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PROCESS MODELS FOR ESTIMATING FILTRATION PERIOD AND AMOUNT OF TOMATO CONCENTRATE OBTAINED FROM MINIMALLY PROCESSING METHOD USING A SIMPLE FILTRATION UNIT

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Abstract: In order to easily estimate the desired quantities of food products based on some quantities of the raw materials used, and for proper development of efficient food and crop fluid filtration system, a process model is required. In this study, fresh tomatoes (*Solanum lycopersicum*) (3.50 kg) were bought and cleaned. They were blended and 30.0 g of the slurry used in determining the initial moisture content. Exactly 0.1, 0.2, 0.3, 0.4 and 0.5 kg slurry were filtered in batches using simple fabricated filtration device in duplicates. The amounts of the concentrate, filtrate and filtration period were noted. Their mean and standard deviation were calculated. The results showed the initial moisture content of the fresh tomato / slurry and concentrate were 93.5 and 73.3%, respectively, while their corresponding mass fractions of total solids were 0.065 and 0.267. Filtrate flow rate was 0.029 litres /min .The process models were developed, verified and validated. Technical analysis revealed that the values of coefficient of determination (R^2) were nearly equals correlation coefficient (r ≈ 1), and were greater than that of reduced Chi–square (χ_c^2), root mean square error (RMSE) and mean bias error (MBE). The values of coefficient of residual mass (CRM) and modelling efficiency (EF) were practically perfect. Thus, the developed process models are basically good for estimating the filtration period and amount of tomato concentrate obtained from minimally processing method using a simple filtration unit.
Keywords: Process models, Estimating, Tomato slurry, Concentrate, Simple filtration unit

1. INTRODUCTION

Efficient food and crop processing unit operations depend on a number of factors. Techniques and equipment employed are some of aspects that are likely to determine the quality and quantity of the final product. A product is expected to pass through processing machine or unit operation. A badly designed process and processing vessel /equipment may contribute to the product wastage. Hence, a well–developed process model would enhance product integrity. However, process model is a type of model that relates process control and product movement in a system. A process can be denoted by equipment, unit operation, and so on. The amounts, in terms of mass, volume, fractions, flow rate, etc. of several input and output parameters in a system must be identified. Generally, process model creates room for system, process or equipment efficiency and total engineering design performance improvement, before fabrication. It promotes rapid and simple evaluation of various options that could give a desired solution. It evades wastage in the design and testing of results (Assian *et al.,* 2021a & 2021b). Many works have been conducted by researchers relating the establishment of several models which could be used in food and crop processing / process optimization as well as machine development (Alonge and Oje, 2003; Ndukwu and Asoegwu, 2011; Alonge and Onwude, 2013; Antia and Assian, 2018a & 2018b; Antia *et al.,* 2019a, 2019b and 2019c; Assian *et al.,* 2021a; Antia *et al.,* 2021). In this study, fresh tomatoes were locally processed to its concentrate using simple fabricated filtration unit. However, the main objective of this study was to establish process models for estimating the period of filtration and amount of tomato concentrate got from minimally processing method using a simple filtration unit. The revelation from this study and the developed process models could be vital in the design of a large scale filtration system for various food and crop fluid mixtures.

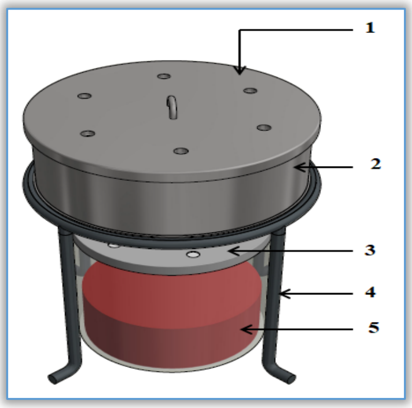

Figure 1: Simple filtration device: 1– Cover, 2–Hopper, 3– Filtrate lid, 4– Frame, and 5–Transparent container

