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MATHEMATICAL MODELLING OF DERIVED ENERGY CONTENT FROM MOISTURE CONTENT OF PALM KERNEL TREE

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ABSTRACT: *It is important to model out the optimization of energy process of palm kernel tree so as to evaluate the optimal values of the energy content parameters which will determines the performance and the useful lifespan of the palm kernel tree. This present study aims to develop models to investigate the effect of moisture content on the energy content of palm kernel tree that are 10 years and 20 years old using regression technique. In order to check the adequacy of the regression model, analysis of variance (ANOVA) was used. The experimental results are based on adequate laboratory methodology to increase the reliability of the experiments. It was clear from the ANOVA that the regression model is capable to predict the energy content with high accuracy.*

KEYWORDS: Energy content, Moisture content, Palm kernel tree, ANOVA, Regression

INTRODUCTION

Maximizing energy recovery from the waste of palm kernel trees is desirable for both the environmental and economic reasons [1]. Research study has showed that biomass has attracted increasing interest in recent years as an alternative feedstock for production of energy, chemicals and other bio-based products in the form of electricity and heat [2]. In Nigeria, oil palm is an important tree because of the value of the crude palm oil, fronds, stems and leaves [3]. The palm tree plantation produces huge quantity of palm wastes such as oil palm frond, palm kernel shell, empty fruit bunch, palm trunk and mesocarp fibres [4-5]. In general, oil forms about 10% of the whole palm oil trees while the other 90% remains as biomass [6]. It has been found that these wastes can be reintegrated to contribute in solving the energy problem in Nigeria [7]. Palm oil wastes are considered as a great potential to become alternative source of renewable energy [6]. Thus, it is important to model out the optimization of energy process so as to evaluate the optimal values of energy content parameters to determine the performance and useful lifespan of palm kernel trees. Luangwilai et al. [8] modelled the effects of moisture content in compost piles using one and tow dimensional spatially dependent models and incorporating terms that accounted for self-heating due to both biological and oxidative mechanisms. Analyses were undertaken for different initial water contents within the compost pile. The experimental investigation showed that when the water content is too low, the reaction is almost negligible whereas, for the case when the water content is too high, the reaction only commences when the water content evaporates and the water ratio drops into an appropriate range. The result also showed that for an intermediate water content range, biological reaction is at its optimum and there is a possibility of spontaneous combustion of the compost pile. Mariem and Mabrouk [9] conducted a study on convective drying kinetics of tomato slices in order to identify the characteristic parameters of such high moisture content product and to establish mathematical models of the drying kinetic for various range of temperatures typically encountered in industrial dryers. The results revealed that to reach a final moisture content of 11% at 38^0C, 44^0C, 50^0C, 57^0C and 64^0C, the drying time for 1m/s respectively, was 22.4h, 18.5h, 16.7h, 13.5h and 9.9h. Chayjan and Esna-Ashari [10] employed artificial neural networks (ANN) and four empirical mathematical models (Henderson, GAB, Halsey and Oswin) for the estimation of equilibrium moisture content (EMC) of dried grape (black currant). The results showed that the EMC of the grape were more accurately predicted by ANN models than by the empirical models. Yan et al., [11] carried out a mathematical modelling of the kinetic of quality deterioration of intermediate moisture content (IMC) banana during storage. The moisture content of the investigated samples was monitored over time. The experimental results showed that IMC banana absorbed moisture faster when stored at high temperature and at high relative humidity, at the beginning of storage. The result also showed that the water activity of IMC banana during storage was found to follow an exponential increase, which was described by the lumped capacity model. Sridhar and Madhu [12] experimentally investigated on Casuarina wood chips of dimension 5.08 cm x 5.08 cm with 2.54 cm thickness between 80^0C to 100^0C in a tray drier using air flow velocity of 0.5 m/s. Eleven thin-layer drying kinetic models were fitted with the experimental drying kinetics values and individual model constants. The models were compared using statistical measures to estimate the best model that would fit for the experiment. The investigated showed that logarithmic, modified Henderson and Pabis models predicted the drying rate in a best manner among the models used in the temperature range 80^0C to 100^0C. Sagia and Fragkou [13] presented an experimental data from several studies about drying behaviour of various species of mushroom which were selected and used to compare different drying methods and different mathematical thin layer drying models to stimulate mushroom drying rate for drying air temperatures (45^0C to 90^0C) and drying air velocities (0.2m/s to 5m/s). The study showed that the drying air temperature and the drying air velocity have an effect on the moisture removal from mushrooms and also on the drying time. Mathematical models in the study have also been proved to be useful for design and analysis of heat and mass transfer during drying processes. Meisami-asi et al. [14] experimentally investigated the moisture content of thin layer drying kinetics of apple slices in a convective dryer and the mathematical modelling was performed by using thin layer drying models in the literature. Drying characteristics of apple slices were determined using heated ambient air at temperatures between 40^0C and 80^0C, velocities at 0.5 m/s and thickness of thin layer 2, 4, 6 mm. The results showed that increasing drying air temperature resulted to shorter drying times. Among the investigated models, the Midilli model was found to be the best model for describing the drying curves of apples. Baronas et al. [15] modelled moisture movement in wood for two-dimensional in space formulation. The finite-difference technique was adopted in the study so as to obtain the solution of the problem. The model was applied to predict the moisture content in sawn boards from pine during long term storage under outdoor climatic conditions. The investigation result showed satisfactory agreement between the numerical solution and experimental data obtained. Triwahyudi et al. [16] investigated the effect of temperature and relative humidity on the equilibrium moisture content (EMC) of local cardamom and also suggested appropriate mathematical models using dynamic method for a laboratory air dryer at temperature of 40^0C to 60^0C and at relative humidity of 20% to 60%. The accuracy of the model (modified Henerson, modified Chung-Pfost, modified Oswin and modified Halsey) was evaluated by comparing the value of the coefficient of determination (R^2) and the value of the root mean square error (RMSE) between the experimental and the predicted value of EMC by using nonlinear regression analysis. The investigation showed that the modified Chung-Pfost equation has the ability to properly described EMC of local cardamom on a selected range of temperature and relative humidity.

