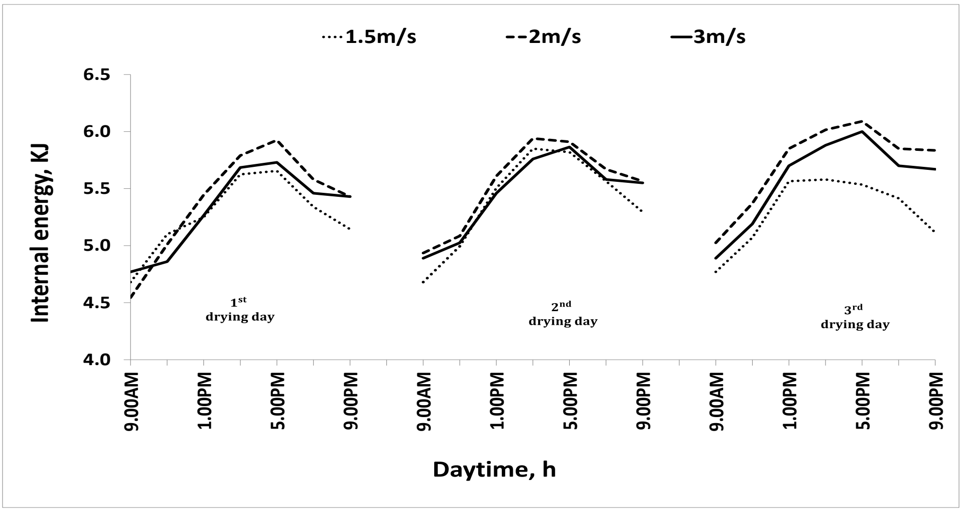

Figure 13. The effect of ambient temperature and solar radiation on internal energy of water tank at different drying air velocities

In general, the specific enthalpy of drying air increases with the increase of drying air velocity. The ambient air has higher latent specific enthalpy than that of air inside the parallel and counter drier units. In contrast, the sensible specific enthalpy of the air inside parallel and counter drier units has higher values than that of the ambient air. The maximum effectiveness of heat exchanger over the drying time, at drying air velocity of 1.5m/s, was of 0.282 at the end of the first drying day in the parallel flow heat exchanger at 9:00PM, **Figure 16.** While for the counter flow heat exchanger, it was of 0.0562 for the third drying day at 11:00AM. At drying air velocity of 2m/s, the maximum effectiveness of the counter flow heat exchanger was of 0.195 at the end of the second drying day. In general the parallel system had the highest effectiveness at drying air velocity of 1.5m/s but for the counter system, the highest effectiveness was achieved at drying air velocity of 2m/s. The thermal resistance in the counter flow heat exchanger is less than that of the parallel flow heat exchanger for the three drying air velocities, **Figure 17.** The thermal resistance begins to increase at the beginning of the drying process and decreases with the evolution of drying time due to the high water temperature emerging from the collector and the input to heat exchanger. Consequently, the counter flow system is better than the parallel one for enhancement of the thermal efficiency of the solar drying system.

