A PREDICTION MODEL OF ENERGY REQUIREMENTS FOR DRYING OF OKRA SLICES IN A HYBRID SOLAR-ELECTRIC DRYER

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ABSTRACT

A prediction model of energy requirements for drying of sliced okra samples in a hybrid solar-electric crop dryer is presented using the Buckingham's $\boldsymbol{\pi}$-theorem. The major important variables considered in developing the prediction model include: area of exposed surface, air velocity, batch size, slice thickness, drying air temperature, initial moisture content and drying time. Okra slices dried in a hybrid solar-electric dryer were used for the experimental validation of the model. The prediction equation was verified and validated by fitting it into experimental data obtained from the developed hybrid dryer. Results obtained show that the fitted model has strong correlation with the experimental data with coefficient of determination, R^2 of 0.9907. The difference between the predicted and experimental energy requirements was observed to have no statistical significant difference at 5% level of probability, hence the suitability of the model: $\boldsymbol{E_R = BV^2\left(\frac{18.293At}{S} + \frac{24.053M_o}{T_D} - 70.325\right)}$ in predicting the energy requirements for drying of okra slices in a hybrid convective solar crop dryer.

Keywords: *Mathematical model, energy requirements, okra slices, crop drying, dimensional analysis.*

1. INTRODUCTION

Okra (*Abelmoschus esculentus)* is a perishable and seasonal crop that is generally grown and widely eaten in Nigeria. It is characterized by being in good quality, rich in vitamins and minerals, high moisture (usually above 85% wet basis), dietary fibre, calcium, low saturated fats contents especially at harvest, excessive and cheap in its season and scarce, costly and in bad quality during out of season. As a result of its relatively high moisture content, its drying process is a highly energy intensive operation; and for this reason, considerable amount of energy is required to bring down the high moisture content to a safe storage level (usually between 5 and 15%) at a temperature range of 35 – 65^{o}C (Mu'azu *et al.*, 2012; Idah *et al.,* 2014) by vaporizing the water contained in the food matrix to the product surface, and then to the ambient air. The energy requirements for drying a freshly harvested vegetable crop has been found to differ owing to the type and specie of crop, initial moisture content at harvest, desired final moisture content, specific heat capacity of crop, latent heat of vaporization of water, intended use, gross mass, size, shape, and biological characteristics such as surface texture, crop porosity, nutritional content, drying times, production capacity, drying temperatures, efficiency of the drying equipment (Gunasekaran and Thompson, 1986; Raghavan *et al.,* 2005; Planters Energy Network, 2000; Billiris *et al.,* 2011; Nwakuba *et al.,* 2016a).

Drying is regarded as a highly energy-consuming process which has substantial effect on the dried product quality such as its nutritional values, colour, shrinkage and other organoleptic properties (Darvishi *et al.,* 2013). Therefore, the following are the major reasons for energy requirements for crop drying (Nwakuba *et al.,* 2016a): (i) estimation of the optimum quantity of temperature, air flow, and drying time most appropriate for a certain sliced crop so as to circumvent over drying which is consequent to undermining the nutritional value of the dried product; (ii) used in the design of proper cost effective drying system which would consume minimum amount of energy to transfer the required sensible and latent heat given the crop's physical and biological characteristics; (iii) for simulation of drying systems. Therefore, with increasing pressures to reduce environmental degradation, both from the public and governments, it is necessary to improve drying processes to reduce its high energy requirements and greenhouse gas (GHG) emissions, while still providing a high quality product with minimal increase in economic input. This, in all would reduce the cost of drying operation, enhance the crop shelflife, product diversity, substantial volume reduction, availability and acceptance of dried food products in the market at a reasonable price (Maskan, 2001; El-Mesery and Mwithiga, 2012). Interestingly, most research works are now tending towards modeling of variables that determine the functionality of processing machines (Ndukwu and Asoegwu, 2011). Most of these models are either crop specific or system/process specific. In modeling generally, the parameters have to be studied in order to provide better understanding of the fundamental relationships between the system and crop variables (Ikejiofor *et al.,* 2016). Dimensional analysis based on the Buckingham's π-theorem has been adopted in establishing prediction models of various systems and processes (Shefii *et al.,* 1996; Ndirika, 2005; Bolaji *et al.,* 2008; Ndukwu and Asoegwu, 2011; Ngwangwa *et al.,* 2014; Ndirika and Onwualu, 2016). From available literature, there has not been any model for predicting the energy requirements for drying of okra slices in any form of dryer. Therefore, this present study aims at establishing a prediction model of energy requirements for drying of sliced okra in a convective active hybrid solar-electric dryer.

