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A Case Study on the Analytical Design and Simulation of Palm Nut Cracker Using Customized M236 Machine Design Spreadsheet

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Abstract*— To facilitate the analysis of large volumes of data and simplify the analytical design and simulation of machine components with high accuracy, the Customized M236 Machine Design Spreadsheet, powered by Microsoft Excel™, was developed. This study presents a case study on the analytical design and simulation of a palm nut cracker's power requirement and process flow using the M236 spreadsheet. Classical frameworks were provided as guides for potential users to navigate the tool. The analytical design determined the total power required to operate the palm nut cracker, and simulation was later performed using pre-developed models. The results indicate that the Customized M236 Machine Design Spreadsheet is a flexible tool that allows for rapid corrections during analysis and simulation.*

Keywords*— Analysis, Machine design, Power, Palm nut cracker, Process flow, Simulation.*

I. INTRODUCTION

In research studies dealing with large and complex datasets, a well-organized and packaged experimental design is necessary to achieve the research objectives. Despite careful planning, errors may be discovered during the analysis phase, which can affect the accuracy and authenticity of research findings. The quality of the analysis is highly dependent on the devices or tools used, emphasizing the need to use reliable tools. To address these issues, a template was developed for the "Development of Palm Shell Particulate Machine for Enhancement of Kernel Separation" proposal, powered by Microsoft Excel™. This template was subsequently refined into a user-friendly interface for use in the data and design analyses of various machine components across different research studies and journal articles (Assian, 2019; Ubong *et al.*, 2019; Antia *et al.*, 2019; Antia *et al.*, 2021; Assian and Alonge, 2021). The Customized M236 Machine Design Spreadsheet is an Excel program that allows users to encode their models based on their specific needs. The program is customized to enable users to create their own calculations and mathematical formulas using syntax that is understood by Microsoft Excel. However, users must be familiar with calculation operators and be proficient in general arithmetic computation. To assist users, especially students and researchers, typical frameworks can be provided as guides to facilitate speedy machine components analytical design and simulation, as well as data analysis with a high level of precision.

The main objective of this study was to use the Customized M236 Machine Design Spreadsheet powered by Microsoft Excel in the analytical design and simulation of the total power required to run a palm nut cracker and process flow. The findings of this study shed more light on the applications of the Customized M236 Machine Design Spreadsheet in various fields.

II. MATERIALS AND METHODS

In this study, the Customized M236 Machine Design Spreadsheet was used in: (i) Analytical design, simulation and optimization of machine components / variables; and (ii) Process flow simulation.

A. *Analytical Design and Simulation*

In the analytical design and simulation of total power required for running the palm nut cracker in order to select electric motor, the components of cracking chamber are to be identified. These include impeller(s), shaft and pulley as shown in Figure 1.

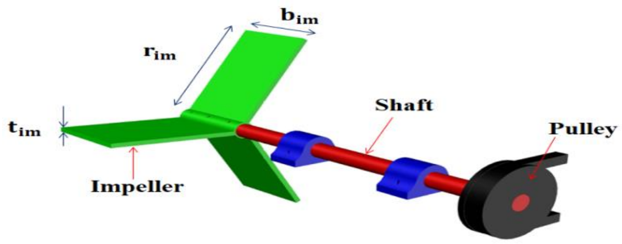

Figure 1: Cracking unit Shaft with Impellers and Pulleys

From Figure 1, forces acting on the cracking chamber shaft are: (i) weight of impellers and pulley, and (ii) belt tensions on the pulley and weight of nuts on impeller(s). However, there are two fundamental forces needed in this operation: (i) force needed to crack the nuts and (ii) force required to drive the shaft and its attachments. Thus, these forces could be transformed directly into power necessary for the whole operation.

(a) Determination of Weight of n- Impeller Blades

Weight of n- impeller blades (W_{im}) was computed thus:

$$W_{im} = \rho_{im} . V_{im} . n_{im} . g \quad (1)$$

$$W_{im} = \rho_{im} . b_{im} . t_{im} . r_{im} . n_{im} . g \quad (2)$$

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Where, ρ_{im} = density of impeller blade material (carbon steel) = 7850 kg/ m^3, V_{im} = volume of impeller blade (m^3), n_{im}= number of impeller blades, b_{im} = width of impeller blade (m), t_{im} = thickness of impeller blade (m), r_{im}= radius of impeller blade (m) and g = acceleration due to gravity (9.8 m/s^2).