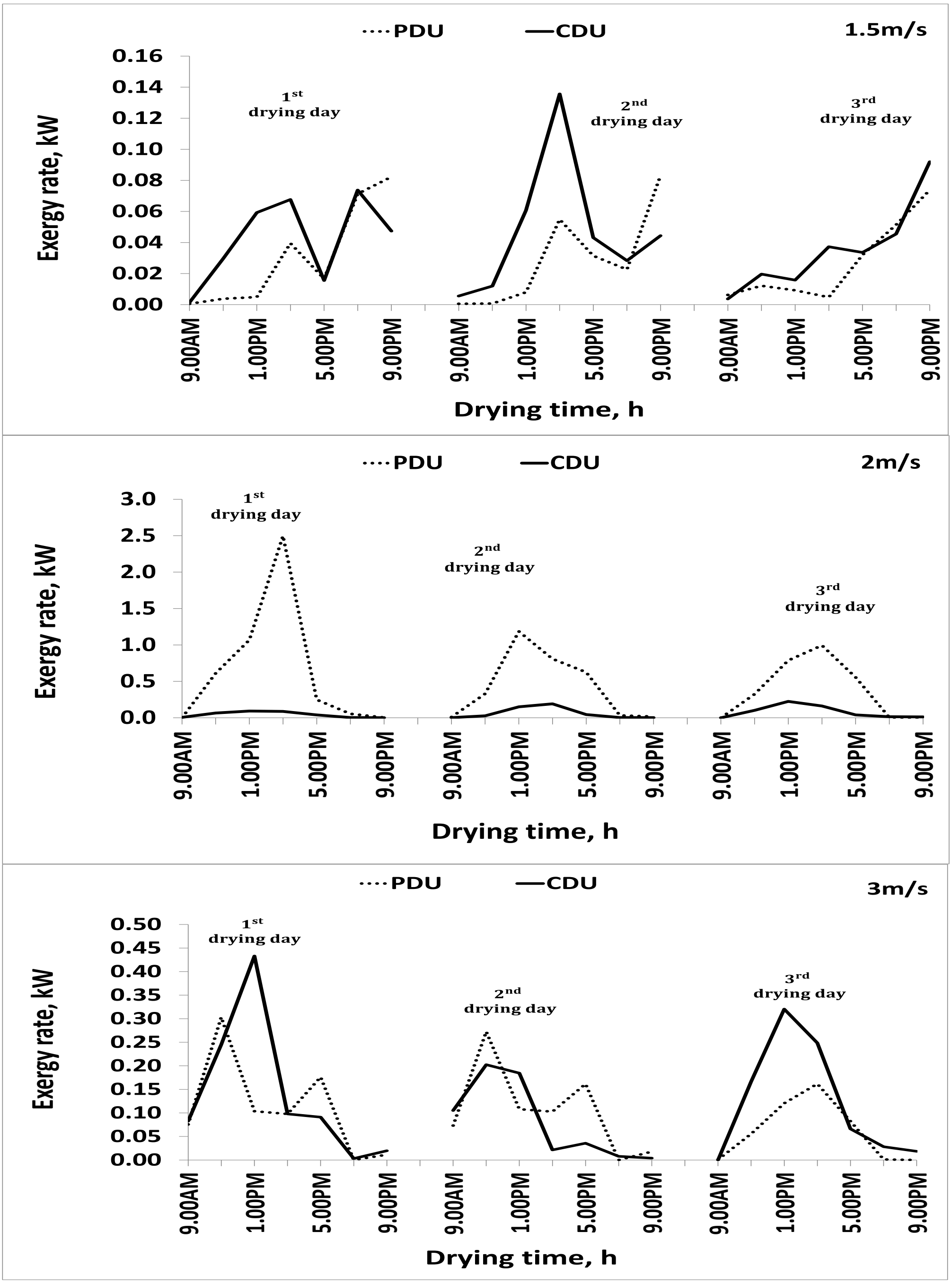

Figure 14. Exergy rate as a function of drying time inside drying chamber at different drying air velocities for both the parallel and counter drier units