2. MATERIALS AND METHODS

2.1 Description of Hybrid Solar Drying System

A convective hybrid solar-electric crop dryer was used in validating the prediction model as shown in Figure 1. It consists of two major integral components namely: the air heater units (solar collector and resistance wire) and the drying chamber having two layer of drying racks made of wire mesh on which the sliced crop samples are placed for drying. Other components of the dryer system include: solar panel (80 W, 12 V), DC battery (75 A, 12 V), control unit, liquid crystal display (LCD), inverter system, weighing balance, pyranometer (Apogee model) inlet and exhaust fans (4 W each), plain glass (4mm thick), temperature and relative humidity sensors (LM-35 transducers), weighing balances, weight sensors, resistance wire (1,500 W), frame support (angle iron), and rollers.

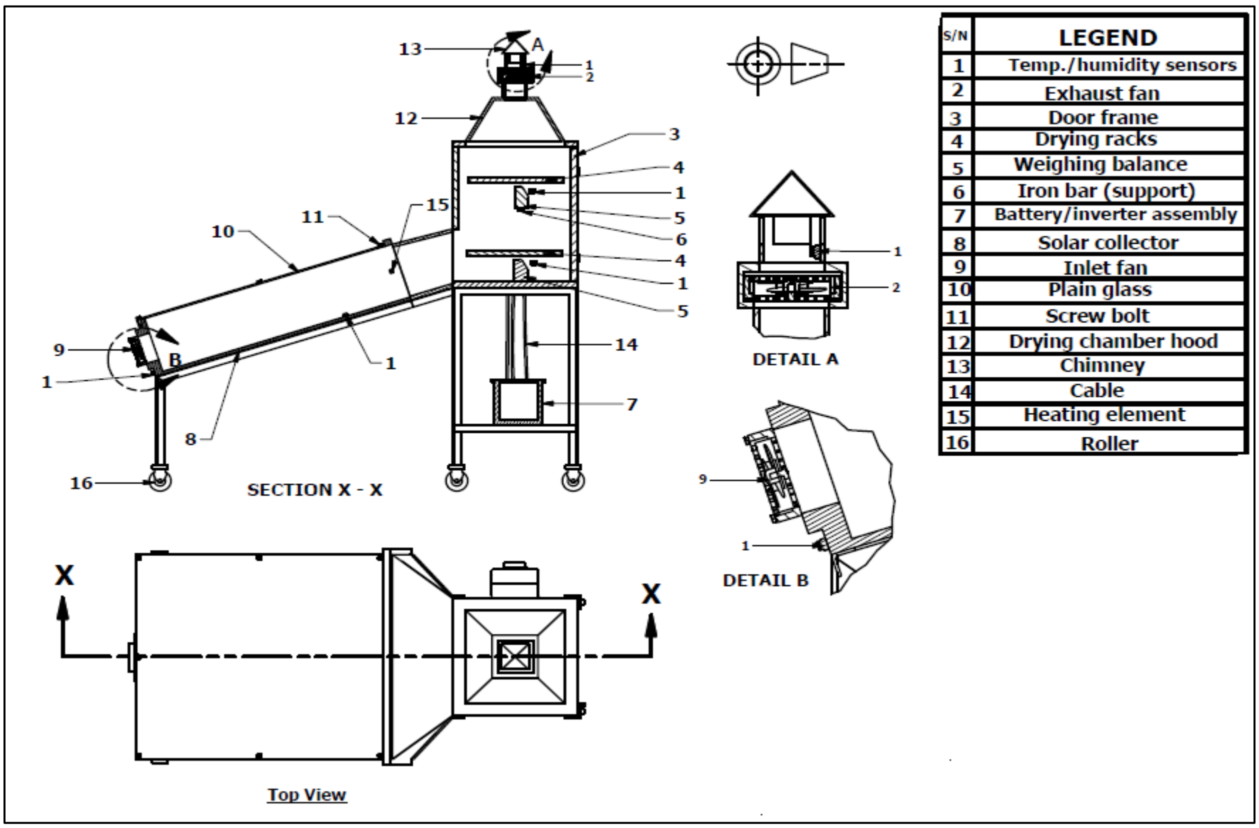

Figure 1. Sectional view of the hybrid convective solar-electric crop dryer.

The air heater unit (solar collector) is in the shape of a wooden box (0.7 m^2). The box was made with a special type of plywood (NBF laminated board) and was lagged with fiberglass. A mild steel plate was formed in the shape of an open box of approximately the same size as the solar box and inserted in the solar box to act as an absorber plate. The whole unit was painted dull black (inside and outside) to enhance absorptivity of solar radiation. A-15 cm diameter circular hole is positioned in front of the solar collector with a suction fan to draw ambient air into the solar collector and subsequently into the drying chamber. A hood was formed at the outlet end of the collector to direct the incoming solar heated air into the drying chamber and also serves as the heating unit of the electric heat source: a 1,500 W resistance wire was mounted across both ends of the plenum perpendicular to the direction of flow of the incoming air. A plain glass of 4 mm thickness with the same cross-sectional area with the solar collector was used to place over the solar box. The glass therefore, served as a glazing material that allows radiation from the sun to pass through it before it is absorbed by the absorber plate. However, the heart of the hybrid dryer comprises an arduino microprocessor which controls the overall operation of the system and automates tasks such as air temperature and relative humidity control, sample weight loss, and electrical energy consumption (from AC and DC sources). The system also contains a main heating element powered by an