(b) Weights of Shaft and Pulley

Weights of shaft (W_{sf}) and pulley (W_p) were assumed to be 10.0 N and 8.8 N, respectively.

(c) Power Required for Cracking Palm Nut

Power required for cracking palm nut (P_c) was computed thus (Antia *et al.*, 2012):

$$P_c = (2.935 \times ½\, M_n . V_p^2) + 4.906 \text{(J/sWatt)} \quad (3)$$

Where, M_n = mean mass of palm nut (0.009 kg) (Assian, 2006 and 2019) and V_p= peripheral velocity (33 m/s) (Fellow, 2000).

(d) Power to Drive the Shaft and Its Attachments

Power to drive the shaft and its attachments (P*) was calculated thus (Oke, 2007):

$$P^* = \frac{Workdone}{Time} \quad (4)$$

$$P^* = \frac{\text{Total loads} \times \text{distance}}{Time} \quad (5)$$

$$P^* = \text{Total loads } (F_T) \times \frac{distance}{Time} = F_T \times V_p \quad (6)$$

But total loads to overcome are equivalent to the sum of the weight of impeller, pulley and shaft (F_T). This is given as:

$$F_T = W_{im} + W_p + W_{sf} \quad (7)$$

Hence, total power required to run the system and crack the nut (P_T) was computed as:

$$P_T = P^* + P_c \quad (8)$$

But the speed of the shaft / impeller in revolution per minute was calculated thus (Khurmi and Gupta, 2012):

$$N_2 = \frac{V_p \; 60}{2 \pi r_{im}} \quad (9)$$

(e) Electric Motor Selection

In selecting an electric motor, factor of safety (*f*) must be incorporated into the design. Thus, power required (P_R) in kilowatt for the entire operation was determined as:

$$P_R = P_T \times f = P_{as} \quad (10)$$

If the electric motor has efficiency (ŋ) of 75%, then, the electric motor power (P_m) was found as (Khurmi and Gupta, 2012):

$$P_m = \frac{P_{as}}{\eta} \text{(kW)} \quad (11)$$

$$P_m = \frac{P_{as}}{\eta \times 0.745} \text{(hp)} \quad (12)$$

While the torque produced at motor pulley (T_t) in N-m was found thus:

$$T_t = \frac{P_{as} \times 60}{2\pi \times N_1} \quad (13)$$

Where, P_{as} = actual power supply (hp) and N_1 = electric motor speed (rpm).

III. Optimization

The total power required to run the system and crack the nut (P_T) could be optimized using Customized M236 Machine Design Spreadsheet. Based on model equations developed, P_T could be minimized or maximized by either reducing or increasing the size of impeller blade (i.e., by varying one of its dimensions, say [r_{im}]). Thus, this could be expressed as:

Optimize,

$$P_T = \begin{pmatrix} [W_p.V_p + W_{sf}.V_p] + [(2.935 \times ½\, M_n.V_p^2) + 4.906]\ldots \\ \ldots + [\rho_{im}.b_{im}.t_{im}.r_{im}.n_{im}.g.V_p] \end{pmatrix} \quad (14)$$

Subjected to the constraint:

$$\begin{bmatrix} r_{im-1} \\ r_{im-2} \\ r_{im-3} \\ \vdots \\ r_{im-n} \end{bmatrix}$$

Where, Equation 14 is objective function; r_{im-1}, r_{im-2}, r_{im-3} … and r_{im-n} are decision variables, and all other parameters are assumed to be constants (Assian *et al.*, 2021).

A. Process Flow Simulation

A typical schematic representation of a process flow where a simple filtration unit was used to minimally process fresh tomatoes into its concentrate is shown in Figure 2.