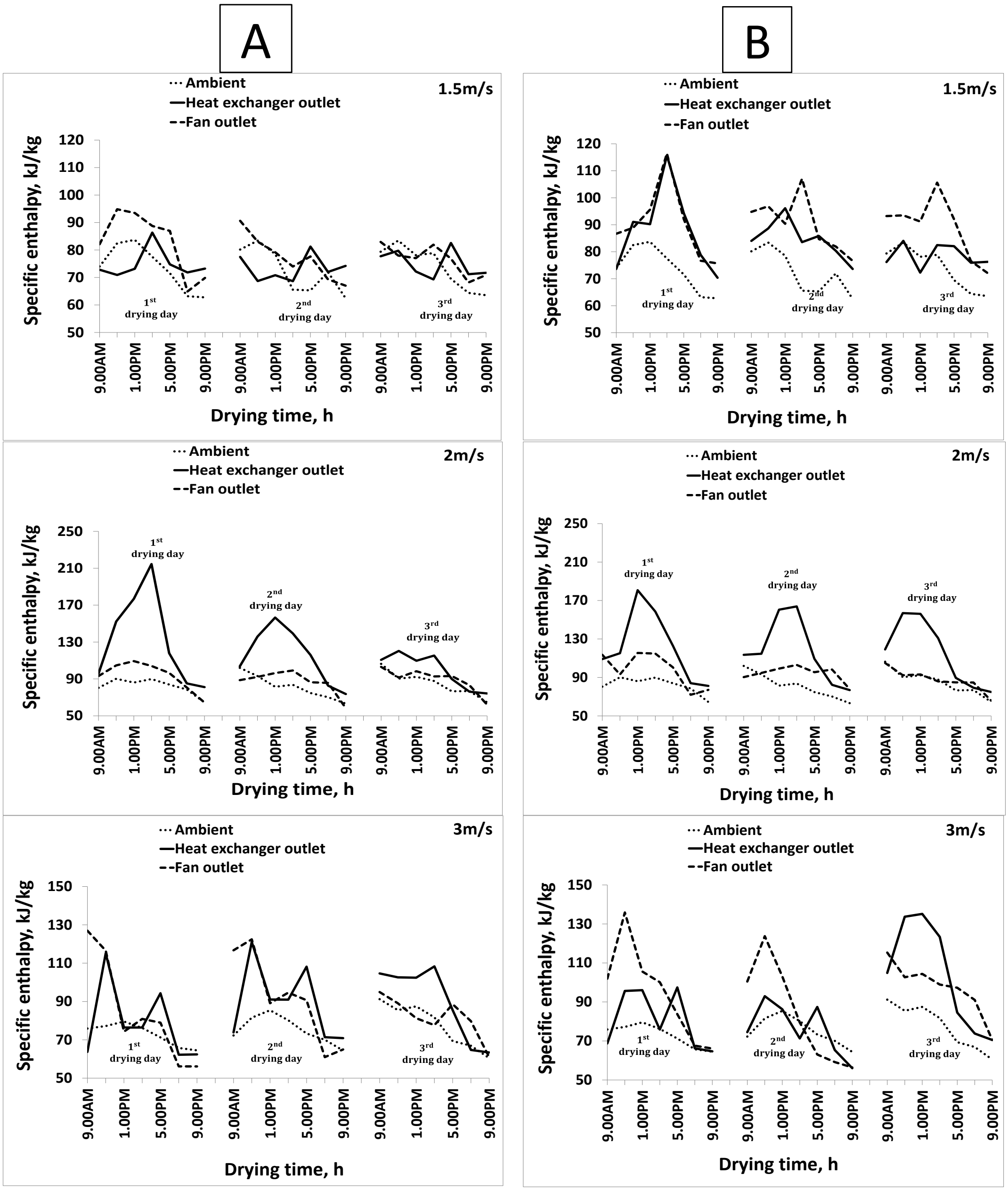

Figure 15. Specific enthalpy of the drying air as affected by drying time at different drying air velocities for both parallel (A) and counter (B) drier units

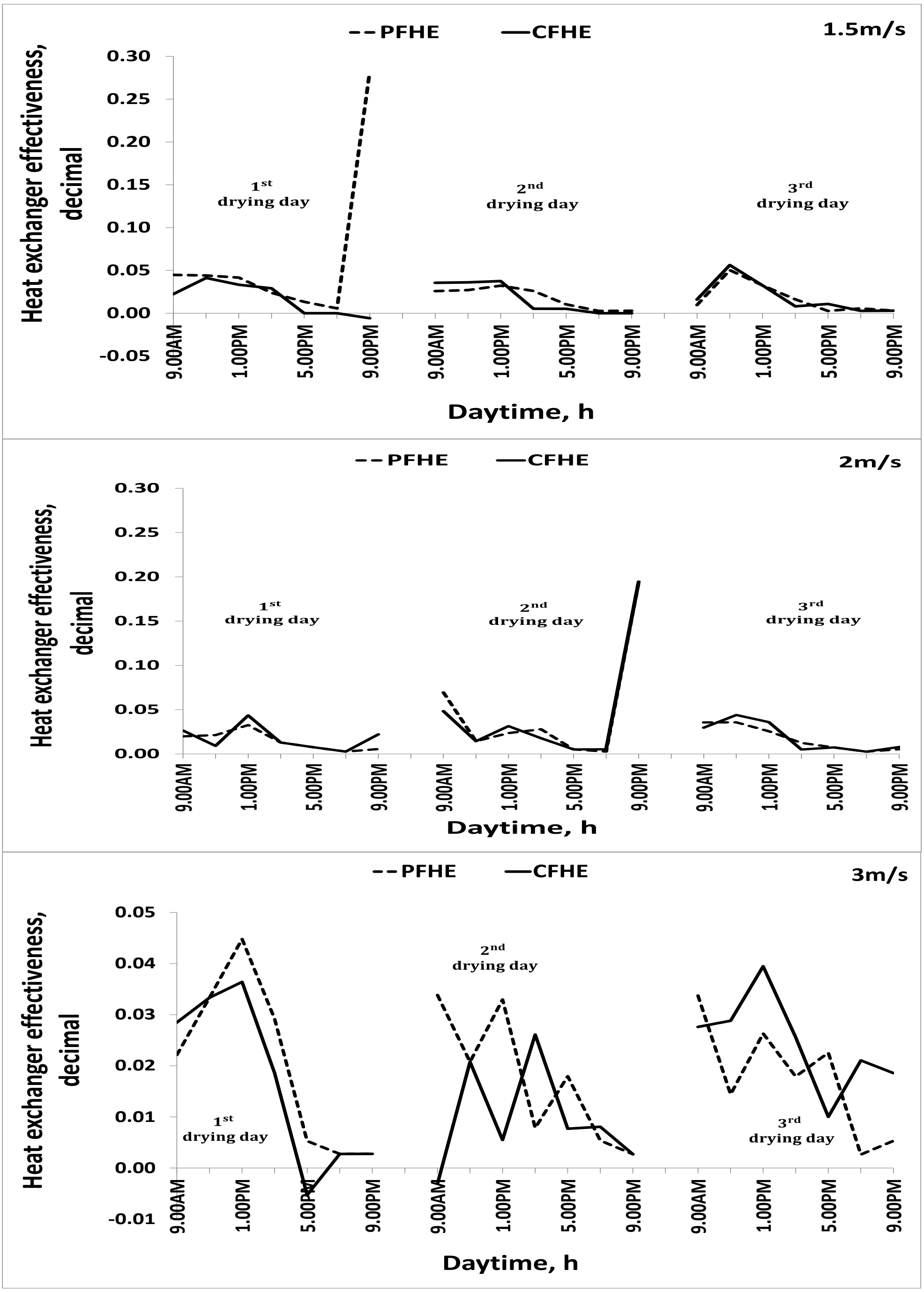

Figure 16. The effect of drying air velocity on the effectiveness of heat exchanger for both parallel and counter flow heat exchangers