alternating current (AC) from the Public Power Supply or an electricity generating set. Transducers (for recording both temperature and relative humidity), as shown in Figure 1 (Legend S/N. 1) are placed at five points on the hybrid dryer (chimney, two drying racks, solar collector and inlet fan), where measurements are taken automatically by the microprocessor unit and displayed on the LCD. Different drying temperatures and air flow velocities can be selected using a 4 x 4 matrix keypad panel and LCD for displaying the current state of the system. In the drying chamber, the drying racks are rigidly suspended on a weighing balance that records the sample weight loss through the use of a weight sensor attached to it with the help of a flat iron bar. A-1,500 W resistance wire supplies electrical heat to the drying chamber at preset temperatures.

The control unit and its accessories as well as other instrumentations are powered by a 75 A, 12 V accumulator, which was simultaneously charged by an-80W solar panel; whereas the resistance wire (heater) was powered by a public power supply or an electric generator. The energy consumption from the accumulator and AC were measured and recorded by the control unit. When the control unit was connected to the computer through the use of a universal serial board (USB), a specialized software known as SCADA (Supervisory Control and Data Acquisition) was used to log the readings at 30 minutes interval and the results stored in a database for immediate or future analyses, thus the system is fully automated.

2.2 Theoretical/ Model Development

The energy requirements for drying of sliced vegetable crops was developed by dimensional analysis using the Buckingham's pi theorem. The following assumptions were made in the model development:

1. The drying process for each batch of dried samples took place under constant air conditions.
2. The process was solely a convective heat transfer.
3. There was no temperature gradient within the sliced samples; i.e., all slices were dried uniformly to a constant weight loss, and thermal diffusion was assumed negligible.
4. The samples were dried in thin layers and convective air passed axially through the sliced samples for uniform drying.
5. All evaporation took place on the surface of the slices.
6. There was a thermal equilibrium between the sample slices and the drying air.
7. The sample slices thermo-physical properties were constant during the drying process.
8. The entire drying process took place in the falling rate period.

