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DESIGN MODIFICATION OF A CASSAVA DEWATERING MACHINE

***[1]Kadurumba, C.H., [2]Ogunsola, T.M. and [1]Nwogu-Chibuike, C.G.**

[1]Department of Mechanical Engineering, Michael Okpara University of Agriculture Umudike, Abia State Nigeria.
[2]Department of Marine, School of Marine Engineering, Maritime Academy of Nigeria, Oron, Akwa Ibom State.
*kaduruchuma@yahoo.com

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ABSTRACT

This design work presents an improved centrifuge for dewatering cassava mash that extracts effluent from the mash for any genotype of cassava. The methods adopted in the execution of this project work include; Machine design, Machine development, Machine evaluation and Optimization to compare the present machine to that of the previous designs. Machine efficiency, safety factors, and portability were considered in this research. The receiver hopper was carefully designed at the angle 23° that the mash can flow smoothly while filter basket, shaft, collector and conveyor auger were designed using stainless steel. Also, the frame of the machine is made up of angle iron at the four corners for support and holding the top bearings are mild steel metals to keep it in place and withstand vibration. Pulleys used in the design were made of cast iron. The screw conveyor and the basket end plate designed using mild steel to serve a dual purpose; cover for the filter basket and shaft for the basket bearing while blower was also introduced for drying of mash faster and yarn used for preventing leakages. The machine runs on a single phase five horsepower electric motor at a speed of 1440 rpm. The capacity of the dewatering fabricated was 158 kg/hr and 30% reduction in size and 50 % reduction in price was achieved.

1. INTRODUCTION

The world attention to engineering design to mechanise cassava production field operations has been very meagre and relatively insignificant regarding concrete achievements or actual machines on the global market. Although cassava indisputably remains a significant food/cash crop of the tropical world. All the cultural operations for its production are still performed manually by the producers who are predominantly peasant farmers (Odigboh, 1986). Nigeria is one of the most significant producers of cassava in Africa. About 1.2 million people of the population are actively involved in the cultivation and supply of cassava roots. The need to mechanise cassava field operations has long been felt worldwide (Aigner *et al*., 1992;

Ajibefun and Abdulkadri, 1999). The estimated annual production ranges from 34 – 42 million tonnes (RMRDC, 2004), with Nigeria accounting for over 70% of the output from West Africa. It is estimated that 172 million tonnes of cassava were produced worldwide in 2000. Africa, Asia, and Latin America and the Caribbean accounted for 54, 28 and 19 percent of the total world production respectively. The average yield in 2000 was 10.2 tonnes per hectare, but this varied from 1.8 tonnes per hectare in Sudan to 10.6 tonnes per hectare in Nigeria and 27.3 tonnes per hectare in Barbados. This study focused on the design and development of a functional dewatering machine which reduces drudgery and labour cost.

Mechanical dewatering machines were also available in all the centres most rural areas in Africa, but it takes a long process. Three types of mechanical dewatering machines were observed; power screw press, parallel board press and hydraulic press. The hydraulic dewatering machine was more favoured by the cassava processors due to its high efficiency but was very difficult to operate. This study modified the design by Kadurumba and Enibe (2011) because of the machine adaptability, speed of dewatering, efficiency and compact nature. Also, the machine has considerable advantages over other dewatering machines. It was observed that most of the cassava dewatering machines usually corrode due to the acidic nature of the cassava fluid. The stainless steel material is used for the fabrication, to ensure all cassava products are free from any sour tastes, odour or infected by iron content of parts (food poisoning) which may affect the quality of their contents (Feikes *et al.*, 2002). Hence the need to modify the design by Kadurumba and Enibe (2011) and use appropriate material for the fabrication.

The current design consists primarily of 3 units: the hopper unit, the grating drum and the delivery channel. All these components are mounted on an angle iron frame. The machine assembly is powered mechanically or manually in case of electricity failure. It can be used in rural settlements where power supply might not exist in exist. Apart from faster rating rate, it required less him involvement. The grating drum is made of metallic pipe that carries a perforated plate which served as the grater. This overcomes the problem faced in the wooden grating drum. Cassava (Manihot Esculenta Crantz) is one of the most important energy sources in the human diet in the tropics.

