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Full Length Research

Theoretical modeling of strain in the single screw feeder of cassava flash dryer

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The aim of this study is to model screw feeder unit to handle granulated wet cassava to the flash dryer column. The knowledge of the flow behavior, physical and mechanical properties, rheology of the product and the geometrical characteristics of feeders unit were essential to evaluate the best conditions of handling granulated cassava based on the theory of virtual works. The effect of granular media strain on the rotational speed which is limited to 2 rps corresponding to the elastic limit of 30% was studied. With the same strain limit, maximum screw length of 1300 mm and the maximum residence time of 100 s in the bin were identified as the best area used to design the screw feeder unit and conduct the process operation. The modeling of the strain was based on the theory of virtual works or energies.

Key words: Modeling, virtual works, strain, screw feeder, cassava.

INTRODUCTION

The screw feeder is one of the most useful feeding devices which not only has good metering characteristics, but also uses relatively simple components and can be designed to feed many kinds of bulk solids, reliably in a variety of applications. Those materials can be chemical, agricultural, pharmaceutical and mineral. The rheology of the granular media is very important when designing devices in order to avoid blockage, flooding, air lock and others which are the main problems. Rheology is the study of the behavior of material when subjected to stress or strength. Metcalf (1965) considered the mechanics of a screw feeder, concentrating on the rate of delivery and

the torque required to feed different types of coal using mining drill rods as screws. The model chosen was that of a rigid plug of material moving in a helix at an angle to the screw axis. A detailed experimental investigation was conducted by Burkhardt (1967). The tests included the effect on the performance of a screw feeder, of the pitch, the radial clearance between the screw flight and trough, the hopper exposure and the head of the bulk solid contained in a hopper. Rautenbach and Schumacher (1987) carried out scale-up experiments with two geometrically similar screws. By dimensional analysis, the relevant set of dimensional numbers was derived for

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the calculation of power consumption and capacity. More recently, Roberts and Manjunath (1994) analyzed the mechanics of screw feeder performance in relation to the bulk solid draw-down characteristics in the feed hopper. In their study, the force exerted on the screw flights is assumed to be uniformly distributed along the whole feed length and three empirical pressure ratios are used in the determination of the required torque. Problems like metering, unsteady flow rates, bridging, channeling, arching, product inhomogeneity, segregation, high startup torques, equipment wear and variable residence time have been reported by many researchers (Cleary, 2007; Owen and Cleary, 2010; Bortolamasi and Fottner, 2001). In addition, the design and optimization of screw feeder performance is not well understood and has been based on semi-empirical approach, numerical or experimental techniques using dynamic similarities (Bortolamasi and Fottner, 2001). Earlier researchers have investigated the effect of various screw (auger) parameters including choke length (the distance beyond which the screw projects beyond the casing at the lower end of the intake) and pitch-diameter ratio (Ghosh, 1967). Augers with large diameters attain maximum output at lower speeds as compared to those with small diameters. They also reported that for maximum throughput during conveying, longer chokes are necessary. The subject of modelling screw conveying of granular materials with the Discrete Element Method (DEM) Cundall and Strack (1979) is fairly recent.

The model we are going to elaborate will help the constructors of screw feeders unit to take decisions when designing devices in order to ameliorate energy consumption, efficiency of the equipment and the best quality product.

MATERIALS AND METHODS

Feeder loads

McLean and Arnold (1979) proposed the simplified approach to evaluate the feeder loads for mass flow bins Q which is uniformly distributed over the hopper outlet by the following relation:

$$\sigma_0 = \frac{Q}{LB} \tag{1}$$

B , opening width of hopper outlet (m); L , length of feed section (m); Q , feeder loads (N); σ_0 , resulting stress (N/m²).

When a moving bulk solid reaches steady state, there is equilibrium between the driving force and the resisting force. Assuming that the axial stress and the radial stress are functions of x only as showed in Figure 1, we have the transverse section of a screw pitch (Figure 2). Stress σ_w is the normal wall pressure acting perpendicularly to the wall of the trough and the core shaft. σ_x , axial compression stress (N/m²); τ_w , shear stress on confining surface (N/m²); R_t , radius of the trough (m); R_c , radius of the core shaft (m).