Based on these assumptions, the major variables of importance are area of exposed surface/plate, air velocity, batch size, slice thickness, drying temperature, initial moisture content and drying time. The energy requirements which is the amount of energy required per kilogram of water evaporated from a drying product during the drying process can be expressed, according to (Okos *et al.,* 1992; Rizvi, 2005; Billiris *et al.,* 2011; Nwakuba *et al.,* 2016a) as:

$$E_R = f(A, V, B, t, S, M_O, T_D) \quad (1)$$

where,

E_R = Energy requirement (kWh); A = area of exposed surface (m^2); V = air velocity (ms^{-1}); B = batch size (kg); S = slice thickness (m); t = drying time (minutes); M_O = initial content (%); T_D = drying temperature (^oC).

Using the Mass (M), Length (L), and Time (T) system of dimension (Ndirika *et al*., 1996; Ndukwu and Asoegwu, 2011; Ndirika and Onwualu, 2016; Ikejiofor *et al.,* 2016), the dimensions of the identified variables and the dimensional matrix are presented in Tables 1 and 2, respectively. There are 8 number of variables, n and 3 number of fundamental units (M, L, T), m. Therefore, the number of dimensionless (π-terms) terms, n – m = 5. It follows that, $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5$ will be formed. From Table 2, parameters M_O and T_D are dimensionless and therefore excluded from the dimensionless terms determination and is added when other dimensionless terms are added (Simonyan *et al*., 2006; Ndukwu, and Asoegwu, 2011).

The required solution of Equation (1) is expressed in Equation (2) as:

$$\pi_1 = f(\pi_1, \pi_2, \pi_{3,} \pi_4, \pi_5) \quad (2)$$

Where: $\pi_1, \pi_2, \pi_{3,} \pi_4, \pi_5$ are pi-terms, respectively.

The dimensional equation of the E_R-variable can be expressed as:

$$f(E_R, A, V, B, S, t, M_O, T_D) = 0 \quad (3)$$

Table 1. Dimensions of variables influencing E_R.

Variable	Symbol	Unit	Dimension
Energy requirement	E_R	kWh	ML^2T^{-2}
Area	A	m^2	$M^0L^2T^0$
Air velocity	V	ms^{-1}	M^0LT^{-1}
Batch size	B	Kg	ML^0T^0
Slice thickness	S	m	M^0LT^0
Drying time	t	Sec.	M^0L^0T
Initial moisture content	M_O	%	$M^0L^0T^0$
Drying temperature	T_D	^oC	$M^0L^0T^0$

Table 2. Dimensional matrix of the variables.

Dimension	Parameter							
	E_R	A	V	B	S	t	M_O	T_D
M	1	0	0	1	0	0	0	0
L	2	2	1	0	1	0	0	0
T	-2	0	-1	0	0	1	0	0

However, the geometric, kinematic (time-dependent), and dynamic (mass-dependent) variables: S, V, B respectively are chosen as recurring set since their combinations cannot form a dimensionless group but the units of [M], [L] and [T]. The dimensions of these variables are given in Equation (4) – (6) as expressed by (Simonyan *et al.,* 2010; Nwakuba *et al.,* 2017):

$$S = L \quad (4)$$

$$V = \frac{L}{T} \text{ or } LT^{-1} \quad (5)$$

$$B = M \quad (6)$$

Rewriting the dimensions in terms of the chosen variables yields Equations. (7) – (9):

$$[L] = S \quad (7)$$

$$[T] = \frac{S}{V} \quad (8)$$

$$[M] = B \quad (9)$$

The dimensionless groups are formed by considering in turn each of the remaining E_R-variables in Equation (3): E_R, A, and t. using the Buckingham's π-theorem, $\pi_1, \pi_2, \pi_3\ \pi_4, \pi_5$, and π_6 were obtained as given in Equation (10) – (14):

$$\pi_1 = \frac{E_R}{BV^2} \quad (10)$$

$$\pi_2 = \frac{A}{S^2} \quad (11)$$

$$\pi_3 = \frac{t}{S} \quad (12)$$

$$\pi_4 = M_O \quad (13)$$

$$\pi_5 = T_D \quad (14)$$

Substituting Equations (10) – (14) into Eq. (3), yields Equation (15) as:

$$f\left(\frac{E_R}{BV^2};\ \frac{A}{S^2};\ \frac{t}{S};\ M_O;\ T_D\right) = 0 \quad (15)$$

