VOL. 04 NO. 5,
MAY, 2024
E-ISSN 3027-1339
P-ISSN 3026-8257

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Systematic, Evaluation and Diversity Engr. (JSEDE)

DEVELOPING A MODEL FOR DESIGNING SOLAR COLLECTOR BASED ON NASARAWA SOLAR DATA

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Abstract

Efforts to maximize the utilization of the huge solar radiation in Nasarawa cannot be a wasted effort. Again, looking at the lean efficiencies of a good number of the produced solar dryers in Nasarawa paved way for more improvement of this subject area. Also, research gathered that majority of the solar appliances used in Nasarawa were not designed based on the solar data of the town. This paper looked into coming up with a model to design and construct solar dryer based on solar radiation data of Nasarawa. The Nasarawa solar data used here were obtained from previous work carried out on direct capturing of Nasarawa hourly solar radiation which lasted for 356 days. The developed model to determine the area of solar collector is $A_C = \frac{1}{n(F_R h_e I_H)}\left[W_1 Cp_m(T_2 - T_1) + I_V\left(\frac{W_1(M_i - M_f)}{100 - M_f}\right)\right]$. The area of the solar collector in drying per boiled rice and sliced mangoes using solar dryer were carried out. From the analyses, the values of the solar collector for Kano - Nigeria, Nasarawa – Nigeria and Zalingei – Sudan are 3.1432 m^2, 2.5689 m^2 and 1.6971 m^2 respectively. This can further be used to determine other parameters needed for further design parameters dimensions. Efforts were made to use the derived equations to determine the size of solar collector of other areas who's their solar data were available and it was quite in agreement.

Keywords: Model, Solar Radiation, Solar Collector, Nasarawa

Introduction

The sun is the ultimate generator of the world's renewable energy. The sun is the centre of the solar system generating this ultimate energy round the clock 24/7. The sun generates this energy at the rate compared to that of a furnace emitting heat energy at a temperature of 6, 000 K. It would have been possible to generate enough energy to meet up with the current energy demand of the world from a portion of the sun if there is no revolution and rotation of the earth and other climatical factors surrounding the earth (William and Michael, 2001).

One of the ancient methods of preserving food is drying. In the olden days, drying fish and meat was done by open sun drying. This was long before history started to be documented. Up till now drying of foods is still an essential method of preservation. Dried foods can be stored for long periods without deterioration occurring. The main reasons for this are that the micro-organisms which cause food spoilage and decay are unable to grow and multiply in the absence of sufficient water and many of the enzymes which promote undesired changes in the chemical composition of the food cannot function without water (Earle, 2013). Dehydration is one of the oldest techniques employed in food or agricultural products storage and preservation. The most common method of dehydration is by open air sun drying but this often results in food contamination and nutritional deterioration. Food dehydration technology employs direct and/or indirect mixed mode systems with natural or forced distribution of heated air (Okoroigwe, *et al.,* 2013).

Types of Solar Dryer

Direct solar dryer

In direct or natural convection type dryers, the agricultural product is placed in shallow layers in a blackened enclosure with a transparent cover. The solar radiations are directly absorbed by the product itself. The food product is heated up and the moisture from the product evaporates and goes out by the natural convection/circulation (Afriyie, *et al.,* 2011).

Indirect solar dryers

In these dryers the food product is placed in a drying chamber. The air is heated in solar air heaters and then blown through

the drying chamber. In some of the designs, dryers receive direct solar radiations and also heated air from solar air heaters. In these dryers' manipulation of temperature, humidity and drying rate is possible to some extent (Afriyie, *et al.,* 2011).

Forced circulation solar dryers

In these dryers, hot air is continuously blown over the food product. The food products itself is loaded or unload continuously or periodically. These kinds of dryers are comparatively thermodynamically efficient, faster and can be used for drying large agricultural product. These dryers can be of Cross-flow type, concurrent flow type or counter-flow type (Madhlopa et al., 2002).

Several attempts have been made to fabricate solar dryers in Nasarawa. However, most of these dryers do not stand the test of time. This is not because they were not properly fabricated but it was discovered that most often, these dryers were fabricated without prior knowledge to the solar radiation data of the locations in which they were being used.

This research therefore, will present a model that will be used to design direct type solar dryers according to Nasarawa solar radiation. to be designed here are the following parts of the dryer: -

i. Area of the solar collector
ii. Tilt angle of solar collector
iii. Determination of the thickness of the bottom insulator (X)
iv. Determination of the thickness of the absorber plate ( )
v. Determination of the surface area of the drying cabinet
vi. Height of the drying cabinet

MATERIALS AND METHODS

Components of solar dryer

The following are the major components of the solar dryer under consideration: -

The Flat Plate Solar Collector

This component is composed of the transparent glass cover, an absorber, the insulation, and the container of collector body.