The ratio $\lambda_s = \frac{\sigma_w}{\sigma_x}$ is known as the stress ratio of the bulk material sliding on the confining surfaces (trough and core shaft surfaces) (Figure 3). A general expression can be obtained by:

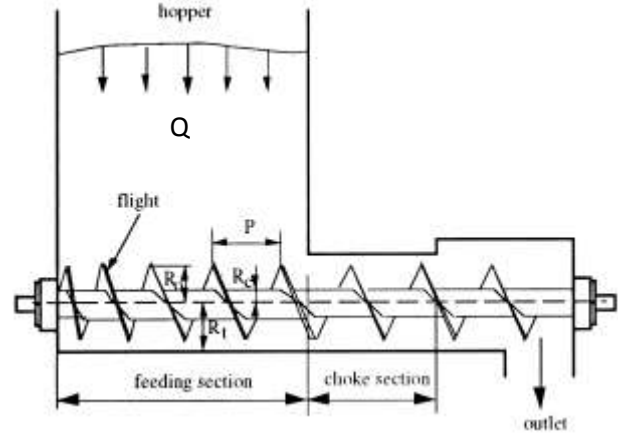


Figure 1. Typical form of a hopper fitted with a screw feeder (McLean and Arnold, 1979).

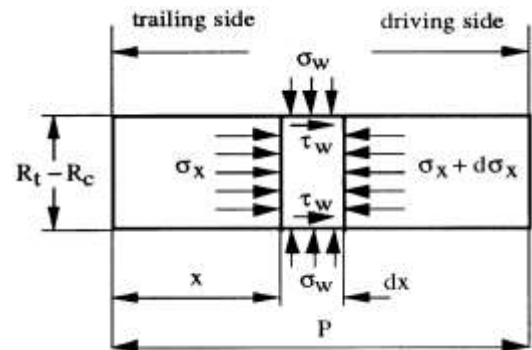


Figure 2. Stress on an element at the lower region of the screw.

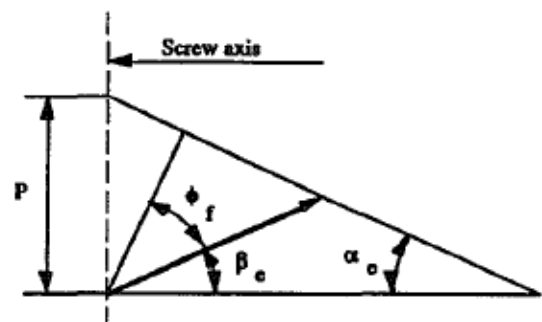


Figure 3. Direction of material element motion.

$$\lambda_s = \frac{\sigma_w}{\sigma_x} = \frac{1}{1+2\mu_d^2+2[(1+\mu_d^2)(\mu_d^2-\mu_w^2)]^{1/2}} \tag{2}$$

μ_w is the friction coefficient between the bulk solid and the confining surface.

$$\mu_w = \frac{\tau_w}{\sigma_w} \tag{3}$$

Table 1. The characteristics of granulated cassava (CIGR Handbook of Agricultural Engineering Volume IV) (1999).

Parameter	Symbol	Values
Bulk density	ρ_b (Kg/m ³)	760
Young modulus	E (N/m ²)	2370000
Poisson's ratio	ν	0.38
Friction coefficient between the bulk solid and a confining surface	μ_w	0.364
Friction coefficient of the bulk solid	μ_d	0.80

μ_d is the friction coefficient between the bulk solid and the confining surface.

$$\mu_d = \tan \delta \quad (4)$$

Where δ is the effective angle of internal friction of the bulk solid. Average wall stress was defined by Yu and Arnold (1997) as:

$$\sigma_{wm} = \sigma_0 \frac{R_t - R_c}{2\mu_w} \left[\exp \left(\frac{2\mu_w \lambda_s P}{R_t - R_c} \right) - 1 \right] \quad (5)$$

The theory of the uniform flow pattern is

$$\mathbf{M} = \rho_g (R_t^2 - R_c^2) P n \eta_v \quad (6)$$

M , mass of product per revolution (kg); ρ_g , density of bulk solid (kg/m³); η_v volumetric efficiency; P screw pinch (m); n , number of screw revolutions.