Rearranging, Eq. (15) becomes:

$$\frac{E_R}{BV^2} = f\left[\frac{A}{S^2};\ \frac{t}{S}; M_O;\ T_D\right] \quad (16)$$

Combining the dimension terms in order to reduce them to a simpler lever (Shefii *et al.,* 1996; Ndukwu and Asoegwu, 2011; Nwakuba *et al.,* 2017) by multiplying and/or dividing Equation (14) yields Equations (15) and (16) as:

$$\pi_2\ x\ \pi_3{}^{-1} = \frac{At}{S} \quad (17)$$

$$\pi_4\ x\ \pi_5{}^{-1} = \frac{M_O}{T_D} \quad (18)$$

Therefore, $\pi_1 = f(\pi_{23}; \pi_{45})$ (19)

Substituting Equations (17) and (18) into Equation (20), yields:

$$\frac{E_R}{BV^2} = \pi_1 = f\left(\frac{At}{S}; \frac{M_O}{T_D}\right) \quad (20)$$

$$E_R = BV^2\left[\frac{At}{S}; \frac{M_O}{T_D}\right] \text{ Or } E_R = BV^2\left[\frac{AtM_O}{ST_D}\right] \quad (21)$$

Equation (21) is the developed prediction model of energy requirements for drying of sliced vegetable crops.

2.3 Prediction Model

The equation predicting the energy requirements for drying okra slices was developed by varying one π-term at a time and keeping others constant while observing the resultant changes in the function (Ndukwu and Asoegwu, 2011; Ngwangwa *et al.,* 2014; Ikejiofor *et al.,* 2016; Nwakuba *et al.,* 2017). This was done by plotting π_1-values against π_{23} at constant π_{45} and π_1-values against π_{45}, keeping π_{23} constant as shown in Figures 2 and 3. The linear function of dimensionless variables are presented in Equations (22) and (23) with coefficient of determination (R^2) = 0.9856 and 0.9915, respectively.

$$\pi_1 = 18.293\pi_{23} + 2.375 \quad [R^2 = 0.9856] \qquad (22)$$

$$\pi_1 = -24.053\pi_{45} + 72.7 \quad [R^2 = 0.9915] \qquad (23)$$

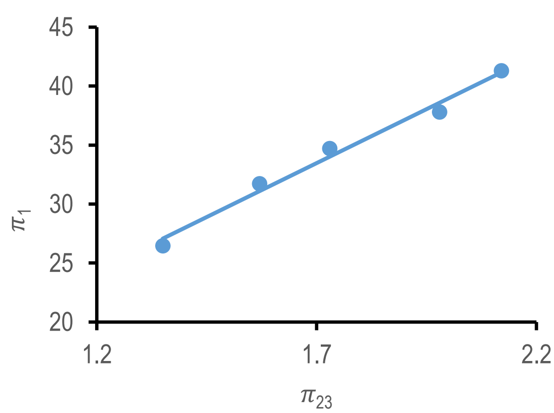

Figure 2. Plot of dimensionless π_1 against dimensionless π_{23} with π_{45} constant at average value of 1.736.