2. MATERIALS AND METHODS

2.1. Materials Collection

Stainless steel materials were used for the production of the machine. Cassava roots used for the analysis and testing of the machine were obtained from the National Root Crops Research Institute Umudike Abia State. The methods adopted in the execution of this work include machine design, machine development, machine evaluation and optimization.

2.2. Machine Description

The main components of the machine are housing, filter basket, screw conveyor supported by bearings at both ends, a pulley drive provided for transmission of the rotation movement of the drive to the screw conveyor and filter basket, pulleys to give a differential rotating speed to screw, motor and so on. Various components of the machine were designed using standard formulae. Autodesk Inventor and Solid work 2015 software were used for all the machine drawings. The machine is powered by electric motor or internal combustion engine via pulley arrangement connected to the main shaft that turns the screw conveyor. The hopper into which the cassava mash is fed located at the top of the housing. To achieve higher conveying compaction by the screw, the screw was designed with gradual reduction of screw pitch toward the direction of dried mash transportation. The screw conveyor was arranged in the filter basket and an outlet for the dried product provided. The cassava mash was introduced in the centrifugal press, pressed to the filter basket through the screw conveyor, (which is supported and driven in rotary motion) and dried in this way.

By the fact that a screw conveyor conveys the mash in the spiral to the outlet, the cassava is dried further during the conveying motion and gets in a very convenient, dry condition to the outlet for the dried product. The liquid, as well as the dried mash, is collected in containers or vessels and then transported away for further utilisation. The design of the centrifuge is such that the driver drives the screw conveyor as well as the filter basket, preferably with different rotary speeds. Since the screw conveyor and the filter basket move at different rotary speeds, a relative movement occurs between the conveyor and the filter basket. Using that, a self-cleaning is achieved, and the perforations of the filter basket prevented from clogging. This saves maintenance which costs time and money. The design modification and development of the centrifuge for dewatering cassava mash produced a machine that can be easily assembled, disassembled, and easily transferred from one location to another. The machine has a hopper that allows materials to pass through efficiently with minimum wastage. The machine spiral flight of the conveyor is made of stainless steel. To increase its durability, the chute and collector are sloppy to allow the grating pulp to slide downward and get a discharge by gravity.

Figure 1 shows the full cassava dewatering machine assembly of the centrifuge. In the housing, a rotatable supported filter basket is provided in which an also rotatable supported screw conveyor is located. The grated cassava mash is pressed in the pipe like shaft via the inlet (hopper) and is conveyed to the more significant diameter screw conveyor inside the filter basket, and it is further pressed there. As the screw conveyor simultaneously carries out motion of rotation, the cassava mash is pressed from the outside to the filter basket, through the perforation of which the liquid (effluent) present in the grated mash gets into the effluent chamber. The collecting chamber was arranged between the exterior walls of the filter basket and the interior wall of the housing. A bottom and top bearings support the shaft of the screw conveyor. The bearings of the filter basket are located on the bottom and top sides of the filter basket. The drive for the centrifuge is an electric motor. The drive has a pulley which can hold four V- belts and two of the V-belts connected to the basket were twisted so that the auger and the basket can be able to work in the opposite direction.

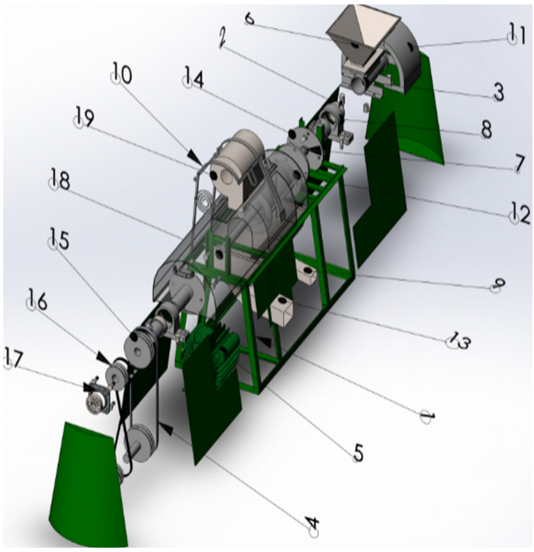
That means the auger move in the clockwise direction and the basket move in the anticlockwise direction. The V-belts are shown in Figure 1 for driving motor, shaft and basket. The rotation motion of the drive is transferred from the pulley to the pulley for screw conveyor and the pulley for the filter basket. In the design, the pulley for the filter basket has a larger diameter than the pulley for the screw conveyor. This secures that the filter basket rotates with a lower speed than the screw conveyor. The reversed principle is possible according to which the screw conveyor can move slower than the filter basket. The invention is not restricted to either of the possibilities. On the end side of the screw conveyor, the dried grated cassava mash is conveyed in the outlet for the product. Vessels are used for collection of the products so that it can be utilised later.