Saad et al. [17] determined and modelled desorption and adsorption equilibrium moisture isotherms of Ziziphus leaves using gravimetric-static method at 300C, 400C and 500C for water activity ranging from 0.057 to 0.898. At a given water activity, the results showed that the moisture content decreases with increasing temperature. After evaluating the models (GAB, BET, Henderson-Thompson, modified-Chung Pfost, Halsey, Oswin, Peleg, and Adam and Shove) according to several criteria, the Peleg and Oswin models were found to be the most suitable for describing the sorption curves.

Although, several studies have been investigated and experimented on palm kernel tree to develop models for energy content but no mathematical model investigations are devoted to moisture content. The intention of the present work is to develop an energy content predictive model and to investigate the influence of moisture content on the energy content of palm kernel tree for 10 years and 20 years respectively using regression method.

Experimentation

In this study, palm trees which were completely uprooted and cut into the following samples namely, palm root, palm kernel shell, stem 1 (lower layer), stem 2 (upper layer), oil palm bunch, palm kernel and chaff were used. The samples were sun dried, pulverized, sieved and stored in respective sample labelled container. Moisture content analyses were carried out on the samples with the aid of petridish, spatula, beam balance, muffle furnace, desiccator and stop watch. The mass of the petridish were determined with the aid of a digital beam balance and recorded as w_1. The determination of the moisture content was carried out by adding 1.00g each of the powered sample of the palm tree of 20μm to the petridish and the mass was noted and recorded as w_2. The petridish containing the sample was heated in a muffle at 105^{0}C for three hours and thereafter taken out, then allowed to cool at room temperature and weigh again which was recorded as w_3. The loss in mass represents moisture. The percentage moisture content (MC) was calculated using the relation in Eq. (1) [18] as shown on Table 1 and Table 2:

$$\%MC = \frac{w_2 - w_3}{w_2 - w_1} \times 100\% \qquad (1)$$

where:

w_1 is the mass of the petridish in grams;

w_2 is the mass of the petridish with the sample in grams; and

w_3 is the mass of the petridish with the sample after being heated in the oven in grams.