Transparent Cover (Glass)

This is a transparent glass covering the solar dryer heating chamber whose function is to convert solar radiation from the sun into heat energy needed for drying of items

inside the solar dryer. This plate is usually inclined at an angle facing the sun for adequate sun radiation reception (Madhlopa et al., 2002)..

Absorber Plate

This is a black oven baked aluminium plate whose responsibility is to convert both direct and diffuse absorbed solar radiation to heat energy required for drying. The surface should have high absorption for solar radiation and low emitted for long wave radiation.

The Insulator (Colatex Material)

It is used to insulate the interior parts of the solar collector so as to reduce heat loss from the absorber. Also, the drying chamber is insulated to reduce excessive heat loss. Colatex is used as the insulator in this design because it is a good heat insulator and readily available at low cost.

Collector Body Cover (Wood)

The entire unit of the solar collector is designed such that the side body covers extend to the dryer unit. The collector body cover is made of wood material. It is readily available and a good insulator.

Drying Chamber

This is the place or space where dehydration of the fish occurs. The objective of dehydration is of course, to reduce the water content of the fish to a point where it can no longer support the growth of micro-organisms. Of these organisms, bacteria and yeasts cease to multiply in the fish when the water content is less than 25% of the total body weight and moulds when it is less than 15%. The design of the drying chamber was done to permit the user to use it as in-bin storage dryer (Abubakar, and Isiyaku, 2014).

Wire Gauze

This is where the fishes to be dried are spread. The products being dried are put on the wire gauze so that heated air from the collector can easily pass through the gauze and consequently cause drying. The wire gauze is of mild steel material and has high resistance to corrosion.

Carriage

A means of easy movement is attached to the system as a unit. A roller type tyre is fixed to the collector while a supporting frame is attached to it.

Design Considerations

For the purpose of this design, all conditions applied will be based on data acquired directly of indirectly for Nasarawa town, and the food item used for this modelling was parboiled paddy rice. Hence, the following points were considered: -

i. To determine the amount of moisture to be removed from the drying food item, its quantity, initial and final moisture contents must be known.
ii. Sunshine hours for Nasarawa
iii. Air temperature, air relative humidity and permissible temperature of the drying air.
iv. Daily or average monthly solar radiation of Nasarawa to determine the energy received by the dryer per day.
v. Heat transfer efficiency (Arinze, 1983).

Design Parameters and Assumptions

The criterion is to develop a par-boiled batch type rice solar dryer. The development is based on some fundamental design parameters and assumptions

Determination of the amount of moisture to be remove from the par-boiled rice

The equation below can be used t calculate the amount of moisture to be removed for the food item to be dried (Afriyie et al., 2011): -

$$M_W = \frac{W_1(M_i - M_f)}{100 - M_f} \quad (1)$$

Energy required to remove the moisture content

Afriyie et al., (2011) also reported that the energy required to evaporate the available moisture content in a drying item can be calculated using the formula below: -

$$E = W_1 Cp_m(T_2 - T_1) + I_V M_W \quad (2)$$

Energy required to remove the moisture content per hour

This equation below gives the relationship to determine the energy required to remove moisture content on hourly basis (Abubakar, and Isiyaku, 2014): -

$$Q_R = \frac{E}{n} \quad (3)$$

Area of the solar collector

To determine the solar collector area of the solar dryer, Abubakar, and Isiyaku, (2014) reported that the equation below can be used: -

$$Q_R = A_C F_R h_e I_H \text{ or}$$

$$A_C = \frac{Q_R}{F_R h_e I_H} \quad (4)$$

Combining all these equations, an equation to determine the area of the solar collectors is as follows: -

$$A_C = \frac{1}{n(F_R h_e I_H)}\left[W_1 Cp_m(T_2 - T_1) + I_V\left(\frac{W_1(M_i - M_f)}{100 - M_f}\right)\right] \quad (5)$$

Meanwhile the length of the breadth of the solar collector and be assumed to determine the other from the area

Tilt angle of solar collector

For proper solar radiation reception, the solar collector is always tilted at an angle and this angle can be calculated using the equation stated below (Basunia and Abe 2001): -

$$\alpha = (L + 5)\ ON \quad (6)$$

Determination of the thickness of the bottom insulator (X)

It is imperative to consider the thickness at the bottom oof the solar collector. This is because the choice made here will go a long way to curb unnecessary heat loss in the drying chamber. Although saw dust is cheap and readily available for use but there is need to calculate its thickness, and this is calculated using the equation below (Abubakar, and Isiyaku, 2014): -

$$R = \frac{X}{K} \quad \text{or}$$

$$X = RK \quad (7)$$

Determination of the thickness of the absorber plate ( )

Amer et al., (2010) reported in his work the relationship to determine the thickness of the absorber plate as thus: -

$$\delta = \frac{0.2}{K} \quad (8)$$

Determination of the surface area of the drying cabinet

The equation to determine surface area of the drying unit can be determined using equation reported by Afriyie et al., (2011);

$$V = \frac{mass\ of\ item\ to\ be\ dried}{Bulk\ density\ of\ the\ item\ to\ dry} \quad (9)$$

The width and height of the solar drying cabinet can be determined by dividing by the area by either of the two parameters.