2. MATERIALS AND METHODS

— Procedure

About 3.50 kg of tomatoes (*Solanum lycopersicum)* were bought from Akpan Andem Market, Uyo, Akwa Ibom State, Nigeria. They were selected at random, washed with distilled water to eliminate extraneous materials, and mopped with clean cloth to remove the surface moisture. Wounded or perishable samples were removed and the good ones stored in clean containers. The samples were weighed using digital weighing balance. The bulk samples (3.05 kg) were blended using an electric blender. Precisely 30.0 g of the slurry was used in determining the initial moisture content of the bulk samples by oven dry method as described by ASABE

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(2010), Assian and Alonge (2021), Antia *et al.* (2014) using Equation 1. Exactly 0.1 kg of the slurry was measured out for filtration using the simple fabricated filtration device at room temperature (Figure 1). The amount of tomato concentrate and filtrate obtained, and period of filtration were noted using digital weighing balance, measuring cylinder and stop watch, respectively. The procedure was repeated with 0.2, 0.3, 0.4 and 0.5 kg tomato slurry in batches due to the capacity of the filtration device. However, the experiment was done in duplicates. The mean and standard deviation of each parameter were calculated using Data Acquisition Template powered by Microsoft Excel ™.

— Moisture Content and Filtration Rate Determination

The sample moisture content in percent wet basis ($\% M_{wb}$) was determined using Equation 1.

$$\% MC_{wb} = \frac{M_i - M_{bd}}{M_i} \times 100\% \quad (1)$$

The rate of filtration was calculated using Equation 2.

$$\text{Rate of filtration} = \frac{\text{Volume of filtration}}{\text{Filtration duration}} \quad (2)$$

where, M_i = initial mass of the sample (g) and M_{bd} = sample mass at bone dry condition (g).

— Data Analysis

▪ Model Formulation for Filtration Process

The schematic representation of filtration process is shown in Figure 2, where, M_{feed} = mass of the feed (bulk tomato samples) [kg], Q = mass of a part of slurry taken for moisture content determination [kg]; S and C are masses of slurry and concentrate [kg], respectively; f = amount of filtrate [kg or litres]; X_w and X_s are mass fractions of water (moisture content) and total solids, respectively; while X_{ws} and X_{ss}, X_{wc} and X_{sc}, and X_{wf} and X_{sf} denote that of slurry, concentrate and filtrate respectively.

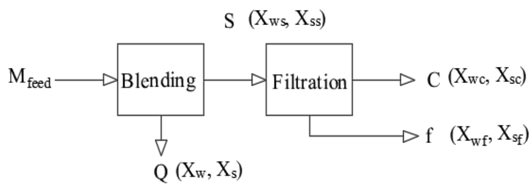

Figure 2: Filtration flow process

Note:

$$X_w + X_s = 1.0 \quad (3)$$

For general materials balance in terms of mass:

$$\text{Input} = \text{output} + \text{accumulation} + \text{generation} \quad (4)$$

Assumed that accumulation and generation are equal to zero, then, from Figure 2, we have,

$$M_{feed} = Q + S \quad (5)$$

$$S = C + f \quad (6)$$

For mass fractions of individual components:

From Equation 5, we have

$$S.X_{ws} = C.X_{wc} + f.X_{wf} \quad (7)$$

$$S.X_{ss} = C.X_{sc} + f.X_{sf} \quad (8)$$

But X_{sf} is equal zero

From Equation 8, we have,

$$C = S.\frac{X_{ss}}{X_{sc}} \quad (9)$$

However, the period of filtration (*t*) and tomato concentrate produced (C) may depend on a number of factors such as atmospheric pressure (P_{atm}), filtering material (m_{filter}), surface area of filtering material (S_{filter}), amount of slurry introduced into the system (S) and so on. Let assumed that P_{atm}, m_{filter} and S_{filter} are constant. Then, mathematically, we have,

$$t = f(S) \quad (10)$$

Similarly,

$$C = f\left(S.\left(\frac{X_{ss}}{X_{sc}}\right)\right) \quad (11)$$

where f is a kind of relationship existing among the parameters. Introducing proportionality constants in Equations 10 and 11, we have,

$$t = k_1 S^{n_1} \quad (12)$$

$$C = k_2 S^{n_2}.\frac{X_{ss}}{X_{sc}} \quad (13)$$

where, k_1 and k_2 are arbitrary constants; n_1 and n_2 are indices that describe that best possible relationship. Hence, Equations 12 and 13 become the suggested process models.