2.3. Optimization of the Centrifuge Process Parameters

Optimization of the centrifugal dewatering machine process generated the highest return on investment and was adopted in this study. Response surface methodology was adopted to optimise the machine parameters.

2.4. Machine Development

Standard formulas were used to design the following components such as housing, screw flight, filter basket, screw conveyor, and hopper and the others were chosen according to existing design standards. Parameters considered in the centrifugation include, process variables such as volumetric feed rate, Product moisture, Feed solid content, Screen-drain, Product (solid) recovery, Effluent recovery and for Machine variables such as Filter basket size, Filter basket speed, Pool depth, Screw conveyor speed.



1 = Frame
2 = Frame cover
3 = Hopper based Setting
4 = Belt
5 = Electric motor
6 = Hopper
7 = Basket end Setting
8 = Bearing
9 = Affluent Passage
10 = Blower Anger
11 = Based setting cover
12 = Internal Basket cover
13 = Mash passage
14 = Spiral flight
15 = Basket Pulley
16 = Shaft Bearing
17 = Flat Bearing

Figure 1: Full labelling of cassava dewatering machine

2.5. Machine Evaluation

The machine was evaluated based on the following process parameters:

- Product (mash) moisture content recovery
- Product (Solid) recovery
- Effluent recovery
- Screen drain recovery

The main and interaction effects of feed volumetric flow rate, solid content and pool depth on these process parameters were investigated.

2.6. Design Calculations

Factors such as machine vibration, maintainability, safety, reliability, efficiency, placement of controls and the physical effort required to arrive at the throughput capacity were considered (Kadurumba and Nwanya 2016).

2.6.1. Determination of the bulk density of the grated cassava mash

A steel cylindrical container (filter basket) with the following dimensions was used. Dimensions for height and internal diameter were arbitrarily chosen:

Height= 38.5 cm=0.39 m

Internal diameter, d=15.2 cm = 0.15 m

Therefore, cross-sectional area of the cylindrical container,

$$A = \frac{\pi d^2}{4} \tag{1}$$
$$= 0.0177m^2$$

$$Volume = \ area\, x\, height \tag{2}$$
$$= 6.89 \times 10^{-3} m^3$$

In other to calculate the bulk density of the cassava mash, the following equation was used.

$$B_c = \frac{W_2 - W_1}{V} in(kg/m^3) \tag{3}$$

Where B_c = Bulk density of grated cassava mash in (kg/m³)
W_2 = weight of container + weight of sample in (kg)
W_1 = weight of container in (kg)
V = volume of cylinder in (m³)

Experiment to calculate the bulk density of the cassava mash was conducted as follows:
Weigh the empty container W_1
Weigh the container + grated cassava mash W_2

The process was repeated for about three times and the bulk density obtained. Table 1 shows the results obtained from the experiment to determine the bulk density of cassava mash. As shown, the average bulk density B_c= 50.9434 kg/m^3

Table 1: Values for the result of the experiment to determine the bulk density of cassava mash

S/N	W_1(kg)	W_2(kg)	B_c (kg/m^3)
1		0.90	50.3145
2		0.92	51.5723
3		0.91	50.9434
Total		2.73	152.8302
Average		2.73	50.9434