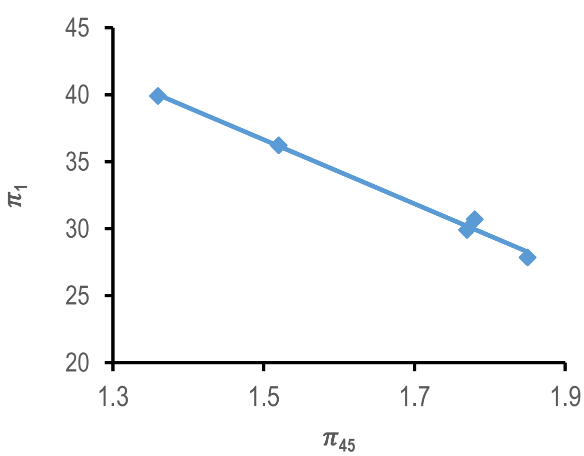

Figure 3. Plot of dimensionless π_1 against dimensionless π_{45} with π_{23} constant at average value of 1.841.

It implies that Equation (22) = Equation (23) = π_1. However, a component equation can be formed by combining Equations (22) and (23) either by summation or subtraction (Shefii *et al.,* 1996; Mohammed, 2002; Ndukwu and Asoegwu, 2011) to obtain Equation (24) as:

$$\frac{E_R}{BV^2} = \pi_1 = f_1(\pi_{23};\pi_{45}) \pm f_2(\pi_{45};\pi_{23}) + K \qquad (24)$$

(Where: K is constant)

At f_1, π_{23} varies at constant π_{45} (1.736), whereas at f_2, π_{45} was varied at constant (1.841)π_{23}.

Subtraction combination yields Equation (25):

$$\frac{E_R}{BV^2} = (18.293\pi_{23} + 2.375) - (-24.053\pi_{45} + 72.7) + K \qquad (25)$$

Rearranging,

$$E_R = [(18.293\pi_{23} + 24.053\pi_{45}) - 70.325]BV^2 \qquad (26)$$

Substituting the dimensionless terms of Equation (20) into Eq. (26) gives the general model (Equation 27) for energy requirements prediction using dimensional analysis:

$$E_R = \left[18.293\left(\frac{At}{S}\right) + 24.053\left(\frac{M_O}{T_D}\right) - 70.325\right]BV^2 \qquad (27)$$

2.3.1 Validation of model parameters

Area of exposed surface (A): The sample exposed surface area was obtained by assuming equal surface area with the drying rack, since the samples were spread in thin layers and their entire cross section covers the drying rack. The drying rack has a square dimension: 39 cm x 39 cm placed 15 cm apart in the drying chamber.

Air velocity (V): The control unit of the dryer system controls and measured the velocity of air through the use of a matrix keypad which inputs predetermined air velocities.

Batch size (B): The batch size was based on the available drying space and quantity of crop to be dried, size of the drying chamber, and amount of heat generated by the heating unit (Ohanwe *et al.,* 1996; Eke, 2014). A batch size of 1 kg was used based on the calculated amount of heat developed by the heating source.

Drying time (t): The time required to dry a given batch of crop sample from the initial moisture content to a final desired moisture level. This time varies with temperature, air velocity, sample thickness, crop type, initial and desired final moisture contents, biological characteristics and batch size (Nwakuba *et al.,* 2016a).

Sample/slice thickness (S): This refers to the sample thickness when cut in a direction perpendicular to the crop line of symmetry. The crop sample thicknesses considered were 10, 13, 15, 17, and 19 mm, obtained using a sharp stainless steel knife and a digital vernier caliper.

Moisture content (M_O): The validation of moisture content was done at five moisture levels. The initial moisture content was obtained by drying a representative slice sample in an oven set at 105°C for 24 hours as a percentage of the initial dried mass of the samples; and the difference between the initial dried mass and the regular time interval measured masses were used to calculate the percentage weight loss for each dried batch.

Drying temperature (T_D): Five different temperature levels were used for the validation. Each preset temperature was used and controlled by a micro-processor in such a way that when the drying chamber temperature exceeds the preset threshold by one degree, the system automatically shuts the heat source. The reverse occurred when the chamber temperature cools below the preset temperature threshold.