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Model Development

The observed data were inputted into the suggested model Equations 12 and 13 using Non–Linear Regression Statistics implanted in Statistical Package for Social Scientists (SPSS) Version 20. The model constants and indices were found.

Model Verification and Validation

The experiment was repeated, and the models verified and validated using statistical computations and analyses namely: coefficients of determination (R^2) and correlation (r); dispersed plots of observed and predicted values, reduced Chi–square (χ_c^2), mean bias error (MBE), root mean square error (RMSE), coefficient of residual mass (CRM) and modelling efficiency (EF) (Assian *et al.,* 2021a and 2021b).

≡ Reduced Chi–square (χ_c^2)

$$(\chi_c^2) = \frac{\sum_{i=1}^{\hat{T}} (MR_{obs} - MR_{pre})}{\hat{T} - q} \quad (14)$$

≡ Mean bias error (MBE)

$$MBE = \frac{1}{\hat{T}} \sum_{i=1}^{\hat{T}} (MR_{obs} - MR_{pre})^2 \quad (15)$$

≡ Root mean square error (RMSE)

$$RMSE = (MBE)^{1/2} \quad (16)$$

≡ Coefficient of residual mass (CRM)

$$CRM = \frac{\sum_{i=1}^{\hat{T}} MR_{obs} - \sum_{i=1}^{\hat{T}} MR_{pre}}{\sum_{i=1}^{\hat{T}} MR_{obs}} \quad (17)$$

≡ Modelling efficiency (EF)

$$EF = 1 - \frac{\sum_{i=1}^{\hat{T}} (MR_{obs} - MR_{pre})^2}{\sum_{i=1}^{\hat{T}} (MR_{obs} - MR_{obs.mean})^2} \quad (18)$$

where, MR_{obs}= observed values, MR_{pre} = predicted values, $MR_{obs.mean}$ = mean observed values, $\hat{T}$ = total number of observation, and q = number of constants. For precise goodness of fit, the value of r should be equal to R^2, and $R^2 > \chi_c^2$, MBE and RMSE. Besides, the observed value of CRM must be ≈ 0 and EF roughly equal to 1.

3. RESULTS AND DISCUSSION

The results of the research are presented in Tables 1 and 2.

Table 1: Mass fractions of water and total solids in the of fresh tomato slurry and concentrate

Parameters	MC (w.b.) in the Fresh Slurry	MC (w.b.) in the Concentrate	X_{ws}	X_{wc}	X_{ss}	X_{sc}
Mean Value	$93.5 \pm 2.5\%$	$73.3 \pm 2.9\%$	0.935	0.733	0.065	0.267

Note: MC = moisture content; mean values were computed from duplicate experiments; $1 - X_{ws} = X_{ss}$, and $1 - X_{wc} = X_{sc}$.

Table 2: Mean data from filtration process

Mass of Slurry, S (kg)	Mass of Concentrate , C (kg)	Volume of Filtrate, f (litre)	Period of Filtration, t (min)	Liquid Flow Rate, R (litre / min)
0.10	0.0380	0.065	2.2	0.030
0.20	0.0790	0.118	3.5	0.034
0.30	0.1210	0.174	6.1	0.029
0.40	0.1620	0.237	8.1	0.029
0.50	0.1950	0.280	11.0	0.025
			Mean	0.029

Note: The values are mean computed from duplicate experiments

From Table 1, the average moisture contents of the fresh tomato slurry and concentrate were $93.5 \pm 2.5\%$ and $73.3 \pm 2.9\%$, respectively. The observed MC of tomato concentrate was lower than that of the slurry due to the fact that part of it had filtered away. Mass fractions of moisture content or water in the slurry and concentrate were 0.935 and 0.733, respectively; while mass fractions of total solids were 0.065 and 0.267, respectively. The observed total solids fraction in tomato concentrate was higher than that of slurry because much water fraction has been drained out as filtrate leaving the more solids behind.