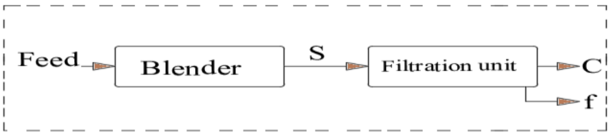

Figure 2: Schematic representation of a typical process flow

A given quantity of fresh tomatoes (feed) was blended using an electric blender. The slurry (S) in kg obtained was channelled into the filtration unit. The unit majorly composes of a lid, funnel, filter, stand and transparent vessel. When there were no more visible drips of filtrate, at filtration duration (t) in minutes, the lid was opened, and certain amount of tomato concentrate (C) in kg was collected while some litres of filtrate (f) were received into the transparent vessel. Assuming there was no accumulation in the blender, the amount of feed input is the same as that of slurry (S) put into the filtration unit. However, the distinctive process flow models developed from this unit operation are given in Equation 15 to 17.

$$C = G_1 . S^q \frac{X_{ss}}{X_{sc}} \quad (15)$$

$$t = G_2 . S^k \quad (16)$$

$$f = G_3 . S + h \quad (17)$$

Where, G_1, G_2, G_3 and *h* are constants; q and k are indices that describe that best relationship among the parameters and $\frac{X_{ss}}{X_{sc}}$ = mass fraction of total solids in the slurry to mass fraction of total solids in tomato concentrate.

B. Design, Simulation and Optimization Using Customized M236 Machine Design Spreadsheet

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i. Electric Motor Selection for Palm Nut Cracker and Optimization Processes

The dependent / independent variables and constants were distinguished from model Equation 1 to 13. With the use of the Customized M236 Machine Design Spreadsheet, power by Microsoft Excel®, columns were generated for parameter, symbol, variables (both variables) and unit. The model equations were encrypted into the Customized M236 Machine Design Spreadsheet. Variation in impeller widths (b_{im}= 0.08, 0.07 and 0.06 m), thickness (t_{im}= 0.005 m), radius (r_{im}= 0.120 m), density (ρ_{im}= 7850 kg /m^3) and number of impeller blades (n_{im}= 3) were used to simulate variable weights of impeller (W_{im}) and total weights of impeller (W_{tim}). Besides, weight of shaft (W_{sf} = 10 N), weight of pulley (W_p= 8.8 N), mean mass of palm nut (M_n = 0.009 kg), peripheral velocity (V_p= 33 m/s), factor of safety for electric motor selection (f = 1.1), motor efficiency (η = 75%) and speed of rotation of the driver pulley (N_1) were employed to generate power required crack palm nut (P_C), total loads to overcome (F_T), power to run the shaft and its attachment (P*), power required to crack the nut and run the system (P_T), speed of rotation of the driven pulley (actual speed = N_2), actual power supply by electric motor (P_{as}), electric motor power (P_m) and torque at the motor (T_t). However, the process was repeated with b_{im} = 0.08, t_{im}= 0.005 m, r_{im}= 0.120 m, n_{im}= 2 and other parameters remaining unchanged. Discrepancies between the responses caused by n_{im} = 3 and 2 were evaluated. In order to minimize (optimize) the value of the objective function (P_T) to 0.745 kW by only varying the width of impeller blade as the decision variables ($r_{im-1}, r_{im-2}, r_{im-3} \cdots r_{im-n}$), a cell where P_T was found was selected. **Data** tab and **What If Analysis** were clicked. From the **drop-down arrow**, **Goal Seek** was clicked and a dialog box appeared. At **Set cell**, the cell where objective function was located must appear. Then, in a cell **to value**, 0.745 was keyed in and the decision variable cell to be altered was inputted at **by changing cell** and clicked **OK**

ii. Process Flow Simulation

Based on the model Equation 15 to 17, input and output variables were identified. A sketch of the process flow layout including the components as seen in Figure 2 was made. Three-D models of the blender and filtration unit were produced, and virtually placed in the worksheet where they should have been positioned in reality. Arrows with distinctive colours were used to link each process stage. Keys were provided to distinguish each component and process stage. The models for simulating the amount of tomato concentrate produced (C), filtration duration (t) and amount of filtrate collected (f) were meticulously encrypted into the Customized M236 Machine Design Spreadsheet, power by Microsoft Excel® as well as their respective constants (G_1= 1.625, q = 0.989 and $\frac{X_{ss}}{X_{sc}}$ = 0.243 for C; G_2= 23.82 and k = 1.141 for t; and G_3= 0.549 and h = 0.0101 for f).The output variables were generated from the range of 0.1 to 0.3 kg feed, and displayed behind its appropriate process stage.