2.6.2. Centrifugal force

The mathematical expression for the centrifugal force was derived by comparing the form of Newton's second law in an inertial frame with its shape in a frame rotating about a fixed axis (Kadurumba and Enibe 2017). Newton's law of motion for a particle of mass *M* can be written in vector form as

$$F \ = \ ma \tag{4}$$

Where F is the vector sum of the physical forces applied to the particle and is the absolute acceleration of the particle given by:

$$a = \frac{d^2 r}{dt^2} \tag{5}$$

Where r is the position vector of the particle from the equation. For a curved motion acceleration of an object is:

$$a = \frac{\Delta v}{\Delta t} \tag{6}$$

Where aΔv = change in velocity, Δt = is the time taken for an object to go from point *A* to point *B*. If the points *A* and *B* are very close together, then $\Delta\theta$ is small and $\Delta \mathrm{v} = \mathrm{v}\Delta\theta$

$$a = \frac{v\Delta\theta}{\Delta t} = v\omega \tag{7}$$

Since:

$$\omega = \frac{\Delta\theta}{\Delta t} \tag{8}$$

But:

$$v = \frac{r\Delta\theta}{\Delta t} \tag{9}$$

$$v = r\omega \tag{10}$$

$$a = r\omega^2 = \frac{v^2}{r} \tag{11}$$

From Newton's second law: $F = ma$

$$F = \frac{mv^2}{r} \tag{12}$$

$$F = mr\omega^2 \tag{13}$$

This equation is the force acting towards the centre, and it is called the centripetal force.

F = Centripetal force
m = Mass of object
ω = Angular velocity in radians per second
r = Length of distance covered

2.6.3. Motor selection

The motor selected has the following specifications:

Power = 3.5KW

Speed = 1410rpm

The angular speed ω is

$$\omega = \frac{2\pi N}{60} \tag{14}$$

Where N = speed in rpm

$$\omega = 147.67 rads/sec$$

2.6.3. Design of screw conveyor

The screw must be immersed in the feed materials at least to the level of the casing otherwise, the conveyor does not elevate the bulk materials. The conveyor design throughput capacity is Q = 0.8682 m^3/hr for a bulk density of 50.9434kg/m³ using Equation 15. In the dewatering machine, both material flow and discharge are continuous, such that the throughput capacity is given by:

$$Q\left(\frac{m^3}{hr}\right) = 60\pi\left(D_S{}^2 - d_S{}^2\right).P.N.f \tag{15}$$

Where:

D_S = major diameter of the screw conveyor (mm)
P = pitch of the worm shaft (m)
N = speed of the shaft in rpm
f = material fill factor = 1.0
D_B = Diameter of filter basket in mm

L_B = length of filter basket in mm

Dimensional assumptions made based on pre-analysis of the strength requirement of the screw conveyor are as follows:

D_S = 320mm
d_S = 42mm
D_B =152mm

L_B = 385mm

The diameters assumed for the screw conveyors are considered reasonable as it gave enough clearance to pass maximum feed material thereby preventing jamming action. The clearance between the filter basket and the screw conveyor is enough to ensure complete conveyance and free rotation of the screw conveyor. Substituting the above values in Equation (15).

P = 0.0517m
P = 51.7mm

A design pitch of 51.7mm was chosen.

2.6.4. Design of the screw flight

The screw flight of the cassava dewatering machine has a very close resemblance to the screw threads of the typical screw. Estimation of the screw flight pitches was calculated as follows:

Assume P_f = pitch at feed end = 51.7mm, P_D= pitch at discharge end, t_w= thickness of the screw t = 8mm.

Therefore, volume of feed at feed-end:

$$V_f = \pi\left(D_S{}^2 - d_S{}^2\right)\left(P_f - t_W\right) \tag{16}$$

Volume of the cassava at discharge end:

$$V_d = \pi\left(D_S{}^2 - d_S{}^2\right)\left(P_d - t_W\right) \tag{17}$$

Volume of feed at feed end and that at discharge end are related to compression ratio with this relation,

$$\frac{V_d}{V_f} = \frac{\pi\left(D_S{}^2 - d_S{}^2\right)(P_d - t_w)}{\pi\left(D_S{}^2 - d_S{}^2\right)(P_f - t_w)} = C.R \tag{18}$$

$$\frac{(P_d - t_w)}{(P_f - t_w)} = C.R \tag{19}$$

$$\frac{(P_d - 8)}{51.7 - 8} = 0.5 \tag{20}$$

$P_d = 29.9mm$

$V_d : V_f = 1 : 2$

The maximum volume of the material that can be contained in the filter basket = volume of filter basket to a height of 385mm – the volume of the auger.