As observed in Table 2, increase in mass of slurry (S), led to increase in mass of concentrate (C), mass or volume of filtrate (f) and period of filtration (*t*). The mean liquid flow rate was found to be 0.029 litres / min. The observed value implies that it took about 60 minutes (1 hour) for the simple fabricated filtration unit to completely remove 1.74 litres (174 ml) of liquid, though in batches. Based on the regression analysis of:

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$$t = k_1 S^{n_1}$$
$$C = k_2 S^{n_2} \cdot \frac{X_{ss}}{X_{sc}}$$

The values of $k_1 = 23.82$, $k_2 = 1.615$, $\frac{X_{ss}}{X_{sc}} = 0.243$, $n_1 = 1.141$ and $n_2 = 0.989$.

Furthermore, the predicted values of *t* and C as functions of S, using model Equations 12 and 13, respectively, are presented in Table 3.

Table 3: Mean observed and predicted values of period of filtration (*t*) and quantity of tomato concentrate (C) as functions of quantity of tomato slurry (S)

Period of Filtration, *t*(min)		Quantity of Tomato Concentrate (kg)	
Observed Values	Predicted Values	Observed Values	Predicted Values
2.20	1.72	0.0380	0.0403
3.50	3.80	0.0790	0.0799
6.10	6.03	0.1210	0.1194
8.10	8.37	0.1620	0.1587
11.0	10.80	0.1950	0.1978

In addition, the plots of mean predicted against mean observed values of the period of filtration (*t*) and amount of tomato concentrate produced (C) from Table 3, are presented in Figures 3 and 4 to study its curve fitness. In Figures 3 and 4, the plots plainly show that the points for predicted and observed values have progressive relationship and $R^2 \approx 1$. The line in which the slope is one is that which the predicted values would be equivalent to observed values. However, the calculated statistical parameters for goodness of fit from Figures 3 and 4 are presented in Tables 4.

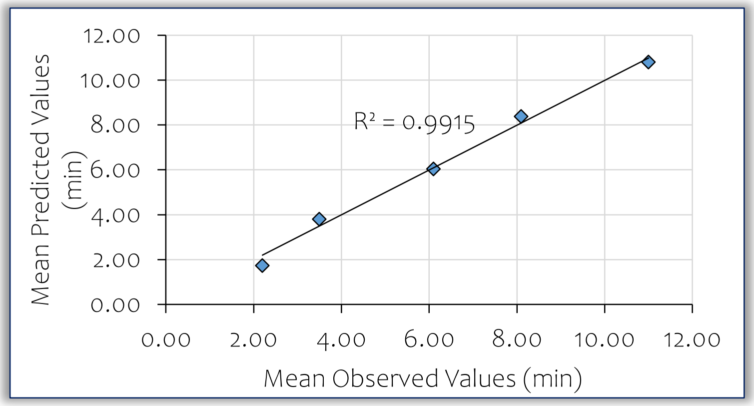

Figure 3: Plot of mean predicted and observed values of period of filtration

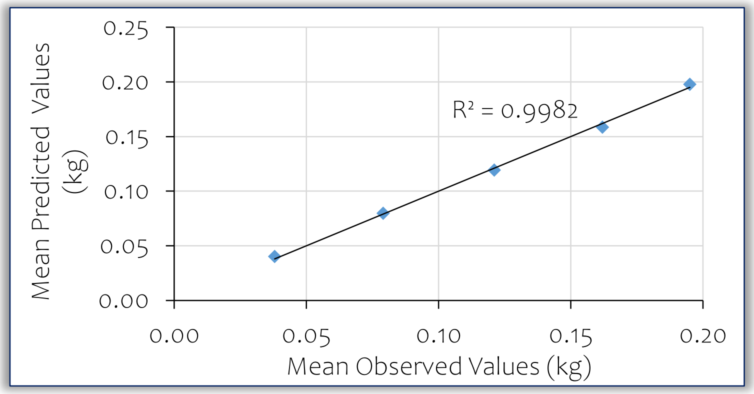

Figure 4: Plot of mean predicted and observed values of the amount of tomato concentrate

From Table 4, the values of R^2 were nearly equal to r, which imply that $R^2 \approx 1$. The values of χ_c^2, RMSE and MBE were less than R^2. The value of CRM were zero and EF approximately one. These are good criteria for perfect quality fit. Therefore, the model Equations 12 and 13 could be used in estimating the period of filtration and the amount of tomato concentrate produced from a filtration unit if the quantity of fresh tomato or its slurry is known.