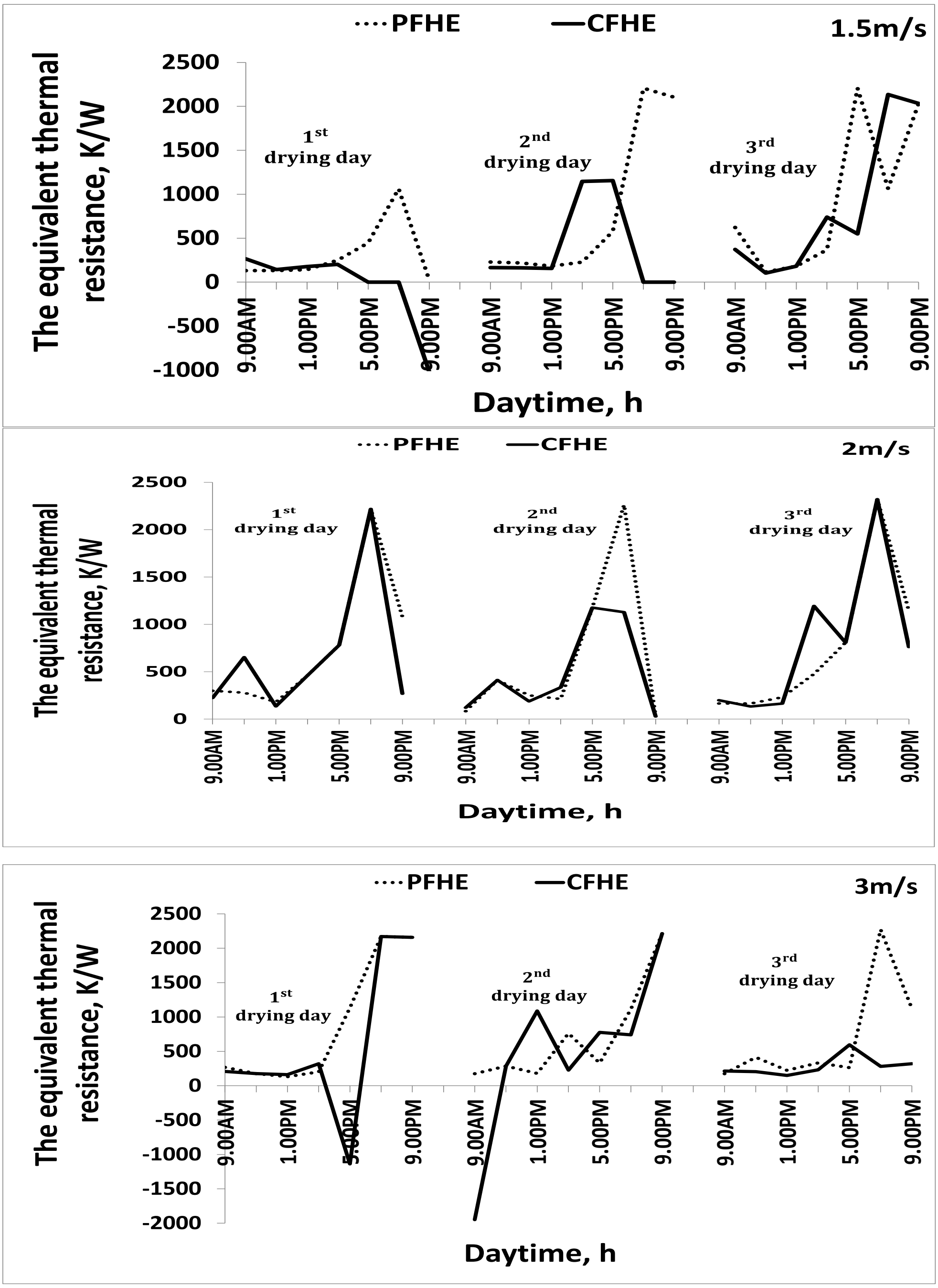

Figure 17. The changes occurred in thermal resistance during heat transfer process through both of parallel and counter flow heat exchangers

Figure 18 shows the relationship between the heat energy transferred against daytime for the three drying air velocities under study. For the first drying day and parallel flow heat exchanger, the heat energy transferred was of 0.77, 1.71 and 1.81kW at drying air velocities of 1.5, 2 and 3m/s, respectively.