III. Results and Discussion

A. *Analytical Design and Simulation Data for Electric Motor Selection for Palm Nut Cracker*

The results obtained from the Customized M236 Machine Design Spreadsheet for the analytical design and simulation of the total power required to run the palm nut cracker are summarized in Tables 1 and 2. Table 1 shows that varying the width of the impeller blades (b_im) between 0.06 m and 0.08 m resulted in corresponding variations in the weight of the impeller (W_im) and the total weight of the impeller (W_tim). The power required to crack the palm nut (P_C) was computed to be 19.29 W, while the total loads to overcome (F_T), the power to run the shaft and its attachment (P*), and the power required to crack the nut and run the system (P_T) were found to be 30 N, 28 N, and 27 N, respectively. The actual speed of rotation of the driven pulley (N_2) was measured to be 2626 rpm. In addition, the actual power supply by the electric motor (P_as), the electric motor power (P_m), and the torque at the motor (T_t) were calculated to be 1.106 kW, 1.056 kW, and 7.039 N-m, respectively.

Table 1: Analytical design and simulation of total power required to run the palm nut cracker based variable impeller width

CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS					
Parameter	Symbol	I	II	III	Unit
Impeller width	bim	0.080	0.070	0.060	m
Impeller thickness	tim	0.005	0.005	0.005	m
Impeller radius	rim	0.120	0.120	0.120	m
Impeller material density (mild steel)	ρim	7850	7850	7850	kg/m^3
Impeller weight	Wim	3.693	3.231	2.769	N
Number of impeller blades	nim	3	3	3	
Weight of n- blades of impellers	Wtim	11.078	9.693	8.308	N
Weight of shaft (assumed)	Wsf	10	10	10	N
Weight of pulley (assumed)	Wp	8.8	8.8	8.8	N
Mean mass of palm nut	Mn	0.009	0.009	0.009	kg
Peripheral velocity of the rotating impeller	Vp	33	33	33	m/s
Power to crack palm nut	Pc	19.29	19.29	19.29	W
Total loads to overcome	FT	30	28	27	N
Power to run the shaft and its attachment	P*	985.97	940.27	894.58	W
Power required to crack the nut and run the system	PT	1.005	0.960	0.914	kW
Speed of rotation of the driven pulley (actual speed)	N2	2626	2626	2626	rpm
Safety factor in selecting electric motor	f	1.1	1.1	1.1	
Actual power supply	Pas	1.106	1.056	1.005	kW
Electric motor efficiency (η)	η	0.75	0.75	0.75	
Electric motor power supply (to be selected)	Pm	1.474	1.407	1.340	kW
Power equivalent supplied to shaft (1 hp = 0.745kW)	Pm	1.979	1.889	1.799	hp
Rotational speed of the electric motor (selected)	N1	1500	1500	1500	rpm
Torque on shaft or the machine pulley	Tt	7.039	6.719	6.399	N-m

E7=E3*E4*E5*E6*9.8
E14=(2.935*(0.5*E12*(E13^2))) +4.906
E18=E13*60/(2*3.142*E5)
E25=(E20*1000*60)/(2*3.142*E24)

Shaft Torque / Forces on Shaft / Sheet1 / Sheet2 / Sheet3

NB: Row(s) in grey represent(s) independent variables while row(s) in yellow represent(s) dependent variables.

Decreasing the width of the impeller blades also led to a decrease in the weight of the impeller, total weight of the impeller, loads to overcome, power required to run the shaft and its attachment, power required to crack the nut and run the system, actual power supply by the electric motor, electric motor power, and torque at the motor. These results indicate that increasing the size of the impeller blade would lead to an increase in these parameters. The Spreadsheet allows users to easily visualize the effects of changes in these variables and make informed decisions accordingly.

Based on the maximum power of the electric motor to be selected (1.979 hp), a 2.0 hp electric motor that runs at 1500 rpm would be suitable for the job. Model equations 1, 3, 9, and 13 in cells E7, E14, E18, and E25 are encrypted based on the syntaxes understood by the Microsoft Excel program. Any input variable that is not assigned a value will not simulate a response. Corrections can be easily made using the Spreadsheet.

In Table 2, the dependent variables (W_tim, F_T, P*, P_T, P_as, P_m, and T_t) were observed to decrease as the independent variables (n_im) decreased from 3 to 2. This is consistent with the expectation that reducing the total weight of the impeller would result in lower values of these parameters.