Table 4: Statistical parameters for goodness of fit for the model Equations

	Model Equation 12	Model Equation 13
Parameters	Values	Values
Coefficient of correlation, r	0.9957	0.9991
Coefficient of determination, R^2	0.9915	0.9982
Reduced Chi–square, χ_c^2	0.0167	0.0011
Mean bias error, MBE	0.0806	0.0000
Root mean square error, RMSE	0.2839	0.0021
Coefficient of residual mass, CRM	0.0058	−0.0018
Modelling efficiency, EF	0.9918	0.9986

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4. CONCLUSION

The model Equations 12 and 13 were developed using experimental approach. They were validated and established to be realistically good for estimating the period of filtration and amount of tomato concentrate produced from certain amount of fresh tomato or its slurry using simple fabricated filtration device. The insight from this work and the developed process models could also be used in designing a large scale filtration system for various food and crop fluid mixtures.

References

[1] Assian, U., Antia, O. and Olosunde, W. (2021a). Predicting Cracking Efficiency and Kernel Breakage of Centrifugal Nut Cracker. International Journal of Advances in Engineering and Management (IJAEM), Volume 3, Issue 5, pp: 1211–1217.

[2] Assian, U. E., Antia , O.O. and William, A. O. (2021b). Empirical Model for Predicting Volume of Palm Nut With Respect to its Moisture Content. Research Inventy: International Journal of Engineering And Science, Vol.11, Issue 5, pp 31–36.

[3] Alonge, A. F. and OJe, K. (2003). Computer modelling of solar radiation available for crop drying at a Tropical Station (Ilorin, Nigeria). Journal of Engineering and Engineering Technology (FUTAJEET), Akure, Nigeria. 3: 41– 46.

[4] Ndukwu, M. C. and Asoegwu, S. N. (2011). A mathematical model for predicting the cracking efficiency of vertical–shaft centrifugal palm nut cracker. Research in Agricultural Engineering, 57(3): 110–115.

[5] Alonge, A. F. and Onwude, D. I. (2013). Estimation of solar radiation for crop drying in Uyo, Nigeria using a mathematical model. Advanced Materials Research, 824: 420–428.

[6] Antia, O.O. and Assian, U. E. (2018a). Empirical modeling of 4–dimensional relationship for dried palm nut of dura variety. American Journal of Engineering Research, 7,(6): 311–316.

[7] Antia, O.O. and Assian, U. E. (2018b). Development of an empirical model for palm nut volume determination. European Journal of Advances in Engineering and Technology, 5, (7), pp.466–469.

[8] Antia, O.O., Assian, U. E. and William, O. (2019a). Development of an Empirical Model Relating Palm Nut Moisture Content, Shell Thickness and soaking Time. International Journal of Mechanical and Civil Engineering, 2, (Issue 1), pp.36–47.

[9] Antia, O.O., Assian, U. E. and William, O. (2019b). Effect of Moisture Content on Palm Nut Shell Fragmentation for Effective Separation of Kernel. International Journal of Mechanical and Civil Engineering, 2, (Issue 1), pp.48–55.

[10] Antia, O.O., Assian, U. E. and William, O. (2019c). Modeling of Water Absorption by Dried Palm Nut Soaked at Room Temperature. International Journal of Trend in Scientific Research and Development (IJTSRD), Vol. 3, (Issue 3), pp.1499–1504.

[11] Antia, O. O., William, O. and Emem, E. O. (2021). Application of basic drying theory to determine drying mass constants of selected seafoods. Global Journal of Engineering and Technology Advances, 07(1), 137–143.

[12] ASABE (2010). ASABE Standard. Year Book, American Society of Agricultural and Biological Engineers.

[13] Assian, U. E. and Alonge, A. F. (2021). Some physical properties of kariya (Hildegardia barteri) nut/ kernel relevant to the design of its processing equipment. Global Journal of Engineering and Technology Advances, 7(2): 83–90.

[14] Antia, O. O., Olosunde W. and Offiong, A. (2014). Determination of optimum moisture content of palm nut cracking for efficient production of whole kernel. Nigerian Journal of Technological Development, 11(2): 27–30.

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