Table 1: Percentage of moisture for palm tree of age 10 years

S/N	Sample(s)	Mass of Petridish (w_1) (g)	Mass of Petridish + Sample Mass (w_2) (g)	Sample Mass (w_2 - w_1) (g)	Mass of heated sample with crucible (w_3) (g)	% Moisture Content (% MC)
1	Palm Root	31.5428	32.5428	1.0000	32.4326	11.02
		31.5428	32.5428	1.0000	32.4328	11.00
2	Palm Kernel Shell	30.4345	31.4345	1.0000	31.3517	8.28
		30.4345	31.4345	1.0000	31.3515	8.30
3	Stem1 (Lower Layer)	31.542	32.542	1.0000	32.3962	14.58
		31.542	32.542	1.0000	32.396	14.60
4	Palm Frond	31.543	32.543	1.0000	32.4501	9.29
		31.543	32.543	1.0000	32.4500	9.30
5	Stem 2 (Upper Layer)	30.5425	31.5425	1.0000	31.3967	14.58
		30.5425	31.5425	1.0000	31.3968	14.57
6	Oil Palm Bunch	30.525	31.525	1.0000	31.4096	11.54
		30.525	31.525	1.0000	31.4096	11.54
7	Palm Kernel	31.0025	32.0025	1.0000	31.9365	6.60
		31.0025	32.0025	1.0000	31.9364	6.61
8	Chaff	30.2545	31.2545	1.0000	31.163	9.15
		30.2545	31.2545	1.0000	31.1628	9.17

Table 2: Percentage of moisture for palm tree of age 20 years

S/N	Sample(s)	Mass of Petridish (w_1) (g)	Mass of Petridish + Sample Mass (w_2) (g)	Sample Mass (w_2 - w_1) (g)	Mass of heated sample with crucible (w_3) (g)	% Moisture Content (% MC)
1	Palm Root	31.5428	32.5428	1.0000	32.4327	11.01
		31.5428	32.5428	1.0000	32.4326	11.02
2	Palm Kernel Shell	30.4345	31.4345	1.0000	31.3515	8.30
		30.4345	31.4345	1.0000	31.3516	8.29
3	Stem1 (Lower Layer)	31.542	32.542	1.0000	32.3961	14.59
		31.542	32.542	1.0000	32.396	14.60
4	Palm Frond	31.543	32.543	1.0000	32.45	9.30
		31.543	32.543	1.0000	32.4498	9.32
5	Stem 2	30.5425	31.5425	1.0000	31.3964	14.61

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	(Upper Layer)	30.5425	31.5425	1.0000	31.3965	14.60
6	Oil Palm Bunch	30.525	31.525	1.0000	31.4097	11.53
		30.525	31.525	1.0000	31.4095	11.55
7	Palm Kernel	31.0025	32.0025	1.0000	31.9363	6.62
		31.0025	32.0025	1.0000	31.9362	6.63
8	Chaff	30.2545	31.2545	1.0000	31.1629	9.16
		30.2545	31.2545	1.0000	31.1629	9.16

The heating value analysis of the palm kernel samples were also carried out with the aid of bomb calorimeter (CAL 2K-ECO) which consists of filling station (CAL K-3) and vessel/bomb (CAL 2K-4), crucible, full oxygen cylinder, desiccators, silica gel, beam balance, soft cloth, spatula, PC keyboard, cotton thread, firing wire, crucible holder, lid assembly and benzoic acid standard. The crucible used was washed with clean water and dried in a desiccators containing silica gel as the drying agent. The crucible was weighed in a digital beam balance and the mass was tarred to zero. The various samples was well mixed and 0.50g each of it was weighed into the dry crucible with the aid of beam balance; the sample ID and the mass was entered via PC keyboard prior to the energy determination. The lid assembly was inserted into the vessel body and the cap of the vessel was screwed down until it touches the top of the lid. The vessel was placed into the vessel holder under the filling station and was kept upright and filled with oxygen to a pressure of 3000 kPa and the various samples was automatically fired while the result was displayed on the screen of the bomb calorimeter and recorded as shown on Table 3 and Table 4.

Table 3: Energy content of palm tree of age 10 years

S/N	Sample(s)	Energy (kCal/100g) (1)	Energy (kCal/100 g) (2)	Average Energy (kCal/100g) (1+2)/2	Energy (kCal/kg)	Energy (kJ/kg)
1	Palm Root	412.1	410.3	411.2	4112	17216.94
2	Palm Kernel Shell	453.2	451.5	452.35	4523.5	18939.89
3	Stem 1 (Lower Layer)	380.6	381.4	381	3810	15952.47
4	Palm Frond	418	418.2	418.1	4181	17505.85
5	Stem 2 (Upper Layer)	363.2	359.6	361.4	3614	15131.82
6	Oil Palm Bunch	391.8	389.7	390.75	3907.5	16360.70
7	Palm Kernel	616.8	618.6	617.7	6177	25863.10
8	Chaff	439.3	437.9	438.6	4386	18364.18