Volume of the filter basket to a height of 385mm

$$= \frac{\pi d^2 \times 385}{4 \times 1} \tag{21}$$

$$= 0.00699 m^3$$

In other to calculate the volume of the auger, the volume of the spiral flights is assumed to be negligible, thus:

Volume of shaft

$$= \frac{\pi d_S{}^2 \times 1.2}{4} \tag{22}$$

$$= 0.0005335 m^3$$

d_s = diameter of the shaft
Volume of the mixture in the cylinder is
= (volume of the filter basket – volume of the shaft) m^3
= $0.00646 m^3$

Table 2 shows the values of service factor for different type of service and used in Equation 26 for the computational of the basic dynamic load rating C.

The value for dynamic equivalent load of the desired bearing is estimated by the expression;

$$W = K_s W_R \tag{23}$$

Where, W = equivalent load
W_R = radial load
K_s = service factor
The applied radial load on the shaft is the weight of the screw conveyor and the load on the pulleys.
W = 634.7 x 1.0= 0.6347kN

Table 2: Values of service factor (ks)

S/No	Types of Service	Ball bearings
1	Uniform and steady load	1.0
2	Light shock load	1.5
3	Moderate shock load	2.0
4	Heavy shock load	2.5
5	Extreme shock load	3.0

It was assumed that the machine worked for 8 hours per day for 264 days in a year and 5 years. The number of hours of operation of the machine (L_H)

$L_H = 8 \times 264 \times 5$

= 10,560 hours

Speed of rotation of screw conveyor (N) = 1410rpm

Relationship between life in revolution (L) and the life in working hours is

$$L = 60.N.\ L_{H\ rev} \tag{24}$$

$$= 893 \text{ million rev}$$

This value is the life of the bearing corresponding to 99% reliability.

It is also expected that the bearings are to have 99% reliability corresponding to a life of 10,560 hours. Life adjustment factors for operating condition and material are assumed to be 0.95 and 0.90 respectively. Then from the manufacturer's catalogue specified at 90% reliability, it is essential to calculate the underlying dynamic load rating of the bearings.

L_{90} = Life of the bearing corresponding to 90% reliability

b = 1.17

Considering life adjustment factors for operating condition and material as 0.95 and 0.90 respectively.

$$\frac{L_{99}}{L_{90}} = \left[\frac{\log_e\left(\frac{1}{R_{99}}\right)}{\log_e\left(\frac{1}{R_{90}}\right)}\right]^{1/b} \times 0.95 \times 0.90 \tag{25}$$

$$= 758.5 \times 10^7 \text{rev}$$

From the dynamic load rating Equation 26:

$$C = \left[\frac{WL_{90}}{10^6}\right]^{1/k} \tag{26}$$

(K = 3 for ball bearing)

= 12.47kN

The basic dynamic load rating C is the parameter used in the selection of bearing for the design. Since the bearing is self-aligning ball bearing and C equals 12KN, the bearing number 206 is chosen.

3. RESULTS AND DISCUSSION

3.1. Operating Process Parameters

Table 3 also shows the list of cassava genotypes, used for the experiment. The screw conveyor and the basket speed were maintained at 1365 and 1160 rpm respectively throughout the experiment. These test data were statistically analysed using the Minitab software package. Empirical model equations were developed using the quadratic response surface regression approach. Several types of model equations were investigated, and finally, the equations with the highest adjusted R^2 (coefficient of determination) values were selected for the dewatering responses.