The volumetric efficiency has been proposed by Yu and Arnold (1996) as:

$$\eta_v = \frac{\tan \beta_c}{\tan \beta_c + \tan \alpha_c} \quad (7)$$

$$\text{Where } \beta_c = \tan^{-1} \left[\frac{\pi(D+d) - 2\mu_w P}{2P + \pi\mu_w(D+d)} \right]$$

$\alpha_c = 90^\circ - \phi_w - \beta_c$; α_c = flight helix angle at core shaft (deg), β_c = friction angle between particles bulk (deg), ϕ_w = wall friction angle between bulk solid and confining surface (deg),

Theory of virtual works

The modeling is based on the theory of virtual works or energies which is related by:

$$\int_D f_1 \delta U_1 dv + \int_S F_1 \delta U_1 ds = \int_D \sigma_{ij} \delta \epsilon_{ij} dv \quad (8)$$

σ_{ij} , Tensor of constraints; ϵ_{ij} , tensor of deformations; F_1 , Force of surface (N/m²); f_1 , force of volume (N/m³); U_1 , displacement (m).

It is assumed that there is no internal variation of energy in the medium, then $\int_D f_1 \delta U_1 dv = 0$ and (8) becomes:

$$\int_S F_1 \delta U_1 ds = \int_D \sigma_{ij} \delta \epsilon_{ij} dv \quad (9)$$

Assumptions

1. We work in a plan deformation on the revolution problem,
2. The medium is homogeneous and isotropy, then (9) becomes:

$$\mathbf{F} \mathbf{U} \mathbf{S} = \sigma_{ij} \delta \epsilon_{ij} \mathbf{V} \quad (10)$$

$$\mathbf{F} = \sigma_{ij} \delta \epsilon_{ij} \quad (11)$$

The matrix form of (11) is:

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & F_{zz} \end{bmatrix} = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \begin{bmatrix} \epsilon^2 & \frac{\epsilon^2}{1-\nu} & \frac{\epsilon^2}{1-\nu} \\ \frac{\epsilon^2}{1-\nu} & \epsilon^2 & \frac{\epsilon^2}{1-\nu} \\ \frac{\epsilon^2}{1-\nu} & \frac{\epsilon^2}{1-\nu} & \epsilon^2 \end{bmatrix} \quad (12)$$

$$F_{zz} = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \epsilon^2 = \sigma_{wm} \cdot S \quad (13)$$

Where E is Young Modulus, ν is Poisson's ratio;

Equation (5) in (13):

$$\frac{\pi M g}{LB} (R_t^2 - R_c^2) \frac{R_t - R_c}{2\mu_w \lambda_s P} \left[\exp \left(\frac{2\mu_w \lambda_s P}{R_t - R_c} \right) - 1 \right] = \frac{E(1-\nu) \epsilon^2}{(1+\nu)(1-2\nu)} \quad (14)$$

Equation (6) in (14):

$$\frac{\pi g \rho_b P n \eta_v}{LB} (R_t^2 - R_c^2)^2 \frac{R_t - R_c}{2\mu_w \lambda_s P} \left[\exp \left(\frac{2\mu_w \lambda_s P}{R_t - R_c} \right) - 1 \right] = \frac{E(1-\nu) \epsilon^2}{(1+\nu)(1-2\nu)} \quad (15)$$

$B = 2R_t$ and $L = xP$; x = pitch number after n revolution = $N \cdot t$,

Equation (15) becomes:

$$\frac{\pi g \rho_b N \eta_v}{2R_t x L} (R_t^2 - R_c^2)^2 \frac{(R_t - R_c)}{2\mu_w \lambda_s P} \left[\exp \left(\frac{2\mu_w \lambda_s P}{R_t - R_c} \right) - 1 \right] t = \frac{E(1-\nu) \epsilon^2}{(1+\nu)(1-2\nu)} \quad (16)$$

Where, N is rotational speed and t the residence time.