Table 2: Analytical design and simulation of total power required to run the palm nut cracker based on variable number of impeller blades.

	A	B	C	D	E
1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS				
2	Parameter	Symbol	I	II	Unit
3	Impeller width	bim	0.080	0.080	m
4	Impeller thickness	tim	0.005	0.005	m
5	Impeller radius	rim	0.120	0.120	m
6	Impeller material density (mild steel)	ρim	7850	7850	kg/m^3
7	Impeller weight	Wim	3.693	3.693	N
8	Number of impeller blades	nim	3	2	
9	Weight of n- blades of impellers	Wtim	11.078	7.385	N
10	Weight of shaft (assumed)	Wsf	10	10	N
11	Weight of pulley (assumed)	Wp	8.8	8.8	N
12	Mean mass of palm nut	Mn	0.009	0.009	kg
13	Peripheral velocity of the rotating impeller	Vp	33	33	m/s
14	Power to crack palm nut	Pc	19.29	19.29	W
15	Total loads to overcome	FT	30	26	N
16	Power to run the shaft and its attachment	P*	985.97	864.11	W
17	Power required to crack the nut and run the system	PT	1.005	0.883	kW
18	Speed of rotation of the driven pulley (actual speed)	N2	2626	2626	rpm
19	Safety factor in selecting electric motor	f	1.1	1.1	
20	Actual power supply	Pas	1.106	0.972	kW
21	Electric motor efficiency (η)	η	0.75	0.75	
22	Electric motor power supply (to be selected)	Pm	1.474	1.296	kW
23	Power equivalent supplied to shaft (1 hp = 0.745kW)	Pm	1.979	1.739	hp
24	Rotational speed of the electric motor (selected)	N1	1500	1500	rpm
25	Torque on shaft or the machine pulley	Tt	7.039	6.186	N-m

Shaft Torque / Forces on Shaft / Sheet

Optimization of Total Power Required for Running the Palm Nut Cracker

The initial and final steps of optimization of total power required for running the palm nut cracker are presented in Tables 3 and 4.

Table 3: Initial step of optimization of total power required for running the palm nut cracker

C17 | =(C14+C16)/1000

	A	B	C	D
1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS			
2	Parameter	Symbol	I	Unit
3	Impeller width	bim	0.080	m
4	Impeller thickness	tim	0.005	m
5	Impeller radius	rim	0.120	m
6	Impeller material density (mild steel)	ρim	7850	kg/m^3
7	Impeller weight	Wim	3.693	N
8	Number of impeller blades	nim	3	
9	Weight of n- blades of impellers	Wtim	11.078	N
10	Weight of shaft (assumed)	Wsf	10	N
11	Weight of pulley (assumed)	Wp	8.8	N
12	Mean mass of palm nut	Mn	0.009	kg
13	Peripheral velocity of the rotating impeller	Vp	33	m/s
14	Power to crack palm nut	Pc	19.29	W
15	Total loads to overcome	FT	30	N
16	Power to run the shaft and its attachment	P*	985.97	W
17	Power required to crack the nut and run the system	PT	1.005	kW
18	Speed of rotation of the driven pulley (actual speed)	N2	2626	rpm
19	Safety factor in selecting electric motor	f	1.1	
20	Actual power supply	Pas	1.106	kW
21	Electric motor efficiency (η)	η	0.75	
22	Electric motor power supply (to be selected)	Pm	1.474	kW
23	Power equivalent supplied to shaft (1 hp = 0.745kW)	Pm	1.979	hp
24	Rotational speed of the electric motor (selected)	N1	1500	rpm
25	Torque on shaft or the machine pulley	Tt	7.039	N-m

Goal Seek
Set cell: C17
To value: 0.745
By changing cell: C5
OK Cancel

Shaft Torque / Forces on Shaft / Sheet1 / Sheet2 / Sh

Table 4: Final step of optimization of total power required for running the palm nut cracker