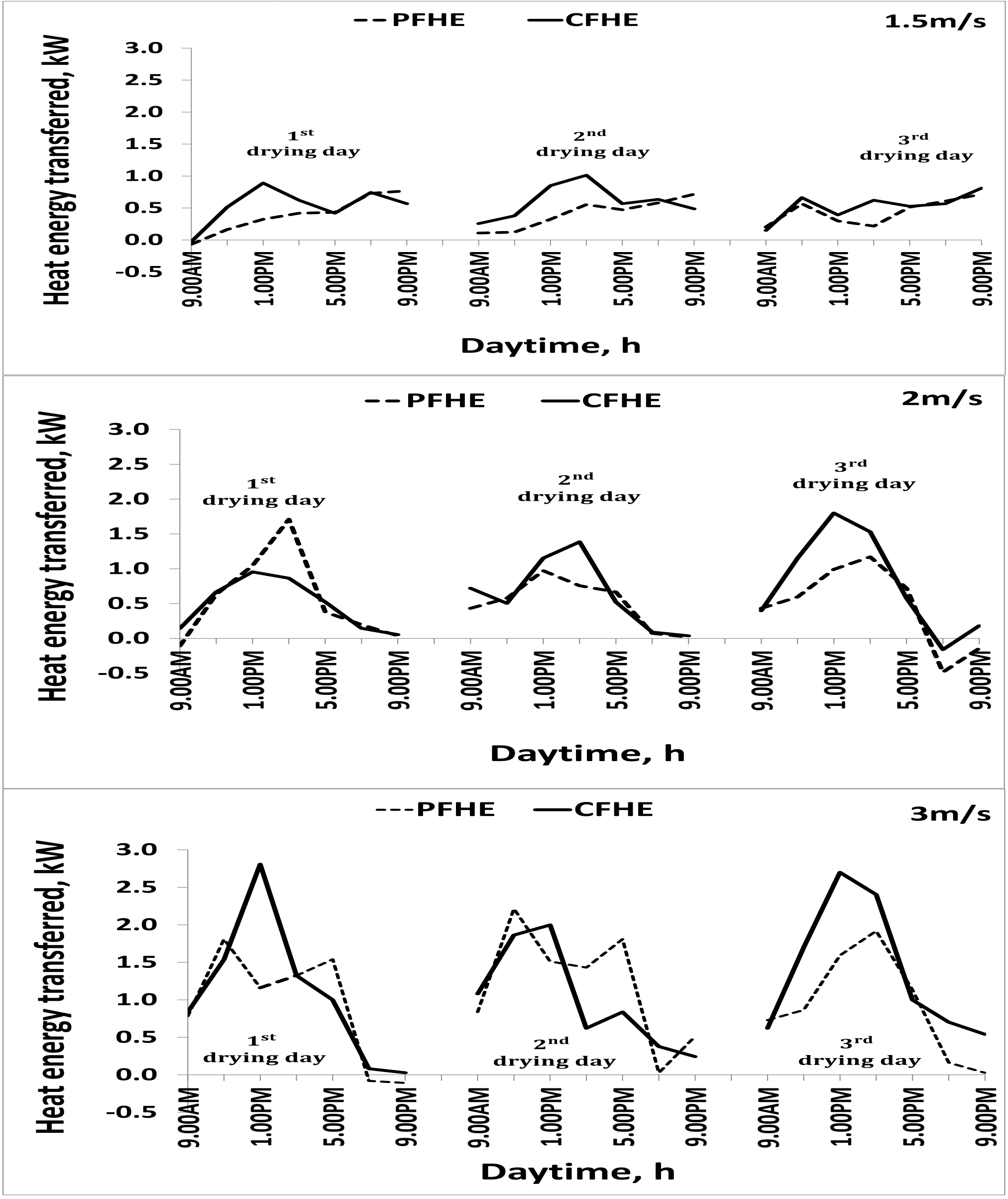

Figure 18. Heat energy transferred through the tube to the drying air in parallel and counter flow heat exchangers

In contrast, for the counter flow heat exchanger and first drying day, the heat energy transferred was of 0.89, 0.96 and 2.81kW at 1.5, 2 and 3m/s drying air velocity, respectively. Moreover, for the second and third drying days, the heat energy transferred behaves the same. In general, the maximum of thermal energy transferred from water to air of 2.21kW and 2.81kW for the parallel and counter flow heat exchangers, respectively. **Figure 19** shows the maximum mass loss of the fish wastes for the three drying air velocities under study.