Equation 7 must also be introduced in 16 which is the final theoretical model. The characteristics of granulated necessary for the simulation of the equation are shown in Table 1.

RESULTS AND DISCUSSION

Figures 4, 5 and 6 present the same evolution of the strain. Each curve in the figures has two parts.

1. The first part is linear and corresponds to the elastic strain. When $N = 0$ rps, the screw is stopped corresponding to the strain of 0%. As N (rotational speed) increases up to 2 tr/s, the strain increases also rapidly until elastic limit of 30%. For the same elastic limit, the maximum screw length is 1300 mm according to Figure 5 and the residence time of product in the hopper is 100 s according to Figure 6.

In those elastic parts, the product flows normally and keeps well his best quality. In those conditions, the flow operation can avoid blockage, flooding, air lock and the

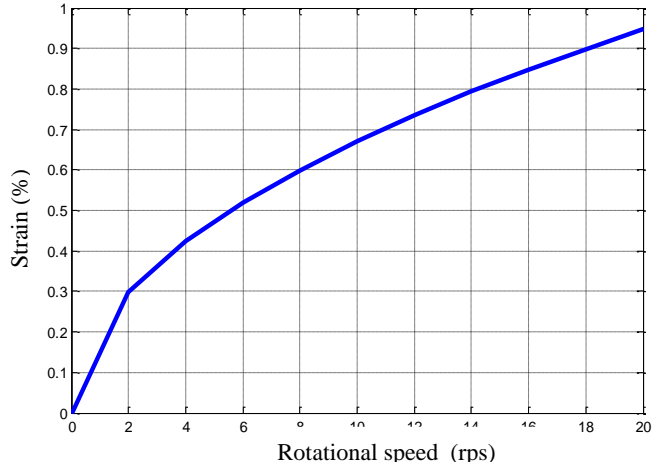


Figure 4. Influence of the screw rotational speed on the strain.

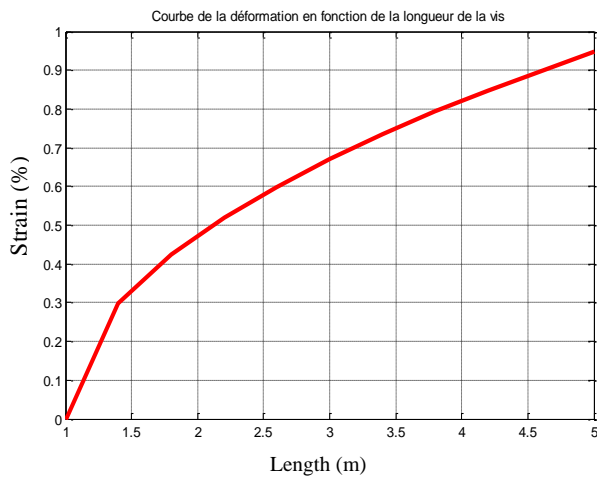


Figure 5. Influence of the screw length on the strain.

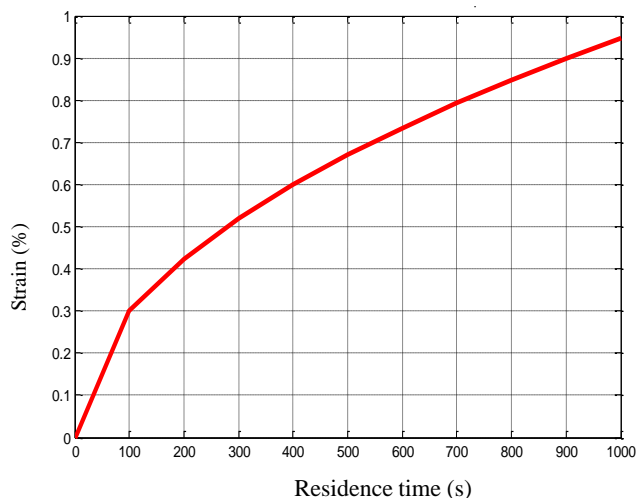


Figure 6. Influence of the residence time on the strain.

equipment is efficient and effectiveness.