Determination of the drying period (day)

Abubakar, and Isiyaku, (2014) reported in their work that the formula to determine the drying period (n) in days of the of substance to be dried in a drying chamber is as follow:-

$M_W H = nA_C I_C$ or

$$n = \frac{M_W H}{A_C I_C} \quad (10)$$

RESULTS AND DISCUSSIONS

The developed model to determine the area of the solar collector was applied to determine Area of solar collector for different food items at three different locations. The locations are Kano in Kano state – Nigeria, Nasarawa in Nasarawa state - Nigeria and Zalingei, Zalingei in Sudan as presented in Table 1 (Abubakar, and Isiyaku, 2014, Akoy et al., 2019).

$$A_C = \frac{1}{n(F_R h_e I_H)}\left[W_1 Cp_m(T_2 - T_1) + I_V\left(\frac{W_1(M_i - M_f)}{100 - M_f}\right)\right]$$

Table **1: Determination of Solar collector area for per-boiled rice and mango slices in Kano, Nasarawa and Zalingei**

Food Item	location	W_i	M_i	M_f	M_w	C_{pm}	T_1	T_2	I_v	E	n	Q_R	F_r	h_e	I_h	A_c	B	L
Per-boiled rice	Kano	30	36	14	7.67	4.595	28	55	2381.65	21999.729	8	2750	0.8	0.8	1367	3.1432	1.5	2.1
	Nasarawa	30	36	14	7.67	4.595	28.4	55	2381.65	21944.589	9	2438.3	0.8	0.8	1483	2.5689	1.5	1.71
	Zalingei, Sudan	30	36	14	7.67	4.595	30	55	2381.65	21724.029	10	2172.4	0.8	0.8	2000	1.6971	1.5	1.13

	Kano	30	81.4	10	23.8	3.74	28.4	70	2428	62453.92	8	7806.7	0.8	0.8	1367	8.9232	4	2.23
Mango slices	Nasarawa	30	81.4	10	23.8	3.74	28.4	70	2428	62453.92	9	6939.3	0.8	0.8	1483	7.3113	4	1.83
	Zalingei, Sudan	30	81.4	10	23.8	3.74	30	70	2428	62274.4	10	6227.4	0.8	0.8	2000	4.8651	4	1.22

The area of the solar collector in drying per boiled rice and sliced mangoes using solar dryer were carried out. From the analyses, the values of the solar collector for Kano, Nasarawa and Zaliingei are 3.1432 m^2, 2.5689 m^2 and 1.6971 m^2 respectively. The results of 3.1432 m^2 for determination of solar collector area for Kano is in agreement with the one calculated in the work carried out by Abubakar, and Isiyaku, (2014). Similarly, the area of 3.1432 m^2 for the solar collector for drying sliced mangoes in Zaliingei sudan was also in agreement with the work carried out by Akoy et al., (2019). From these results, the size of solar collector to dry per boiled rice of 30 kg, the area of Kano is the biggest out of the three towns under investigation, while that of Zalingei has the minimum solar collator area.

From the temperature point of view, the average yearly temperatures of these three locations were 28.13 ºC, 29.11 ºC and 28.00 ºC for Kano, Nasarawa and Zalingei respectively. This indicated that Nasarawa has the highest average annual temperature as recorded in (Weather and Climate, 2022). Despite the high temperatures in Nasarawa, its solar collector area is still very much larger than that of Zalingei.

Going further to the analyses to determine the area of solar collector to dry sliced mangoes, the results obtained from using the model also confirmed the initial is the order of the collector sizes in descending order of 8.923 m^2, 7.311 m^2 and 4.865 m^2 for kano, Nasarawa and Zalngei.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The model to determine the solar collector area or dimensions for Nasarawa was developed as shown. This model was tested with other locations using their respective solar radiation data and the obtained results were in agreement with their respective research. The result showed that Nasarawa has the highest annual mean temperature data compared to Kano and Zalingei Sudan, but instead of the size of the size of the

solar collector to be the lowest, it was not. This can be attributed to the fact that there is different between solar radiation and temperature of a particular location. Also, there are other climate factors that play great role in the solar radiation (Adesina, 2016).

So far so good, this model can comfortably be used in determining the size of solar collector for solar dryer in Nasarawa and other locations whose solar radiation data are available.

Recommendations

There is need to further carryout more research on solar radiation in more locations in order to be able to determine accurate results to design solar appliances

This work can be further expanded to develop a more comprehensive model(s) to accommodate determination of dimensions of other parts of the solar collector

Lastly, the model can be computer programmed based to make the use much easier

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