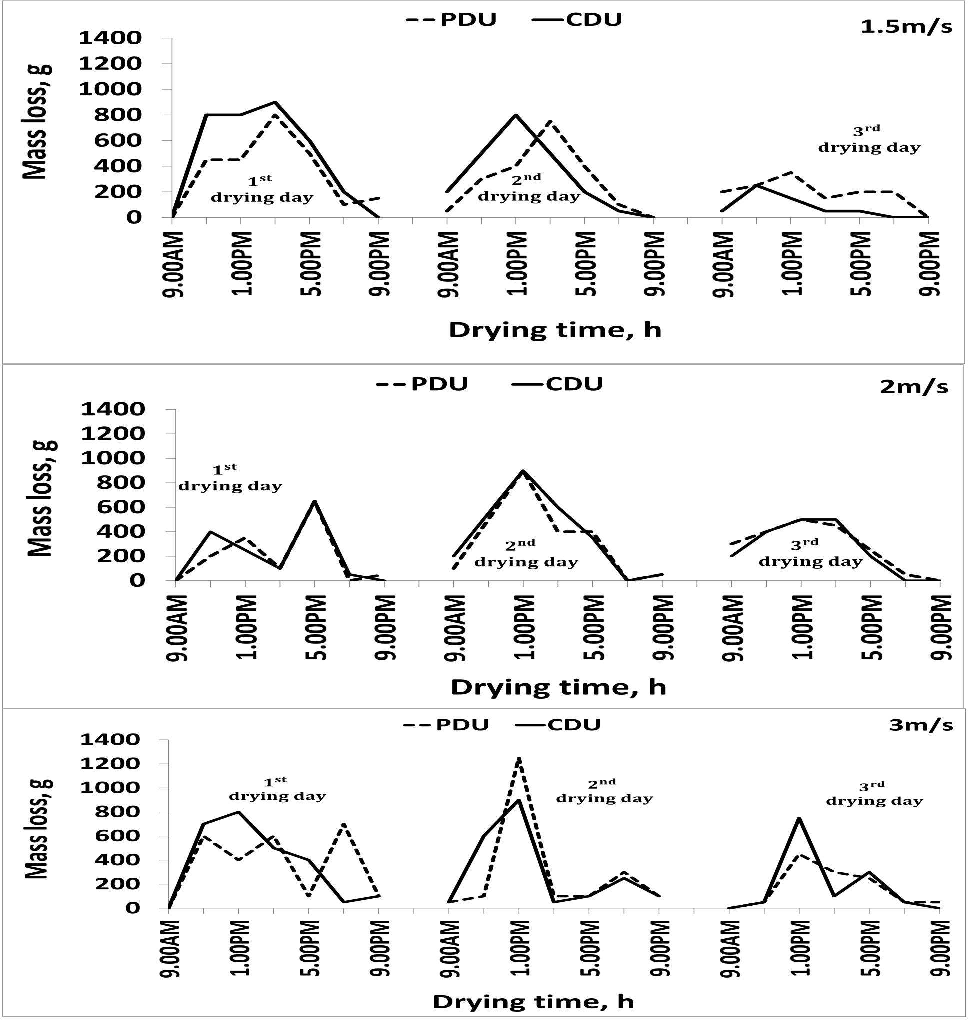

Figure 19. Changes of mass loss of fish farm wastes against drying time at different drying air velocities for the parallel and counter flow heat exchangers

For the first drying day and parallel drier unit, the mass loss of the wastes was of 800, 650 and 700g at drying air velocities of 1.5, 2 and 3m/s, respectively. In contrast, for the counter drier unit and first drying day, the mass loss of the wastes was of 900, 850 and 800 at 1.5, 2 and 3m/s drying air velocity, respectively. Moreover, for the second and third drying days, the mass loss of fish wastes behaves the same. It was found that the mass loss of fish wastes is higher for the counter drier unit than that of the parallel one. **Table 1** shows the final mass and the mass reduction percentage in each of the parallel and counter systems. Each treatment was replicated three times.

Table 1. Mass of fish wastes before and after drying

Drying system	Drying air velocity, m/s	Initial mass, kg	Final mass, kg	Time taken, day	Mass reduction, %
Parallel drier unit	**1.5**	**7**	**1.20**	**3**	**17.14**
	2		**1.35**		**19.28**
	3		**1.35**		**19.28**
Counter drier unit	**1.5**	**7**	**0.90**		**12.86**
	2		**1.10**		**15.71**
	3		**1.15**		**16.43**

Chemical composition of dried fish wastes is presented in **Table 2**.

Table 2. Chemical composition of dried fish wastes

Item	Dry matter, %	Crude protein, %	Crude fat, %	Crude fiber, %	Carbohydrates, %	Ash, %
Moisture content, %wb	85.89	50.04	8.13	0.43	9.05	18.24
Moisture content, %db	100	58.26	9.46	0.51	10.53	21.24

CONCLUSIONS

The experiment was conducted on drying fish ponds wastes. The effect of different drying air velocities of 1.5, 2, and 3m/s on two types of heat exchangers (parallel and counter) was studied. The parallel and counter drier units have the ability to dry fourteen kilograms of small fish with a thin layer where moisture content of the fish wastes was 76.9±1%wb. The drying air temperature and outlet from the fan in the parallel system ranged from 33 to 43.9°C, and in the counter system, ranged from 34 to 45.8°C and therefore outlet air from the fan can be used again for the drying process. The most important results could be summarized as follows:

1. The drying air velocity of 1.5m/s has achieved the drying rate of 0.283 and 0.420kg water/(kg dry matter. min) for the parallel and counter drier units, respectively.
2. Drying time decreases with the increase of drying air temperature and the type of heat exchangers (parallel and counter) represents a significant impact on the drying process of fish farm wastes.
3. The final moisture content of 11.43 and 6.43%wb is reached after three days of drying for the parallel and counter drier units, respectively at drying air velocity of 1.5m/s.
4. The drying air velocity of 3m/s has achieved the highest heat energy transferred rate from water to air of 2.21 and 2.81kW for the parallel and counter flow heat exchangers, respectively.
5. The thermal resistance of the counter flow heat exchanger is less than that of the parallel one for all the drying air velocities.
6. The maximum effectiveness of heat exchanger was of 28% at 1.5m/s for the parallel drier unit, but it was of 20% at 2m/s for the counter one.
7. Moisture content decreases tremendously with the evolution of drying time, where the reduction rates of fish wastes moisture content for counter drier unit were higher in comparison with parallel one throughout the drying process.
8. The highest internal energy of water tank is 6.09kJ at 5.00PM, temperature of water is 40.6°C and less radiation is 77.43 W/m^2.