Table 3: Values of the operating process parameters using during the study

Test No	Cassava Genotypes	Feed flow (m^2/s)	Feed solids (% weight)	Screw conveyor (rpm)	Basket speed (rpm)	Pool depth (cm)
1	TMS94/0039	20	12.5	1365	1160	5.08
2	TMS98/0002	20	5.0	1365	1160	2.54
3	TMS99/2123	35	5.0	1365	1160	0.00
4	TMS98/0068	20	12.5	1365	1160	0.00
5	TMS96/1565	35	20	1365	1160	5.08
6	TMS99/3073	35	12.5	1365	1160	2.54
7	TMS95/0166	35	12.5	1365	1160	2.54
8	TMS98/0505	35	12.5	1365	1160	2.54
9	TMS950397	35	12.5	1365	1160	2.54
10	TMS98/0510	35	20.0	1365	1160	0.00
11	TMS96/0603	50	12.5	1365	1160	5.08
12	TMS97/4779	50	12.5	1365	1160	0.00
13	NR8082	50	20.0	1365	1160	2.54
14	TME 419	35	5.0	1365	1160	5.08
15	TME94/0026	50	5.0	1365	1160	2.54
16	M98/0028	35	12.5	1365	1160	2.54
17	TMS82/0058	35	12.5	1365	1160	2.54
18	TMS92/0067	20	12.5	1365	1160	2.54

The individual model equations for the four dewatering responses using the quadratic response surface regression approach using coded units are described as follows:

$$\text{Product moisture (\%)} = 24.14 - 0.05F_S + 0.32F_R - F_S{}^2 + 0.01F_S * F_R \qquad (28)$$

Product (dewatered cassava mash, %) recovery

$$= 68.92 - 4.32F_R + 8.53F_S + 1.82P_D - 0.12{F_R}^2 + 1.96{F_S}^2 + 2.83{P_D}^2 - 0.32F_R * F_S - 0.18F_R * P_D + 0.77F_S * P_D \quad (29)$$

Effluent stream recovery (%)$= 12.06 + 0.66F_S + 3.97P_D - 0.03{F_S}^2 - 0.51{P_D}^2 - 0.16F_S * P_D$ (30)

Screen-drain recovery (%)

$$= -0.64 + 0.87F_R + 0.41F_S - 2.52P_D + 0.02{F_R}^2 - 0.08{P_D}^2 - 0.05F_R * F_S + 0.04F_R * P_D + 0.11F_S * P_D$$

(31)

Where F_R is the feed flow rate in litres per minute (m^2/s), F_S is the solid content in % by weight, and PD is the pool depth in cm. Comparison of experimental data and the predicted data generated from the original model equations for various dewatering performance response.

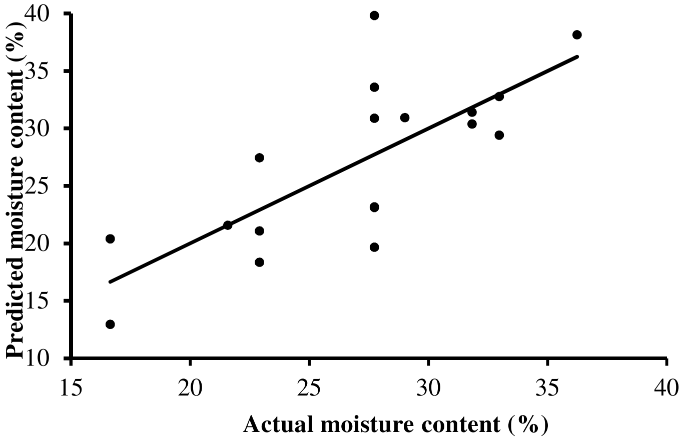


Figure 2: A plot of predicted moisture content against actual moisture content

Figure 2 shows a high scatter in the moisture recovery data and this is the main reason for the low coefficient of determination R^2 (0.562) of the corresponding regression fit. Temperature plays a vital role in the moisture content of dewatered products. It also contributed to the high scatter of data recorded.