C17 | =(C14+C16)/1000

	A	B	C	D
1	CUSTOMIZED M236 MACHINE DESIGN SPREADSHEET ANALYSIS			
2	Parameter	Symbol	I	Unit
3	Impeller width	bim	0.080	m
4	Impeller thickness	tim	0.005	m
5	Impeller radius	rim	0.035	m
6	Impeller material density (mild steel)	ρim	7850	kg/m^3
7	Impeller weight	Wim	1.071	N
8	Number of impeller blades	nim	3	
9	Weight of n- blades of impellers	Wtim	3.213	N
10	Weight of shaft (assumed)	Wsf	10	N
11	Weight of pulley (assumed)	Wp	8.8	N
12	Mean mass of palm nut	Mn	0.009	kg
13	Peripheral velocity of the rotating impeller	Vp	33	m/s
14	Power to crack palm nut	Pc	19.29	W
15	Total loads to overcome	FT	22	N
16	Power to run the shaft and its attachment	P*	726.42	W
17	Power required to crack the nut and run the system	PT	0.746	kW
18	Speed of rotation of the driven pulley (actual speed)	N2	9054	rpm
19	Safety factor in selecting electric motor	f	1.1	
20	Actual power supply	Pas	0.820	kW
21	Electric motor efficiency (η)	η	0.75	
22	Electric motor power supply (to be selected)	Pm	1.094	kW
23	Power equivalent supplied to shaft (1 hp = 0.745kW)	Pm	1.468	hp
24	Rotational speed of the electric motor (selected)	N1	1500	rpm
25	Torque on shaft or the machine pulley	Tt	5.221	N-m

Goal Seek Status
Goal Seeking with Cell C17 found a solution.
Target value: 0.745
Current value: 0.746
Step Pause OK Cancel

Shaft Torque / Forces on Shaft / Sheet1 / Sheet2 / Sh

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As displayed in Tables 3 and 4, the **Goal Seek Status** dialog box found a solution with the **Current value** (0.746 kW) instead of the **Target value** (0.745 kW) with r_{im} of 0.035 m. This value is smaller than the b_{im} = 0.08 m which resulted in a reduction of W_{im} (from 3.693 to 1.071 N), W_{tim} (from 11.078 to 3.213 N), F_T (from 30 to 22 N), P* (from 985.97 to 726.42 N), P_{as} (from 1.106 to 0.820 kW), P_m (from 1.474 to 1.094 kW) and T_t (from 7.039 to 5.221 N-m). Meanwhile, N_2 was found to increase from 2626 to 9054 rpm. It is noteworthy to observe that the optimization process automatically varied all the parameters that were directly or indirectly related to r_{im}. Since the power required for cracking the nut and running the system was reduced, the impeller size was also reduced, implying that impeller blades would be running at a higher speed compared to the initial speed. With this operation, a lot of time is saved in changing the decision variables one after the other ($r_{im-1}, r_{im-2}, r_{im-3} \dots r_{im-n}$) so as to minimize the objective function (P_T).

3.3 Process Flow Simulation

The simulations of filtration process based on varying input feed are displayed in Figure 3 to 5.

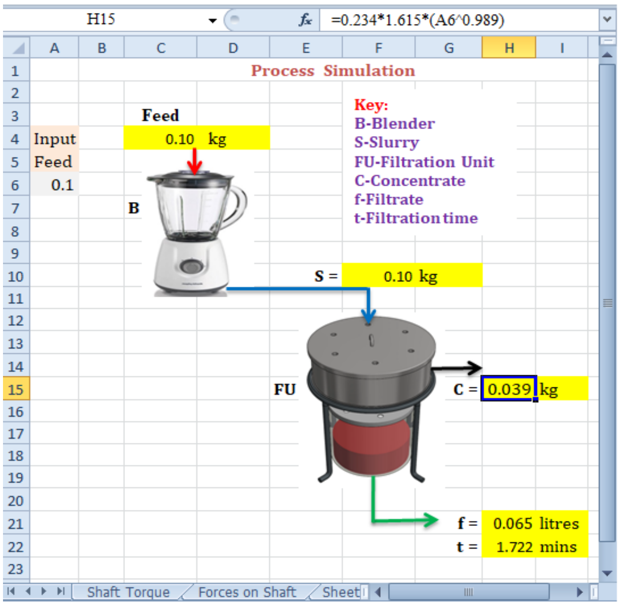

Figure 3: Yield of tomato slurry, concentrate and filtrate, and filtration duration for 0.1 kg feed

As observed in Figure 3 to 5, the letters B and FU represent blender and filtration unit, respectively. The transport link, that is, a line with arrow head indicates the direction of process flow. However, 0.1, 0.2 and 0.3 kg feed /slurry generated tomato concentrate (C), duration of filtration (t) and filtrate (f) of 0.039 kg, 1.722 mins and 0.065 litres; 0.077 kg, 3.797 mins and 0.120 litres; and 0.115 kg, 6.030 mins and 0.175 litres, respectively. Cell **A6** is where the amount of feed in kg was inputted. This was replicated in cells **C4** and **F10**. As the amount of feed or S increased, the C, t and f also increased. With the aid of the encrypted models in Cells **H15**, **H22** and **H21**, C, t and f were easily simulated.