Energy requirements: The energy required for drying of crops is expressed mathematically as:

$\mathbf{E_R = AV\rho_a C_{pa} \Delta T Dt}$ (El-Mesery *et al.,* 2012; Darvishi *et al.,* 2013; Nwakuba *et al.,* 2016a) (28)

where,

E_R = energy required for each drying phase (kWh); A = sample plate area (m^2), V = air velocity ($m.s^{-1}$), ρ_a = air density ($kg.m^{-3}$), D_t = total drying time of each sample (h), ΔT = temperature difference between ambient and hot air (°C), and C_{pa} = specific heat of air ($kJ.kg^{-1}$°C).

2.4 Experimental Procedure

Fresh okra samples (*Nwaidu species*) were purchased from a local market in Owerri, Imo State, Nigeria and were sliced into various thicknesses (10, 13, 15, 17, and 19 mm), and placed on two drying racks of the dryer (0.5 kg per rack) amounting to batch size of 1 kg. Different air velocities (0.1, 0.5, 1.0, 1.5, and 2 ms^{-1}) and air temperatures (50, 55, 60, 65, and 70°C) were used for drying. The initial mass of the samples were weighed (for each rack) before placing into the drying chamber. Subsequent reduction in sample mass was measured at 30 minutes interval by a weight sensor attached to a weighing balance placed in the drying chamber. Each drying batch was stopped when there was no noticeable reduction in the mass of the drying samples. The amount of energy (electric and solar) consumed for each batch at various slice thicknesses, temperatures, air velocities and drying time were measured and recorded by the control system.

The mean amount of energy consumed by each batch which was measured by the arduino micro-processor when compared with the energy values obtained from Equation (29) was found to be less by an average of 9.78%. This difference could probably be as a result of the constant air density and air velocity used in the calculated values (Equation 29), whereas in the measured values, different air velocities were considered by the arduino platform and was considered negligible. The calculated energy values were used to calibrate the arduino system as well as validating the arduino-measured values. This was done in triplicates for each combination of experimental treatments: air velocity, slice thickness and temperature (A, S, T) and their average values were recorded and used for the analysis.

4. RESULTS AND DISCUSSION

4.1 Model Validation

The mathematical model in Equation (27) was validated using the data obtained from a hybrid solar-electric crop dryer (Figure 1). Five levels of air velocities, slice thicknesses and temperatures were used to validate the model at an approximately constant initial moisture content, exposed surface area, and batch size as well as other evaluation parameters presented in Table 3. Minitab version 17 and Microsoft Excel 2013 statistical packages for Windows 7 operating system were used for the statistical analyses based on general linear model (GLM). The mean predicted and measured energy requirement values obtained from the subtraction combination approach are presented in Table 4 with standard deviations of 7.99 and 8.55, respectively.

Table 3. Evaluation Parameters

Parameter	Value					Standard deviation
Area (cm^2)	812.25	812.25	812.25	812.25	812.25	-
Air velocity (ms^{-1})	0.1	0.5	1.0	1.5	2.0	0.76
Batch size (kg)	1.0	1.0	1.0	1.0	1.0	-
Slice thickness (mm)	10	13	15	17	20	3.49
Drying time (mins.)	210	180	120	90	60	62.21
Initial moisture content (%w.b)	87.83	87.83	87.83	87.83	87.83	-
Drying temperature (^oC)	50	55	60	65	70	7.91

Figure 4 illustrates that the measured and the predicted energy values have a very high correlation coefficient (R^2 = 0.9907) with a standard error of 0.11 between the measured and the predicted value which is less than 1% (0.261) of the average value of the measured energy requirements and with standard deviation of 7.99 and 8.55 for predicted and measured energy requirement values, respectively. The closeness of the plotted data to the straight line and the associated high coefficient of determination (R^2 = 0.9907) which is close to unity indicate that the values of energy requirement parameters strongly correlated with the energy model parameters, which in turn illustrates the suitability of the model in predicting the energy requirements for drying of sliced vegetables in a hybrid solar-electric dryer to a constant weight level. The significance levels for the coefficient of determination, R^2 at 1% and 5% between the modeled (predicted) and the experimental (measured) were significant when compared using the least significant method (LSD). Table of 't' values was used and no statistical difference was observed since the calculated 't' (0.784) was less than the tabulated 't' (1.879) (Obi, 2002).