9. The counter flow system has achieved the highest exergy rate of 0.433kW at the drying air velocity of 3m/s and the parallel system is 2.49kW at drying air velocity of 2m/s.
10. Specific enthalpy of drying air of counter drier unit is higher than that of parallel one at drying air velocities of 1.5 and 3m/s while lower at drying air velocity of 2m/s.
11. Latent specific enthalpy of the ambient air is less than the sensible specific enthalpy of the air outside the parallel and counter systems.

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الملخص العربي

الإستفادة من المبادلات الحرارية في تجفيف مخلفات المزارع السمكية لإنتاج مركزات الأعلاف

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عبدالفتاح عبدالرؤف القويعي [٣] و مصباح مرجان عبدالعال [٤]

يولد إرتفاع أسعار الأعلاف الحيوانية والسمكية في مصر فجوة كبيرة في مجال التغذية، حيث يتطلب ذلك البحث عن مصادر جديدة للبروتين الحيواني مثل مركزات الأعلاف المحلية بدلاً من إستيرادها. حيث يتم إهدار كميات كبيرة من الأسماك صغيرة الحجم عند حصاد المزارع السمكية وإلقائها على الأرض دون أي استغلال. لذلك أصبح من الضروري معالجة تلك المخلفات من أجل الحصول علي مركزات أعلاف منخفضة التكاليف. لذلك يهدف هذا البحث إلي تجفيف عينة من مخلفات الأسماك بأبعاد ٣,٦±٤,١سم طول، ٢±٧,٠سم سمك ووزنها ١٩±٢,٨٨ جرام، بإستخدام تيار من الهواء الساخن الناتج من المبادلات الحرارية. أجريت التجربة خلال شهر سبتمبر لعام ٢٠١٥م بمركز ميكنة الأرز بميت الديبة، محافظة كفرالشيخ.

الهدف العام من الدراسة الحالية هو الإستفادة من المبادلات الحرارية في تحسين الكفاءة الحرارية لعملية التجفيف الشمسي لمخلفات المزارع السمكية بهدف إنتاج الأعلاف المركزة المستخدمة في عملية التغذية للإنتاج الحيواني. تم دراسة المتغيرات البحثية الأتية:

١- دراسة التحليل الرياضي للمبادلات الحرارية

٢- دراسة تأثير سرعة هواء التجفيف (١,٥، ٢، ٣م/ ث) خلال نوعين من المبادلات الحرارية (المتوازي و المتقابل الانسياب)

٣- بحث وتطبيق التكامل بين كلاً المجمع الشمسي والمبادل الحراري في تحسين الكفاءة الحرارية لعملية التجفيف الشمسي لمخلفات الإسماك

ويتكون نظام التجفيف الشمسي من: غرفة التجفيف ، المجمع الشمسي والمبادل الحراري (المتوازي والمتقابل الانسياب).

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١- المجففات الشمسية من نوع الصوبة

يوجد غرفتين للتجفيف لهما نفس الأبعاد الهندسية: (٢م طول × ١م عرض × ٠,٩م إرتفاع). وتم تغطية جميع الجوانب من البلاستيك البولي إثيلين، وضعت تحت الظل لتجنب تأثير أشعة الشمس المباشرة علي غرفة التجفيف من أجل دراسة أداء المبادلات الحرارية. ويتم تعليق غرفة التجفيف بواسطة خلية الوزن لمعرفة الوزن الكلي لغرفة التجفيف، ثم يتم توصيل المبادل الحراري بغرفة التجفيف بواسطة وصلة معدنية معزولة حرارياً. حيث يوجد فتحة في الجانب الآخر في أسفل غرفة التجفيف ويثبت عليها مروحة لسحب بخار الماء الساخن الناتج عن عملية التجفيف وبسرعات هواء مختلفة (١,٥، ٢ ، ٣م/ث). وأيضا في الجزء العلوي من الغرفة يوجد فتحه لدخول الهواء الساخن الناتج من المبادل الحراري بحيث يمر الهواء الساخن لتجفيف مخلفات الأسماك.

٢- المجمع الشمسي

المجمع الشمسي عباره عن إطار خشبي مسطح أبعاده (١ × ١م) ويتم تغطيتة بلوح زجاجي شفاف سمكه ٦مم وبداخله لوح ماص مطلي باللون الداكن لامتصاص أشعة الشمس، ثم يتم وضع أنابيب من النحاس التي تمر من خلالها المياه لتسخينها، والمسافة بين كل أنبوب والآخر ١٥سم ومتصله بخزان مياه معزول حرارياً سعته ١٥٠ لتر.