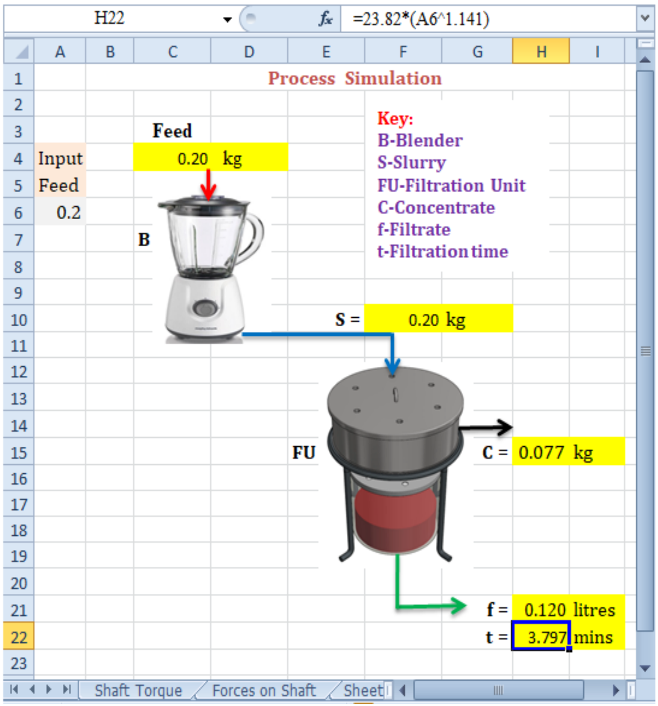

Figure 4: Yield of tomato slurry, concentrate and filtrate, and filtration duration for 0.2 kg feed

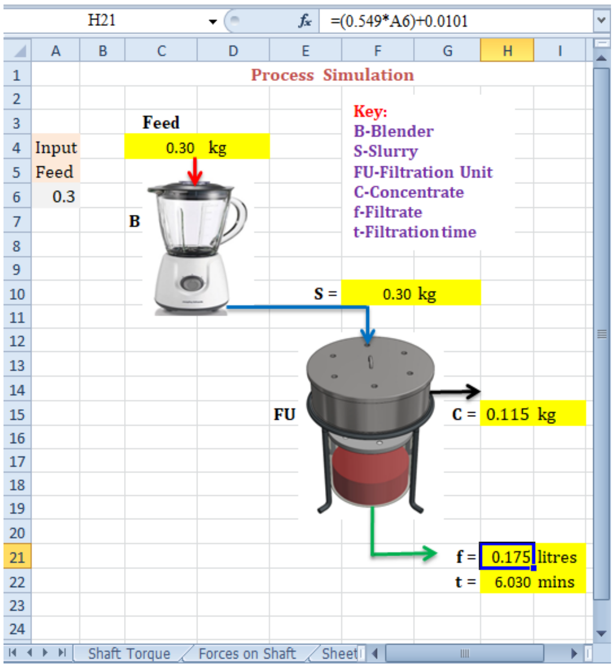

Figure 5: Yield of tomato slurry, concentrate and filtrate, and filtration duration for 0.3 kg feed

IV. Conclusion

In a nutshell, the Customized M236 Machine Design Spreadsheet powered by Microsoft Excel ™ is veritable tool that could be employed in carrying out analytical design, simulation and optimization of machine parts and variables. In this study, guides are presented on how the Customized M236

Machine Design Spreadsheet could be used, to select electric motor required to run a palm nut cracker and to simulate a process flow. The Customized M236 Machine Design Spreadsheet provides room for quick correction and alteration, if any, and to handle a large volume of data within a short interval of time if the syntaxes are correctly encrypted.

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