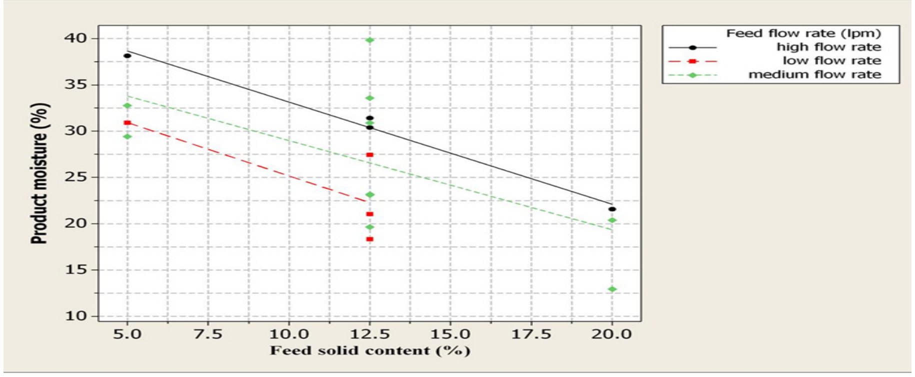


Figure 3: Product moisture versus solid feed content

As shown in Figure 3 the medium feed solid content produces better moisture separation than the low feed solid content. With a centrifugal field of 380Gs maintained inside the centrifuge, the hindered settling environment results in more residual moisture in the thickened solid bed leaving the solid section and entering the screen section of the basket.

Figure 4 shows that at a higher pool depth and higher solid content, effluent recovery is lowest. Effluent recovery is highest with medium pool depth combination of solid feed content.

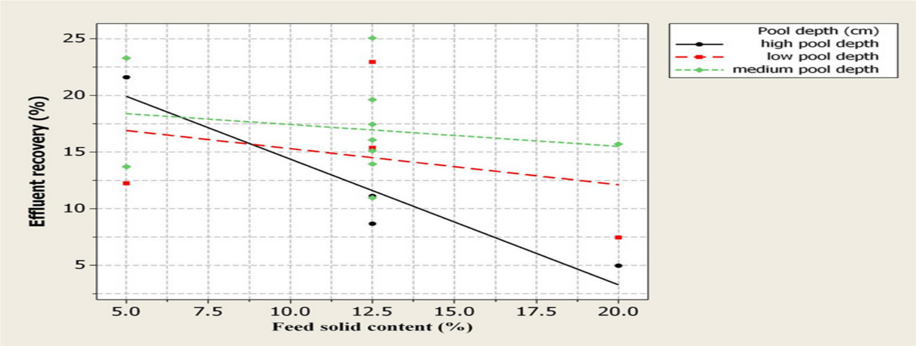


Figure 4: Effluent recovery against solid feed content

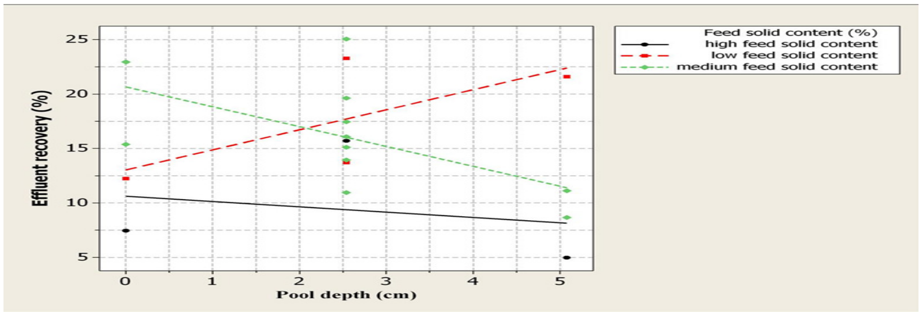


Figure 5: Effluent recovery (%) against pool depth (cm)

Figure 5 shows that at high feed solid content and high pool depth, effluent recovery is lowest. This agrees with Figure 6. It is highest with low feed solid content combination of pool depth. This means that the plate-dam height needs to be adjusted to maintain the same level of product loss at various levels of solid feed content. It can also be seen in figures 4 and 5 that at a higher pool depth and higher feed solid content secondary effluent would be recovered. In the dewatering machine, the majority of the water recovered to the effluent stream is more with low feed solid content due to its higher moisture content. The greater the rate of effluent water is believed to carry over a greater amount of entrained ultrafine cassava mash particles causing a greater loss of the product. The interaction effects of solid feed content versus feed flow rate and feed solid content versus pool depth have a significant effect on the product recovery to the screen-drain. Figure 6 shows that at a low feed solid content and high flow rate screen –drain recovery is highest. At high feed solid content and low flow rate, screen-drain recovery is lowest.