٣- المبادل الحراري

عباره عن إسطوانتين: الإسطوانة الداخلية مصنوعة من الحديد المجلفن قطرها ٠,٣٠٤٨م وطولها ١,٥م وسمكها ٠,٠٠٠٩م ويتم ملئ ماسوره مرور الهواء بأسلاك دقيقة من الحديد التي تعمل علي إعاقة مرور الهواء فتزيد من مساحة السطح المعرض للهواء. وبعد ذلك يتم وضعها داخل إسطوانة أخرى قطرها ٠,٥م حيث يمر بها الماء الساخن، وبعد ذلك يتم عزل المبادل الحراري من الخارج بالصوف الزجاجي سواء يمر الهواء في نفس إتجاه المياه أو في الإتجاه المعاكس.

٤- مخلفات الأسماك

تم الحصول على مخلفات الأسماك (الأسماك الصغيرة) من المزارع السمكية من قرية دمرو، مركز سيدي سالم، بمحافظة كفر الشيخ. ثم نقلها إلى مركز ميكنة الأرز بميت الديبة، محافظة كفرالشيخ وكان المحتوى الرطوبي ٧٦,٩±١٪ على أساس رطب.

ويمكن تلخيص أهم نتائج الدراسة كما يلي:

١- حققت سرعة هواء التجفيف ١,٥م/ث أقصي معدل تجفيف لنظامي المتوازي والمتقابل الانسياب هو ٠,٢٨٣ & ٠,٤٢٠كج ماء/ (كج مادة جافة. دقيقة)، على الترتيب.
٢- يقل زمن التجفيف بزيادة درجة حرارة هواء التجفيف ، وأظهرت النتائج ان نوعية المبادل الحراري (المتوازي أوالمتقابل الإنسياب) له تأثير كبير على عملية تجفيف مخلفات الأسماك.
٣- المحتوي الرطوبي النهائي لنظامي المبادل الحراري المتوازي والمتقابل الإنسياب هو ١١,٤٣ ، ٦,٤٣٪ علي اساس رطب علي الترتيب عند سرعة هواء تجفيف ١,٥م/ث والتي أجربت في ثلاثة أيام تجفيف.

٤- أعلي طاقة حرارية منقولة من الماء للهواء هي ٢,٢١ ، ٢,٨١ كيلووات للمبادل الحراري المتوازي والمتقابل الانسياب علي الترتيب عند سرعة هواء تجفيف ٣م/ث مقارنة بسرعات الهواء الأخري.

٥- المقاومة الحرارية للمبادل الحراري المتقابل الإنسياب أقل منها للمتوازي الإنسياب عند سرعات هواء التجفيف تحت الدراسة. لأن درجة حرارة الهواء الخارج من المبادل الحراري المتقابل الإنسياب أعلي من المتوازي الإنسياب.

٦- أعلي كفاءة حرارية للمبادل الحراري المتوازي الإنسياب هي ٢٨٪ عند سرعة هواء تجفيف ١,٥م/ث والمتقابل الإنسياب ٢٠٪ عند سرعة هواء تجفيف ٢م/ث.

٧- المحتوي الرطوبي لمخلفات الأسماك ينخفض جدا بتقدم زمن التجفيف، حيث أن معدل الإنخفاض في المحتوي الرطوبي لمخلفات الأسماك لنظام المبادل الحراري المتقابل الإنسياب أعلي منه مقارنة بالنظام المتوازي الإنسياب خلال فترات عملية التجفيف.

٨- أقصي طاقة داخلية للمياة في الخزان ٦,٠٩ كيلوجول عند الساعة الخامسة مساءً وكانت درجة حرارة الماء ٤٠,٦ م° وأقل إشعاع ٧٧,٤٣ وات/م^{٢} .

٩- حقق نظام المبادل الحراري المتقابل الإنسياب أعلى معدل للطاقة الفعالة لهواء التجفيف ٠,٤٣٣ كيلووات عند سرعة هواء تجفيف ٣م/ث والنظام المتوازي الإنسياب ٢,٤٩ كيلووات عند سرعة هواء تجفيف ٢م/ث .

١٠- الإنثالبيا النوعية لهواء التجفيف لوحدة النظام المتقابل الإنسياب أعلي من الإنثالبيا النوعية في وحدة النظام المتوازي الإنسياب عند سرعة هواء تجفيف ١,٥- ٣م/ث بينما أقل منة عند سرعة هواء تجفيف ٢م/ث.

١١- الإنثالبيا الكامنة للهواء المحيط الخارج من النظامين المتوازي والمتقابل الإنسياب أقل من الإنثالبيا المحسوسة للهواء الخارج من كلا النظامين تحت الدراسة.

١٢- أعلى كفاءة حرارية لنظام تسخين المياه بالطاقة الشمسية ٥٣,٦٣٪ وأعلى كفاءة تخزين للطاقة الحرارية هي ٥٠,٢٨٤٪.