Table 4. Experimental and Measured values of Mean Energy Requirements

Slice thickness (mm)	Mean energy requirements, E_R (kWh)	
	Measured (E_{Rmea})	Predicted (E_{Rpre})
10	13.48	11.89
13	19.84	17.87
15	27.02	26.3
17	36.40	33.4
19	33.88	30.44
Standard deviation	8.55	7.99

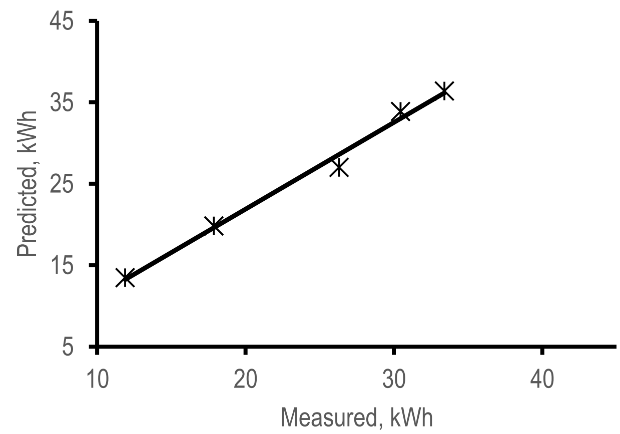

Figure 4. Plot of mean measured and predicted energy requirements at various slice thicknesses, air velocities, and temperatures.

The result revealed a higher correlation of the model with data from the developed hybrid solar-electric dryer. The least square method (LSD) was used to obtain Equation (30), which described the linear regression of the predicted and experimental energy requirements as:

$$E_{Rpre} = 1.0654E_{Rmea} + 0.5751 \quad [R^2 = 0.9907] \qquad (30)$$

where,

E_{Rpre} and E_{Rmea} = Predicted energy requirements (kWh) and measured energy requirements (kWh), respectively.

The validity of the predicting model was also examined by testing the intercept and slope of Equation (30). They were found to be statistically significantly different from 0 and 1.0, respectively in the ratio of 1:1 model equation (Simonyan *et al.,* 2010; Ndukwu and Asoegwu, 2011). The slope of the line was found to be insignificant at 5% level of probability. From Table 4, the developed prediction model under-predicted the energy requirements at all levels of slice thickness air velocity, and air temperature by an average of 10.2%. This might be as a result of changes in hourly solar radiation, difference in the maturity age of the sliced okra samples which affected its capillary transport, as well as the marginal error from the programmable weight sensor and the entire control unit. It was observed that the difference between the measured and predicted values energy requirements were below 20% which implies a good model.

5. CONCLUSION

Dimensional analysis based on the Buckingham's π-theorem was used in presenting a prediction model of the energy requirements for drying of okra slices in an active hybrid convective crop dryer which include variables such as the area of exposed surface, air velocity, batch size, slice thickness, drying time, initial moisture content, and drying time. The model equation expressed as $E_R = BV^2\left(\frac{18.293At}{S} + \frac{24.053M_o}{T_D} - 70.325\right)$ was validated with measured and predicted energy values of the developed hybrid solar dryer with high correlation coefficient (R^2 = 0.9907) and a standard error of 0.11 between the measured and the predicted value which is less than 1% of the average value of the measured which indicates good agreement. The difference between the predicted and measured E_R was insignificant at 5% level of probability. The prediction model fitted in very well with the experimental (measured) results from the developed hybrid dryer. The significance of the developed prediction model is that the energy required to dry any sliced fruit vegetables from its initial moisture level to any desired final moisture level can be predicted. This is however, important in design calculations of agricultural dryers (such as in calculating the total and specific energy consumptions for crop drying) in order to ensure optimal dryer design and cost effective dryer operation which yields better quality dried products (Nwakuba *et al*., 2016b).

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