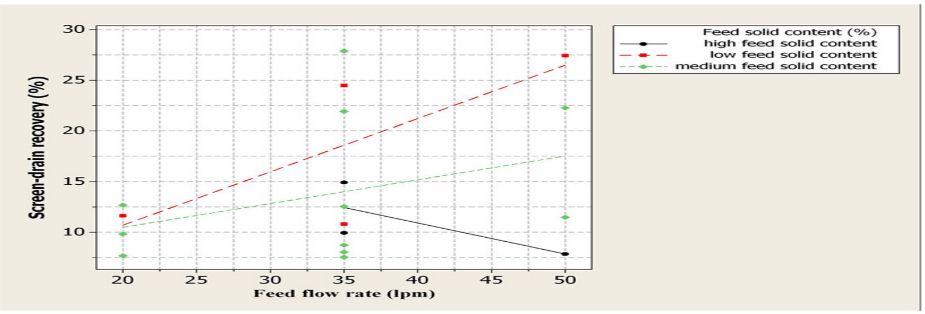


Figure 6: Screen-drain (%) against feed flow rate (m^2/s)

Figure 7 shows that at a high feed solid content between 15-20% and flow rate between 20-37lpm, the product moisture recovery is less than 20%. Moreover, at a solid feed content between 5-7% and feed flow rate between 40-50lpm, the product moisture recovery is higher than 35%. In the second graph of, at a high pool depth between 0-5.08cm and low feed flow rate between 20-35%. The product moisture recovery is between 20-25%. Moreover, at a pool depth between 0-3.2cm and feed flow rate between 42-50lpm, the product moisture recovery is between 30-35%. In the third graph, at a pool depth range between 1.4-5.08cm and feed solid content between 18-20%, the product moisture recovery is less than 20%. At a pool depth between 0-5.08cm and feed solid content between 5-10%, the product moisture recovery was between 30-35%.

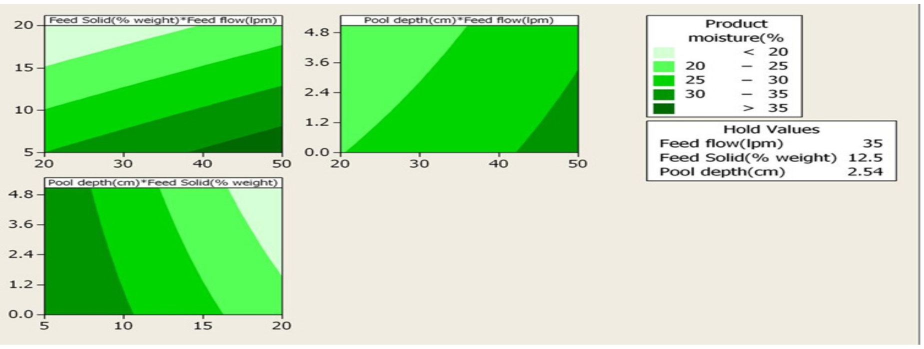


Figure 7: Contour plots of product moisture (%)

4. CONCLUSION

The moisture content of the product is affected by solid feed content, and volumetric feed flow rate maintained in the centrifuge but not by the pool depth. At a high feed solid content, a free settling environment created inside the centrifuge allows an adequate solid-liquid separation, which results in low moisture content of the product. However, the lower solid content of the feed mash tends to create more of a hindered settling environment inside the centrifuge which prevents complete separation of liquid from the grated mash. This leads to the substantial amount of residual moisture in the solid bed, which exits from the solid section of the centrifuge. The high moisture content of the thickened solid entering the screen section results in relatively high moisture content of the product. On the other hand, the decrease in feed flow rate restricts the flow of water to the effluent port. This effectively allows more amount of water to remain in the thickened mixture which exits from the solid section of the basket. The high moisture of the thickened fluid entering the screen section results in the relatively high water content of the product leaving the screen section. It is discharged at the product outlet. The recovery of the product to the outlet is a function of solid feed content, volumetric feed flow rate and pool depth.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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