Table 4: Energy content of palm tree of age 20 years

S/N	Sample(s)	Energy (kCal/100g) (1)	Energy (kCal/100g) (2)	Average Energy (kCal/100g) (1+2)/2	Energy (kCal/kg)	Energy (kJ/kg)
1	Palm Root	412.2	411.4	411.8	4118	17242.07
2	Palm Kernel Shell	452.5	451.4	451.95	4519.5	18923.15
3	Stem 1 (Lower Layer)	380.8	381.6	381.2	3812	15960.84
4	Palm Frond	418.2	418.4	418.3	4183	17514.22
5	Stem 2 (Upper Layer)	363.2	361	362.1	3621	15161.13
6	Oil Palm Bunch	391.2	390.1	390.65	3906.5	16356.52
7	Palm Kernel	617.4	617.6	617.5	6175	25854.73
8	Chaff	440	438.2	439.1	4391	18385.12

RESULTS AND DISCUSSION

Regression model

The model of predicted energy content, E_c , against the average percentage moisture content, MC_A, can be expressed as Eq. (1).

$$E_c = \alpha + \beta MC_A \quad (2)$$

where α and β are model parameters.

By considering the energy content of the palm tree samples for 10 years and 20 years, Eq. (2) can be written as:

$$E_{c10years} = \alpha_0 + \beta_1 MC_{A10years} \quad (3)$$

$$E_{c20years} = \alpha_1 + \beta_2 MC_{A20years} \quad (4)$$

The model parameters in Eq. (3) and Eq. (4) were evaluated by using ordinary least square technique.

Table 5: Average moisture content percentage for palm tree of age 10 years

Sample(s)	Palm Root	PKS	Stem 1	Palm Frond	Stem 2	OPB	PK	Chaff
Average % MC	11.01	8.29	14.59	9.29	14.57	11.54	6.61	9.16

Table 6: Average moisture content percentage for palm tree of age 20 years

Sample(s)	Palm Root	PKS	Stem 1	Palm Frond	Stem 2	OPB	PK	Chaff
Average % MC	11.02	8.30	14.60	9.31	14.61	11.54	6.63	9.16

The data presented in Table 3, Table 4, Table 5 and Table 6 was used for developing the regression models. Accordingly, Eq. (5) and Eq. (6) was obtained for estimating the energy content in kJ/kg.

$$E_{c10years} = 28268.122 - 950.036MC_{A10years} \quad (5)$$

$$E_{c20years} = 28231.081 - 944.592MC_{A20years} \quad (6)$$

Table 7: ANOVA analysis of palm tree of age 10 years

Source of variation	SS	df	MS	F	Sig.
Regression	52141468.51	1	52141468.51	11.83	0.01
Residual	26443639.24	6	4407273.20		
Total	78585107.75	7			

Table 8: ANOVA analysis of palm tree of age 20 years

Source of variation	SS	df	MS	F	Sig.
Regression	51671801.56	1	51671801.56	11.69	0.01
Residual	26510104.52	6	4418350.75		
Total	78181906.08	7			

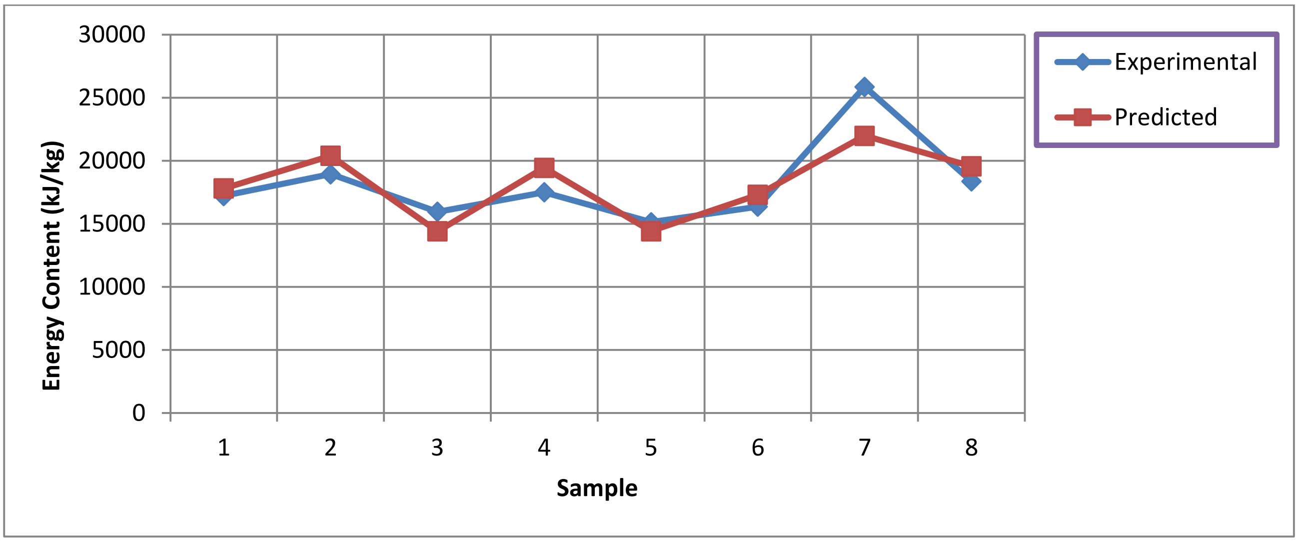

Fig. 1: Comparison of experimental and predicted values of energy content of palm tree of age 10 years by regression model

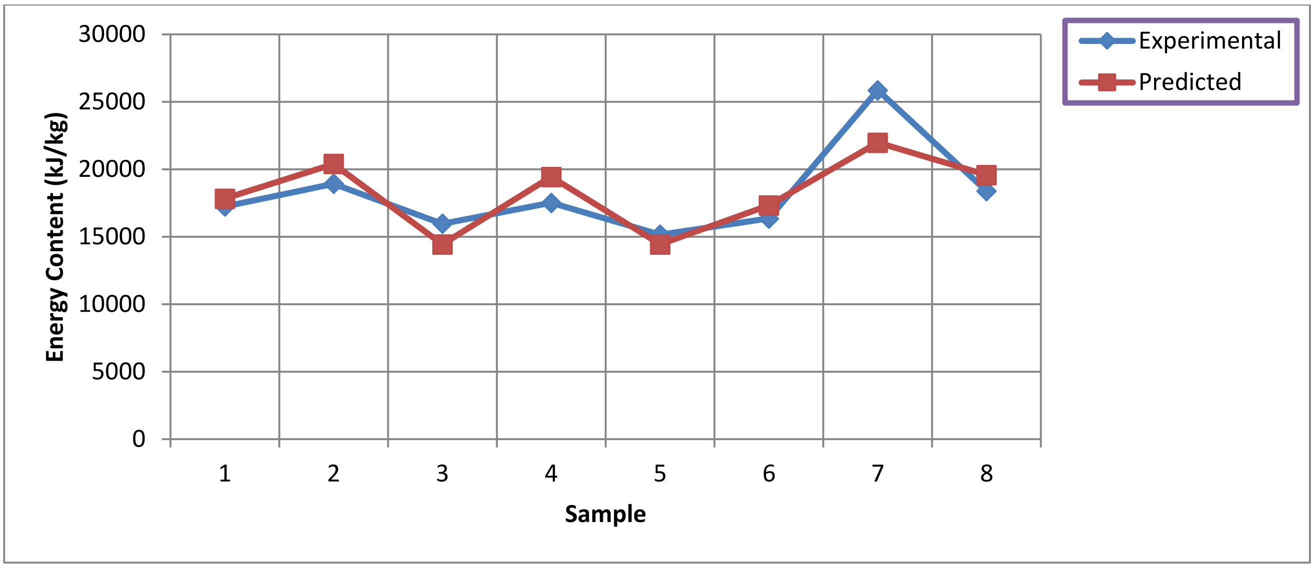

Fig. 2: Comparison of experimental and predicted values of energy content of palm tree of age 20 years by regression model

In order to determine the influence of the moisture content on the energy content, ANOVA was employed. The results of the ANOVA are presented in Table 7 and Table 8. Based on the F-ratio of the predictive models and that of the experimental results, the model was found to be adequate and sufficient. The experimental and predicted values of the regression models are depicted in Fig. 1 and Fig. 2. It is obvious from Fig.1 and Fig. 2 that there is a close agreement between the experimental values and that of the predicted values.

CONCLUSIONS

In this paper, a predictive mathematical model for determining the energy contents was developed for moisture content of palm tree of 10 years and 20 years respectively and the following conclusions were drawn from this experimental investigation:

(i) The energy content increases with decrease in the moisture content;

(ii) The energy content was found to be largely influenced by the samples with the lowest moisture content; and

(iii) On the basis of statistical parameters, it was concluded that the ANOVA results confirm that the regression models is adequate and is capable to predict the energy content.

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