2. The second part is nonlinear corresponding to the plastic strain. In those parts, the deformations increase very slowly with the increase of rotational speed, screw length and residential time in the hopper. It can be concluded that the product is well damaged and affect the flow and the quality. These are the characteristics of poor equipment designed because if the hopper is bigger than the normal, if the length of screw is too long and if the rotational speed is high, then the constrains of the equipment will have time to damage the granulated cassava, transforming it solid nature to liquid. The liquid state of cassava cannot allow the flow in the equipment. The cassava must pass with less time in the screw feeder and must be conducted with low rotational speed in order to keep the quality of the product for the next processing and to enhance the output of the equipment.

Conclusion

The physical properties and structure of the granular matters are often accompanied by modifications of the product which affects the flow directly. The formation of the pasty structure and the interruption of flow in the screw feeder influence the course of drying, the quality of the ended product and reduces the output of the equipment. The choice of operation when designing equipment must be done in the elastic zone to preserve the quality of the product and to allow a better operation of the equipment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Life cycle assessment of cassava flour production: A case study in Southwest Nigeria

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Global climate change resulting from increased greenhouse gas emission and environmental pollution remain a serious threat to the world. Food processing industries is one of the major contributors to global greenhouse gas emissions. Intergovernmental Panel on climate change (IPCC) reported that greenhouse gas emission should be reduced to avert the worst effects of climate change. One of the ways to reducing greenhouse gas emission is by assessing the environmental impact associated with food production, and one of the well-known methodologies used for environmental impact evaluation is life cycle assessment model (LCA). This paper presents the results of LCA analysis of cassava flour production in Southwestern Nigeria. The result shows that global warming potential of cassava flour production was 1.105E+01 kg CO₂ equivalent, eutrophication 2.632E-03 kg NO₃ equivalent and acidification 5.583E-03 kg SO₂ equivalent. In this study, the major contributor to global warming is the carbon dioxide (CO₂) emission from burning of fossil fuel (Coal) used for drying operation which emits 93% of the CO₂, while 7% of the total CO₂ emission is from the diesel generator. This study has shown that cassava flour production is contributing greatly to environmental global warming potential in Southwest Nigeria.

Key words: Greenhouse gas, life cycle assessment, global warming, eutrophication, acidification.

INTRODUCTION

Cassava (*Manihot esculanta crantz*), is extensively cultivated as annual crop in the tropical and subtropical regions of the world for its edible, starchy, tuberous root which serve as a major source of carbohydrates. Cassava, under adverse growth conditions may take about 18 months to produce crop, and 8 months under favourable conditions. Cassava tolerates a wide range of soil pH (4.0 to 8.0). It grows best in the full sun.

Traditionally, it is grown in a Savannah climate, but it can grow in a wide range of rainfall conditions such as 1000 to 2000 mm/a (Kuiper et al., 2007).

Cassava ranks third on the list of major food crops in developing countries after rice and maize with production in 2010 estimated at 249 million tonnes (UNCTAD, 2012). During the last decade, the output of cassava has grown much faster in Africa than in the other major producing

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regions due to increasing cultivation. Thus, cassava is critical to the food security strategy in the world particularly the third world nations. According to FAO statistics in Worldlistmania (2016), Nigeria is the largest producer of cassava in the world, with a production of 52 million tons from an area of 4.118 m ha, a third more than production in Brazil and almost twofold the production of Indonesia and Thailand.

The production of cassava was mainly located in the south and central regions of Nigeria, and accounted for about 70% of the total production of tuber crop in West Africa (IFAD/FAO, 2004). Traditionally, Cassava is consumed in Nigeria in form of 'gari', which is a fermented and dehydrated grains with high starch content, and very few household process it into Cassava flour until recently when the need for Cassava flour in bread baking arose. Cassava is now processed into flour in industries due to the Federal Government of Nigeria policy of 10% inclusion of Cassava flour into bread making. Cassava flour is also used in the making of noodles, biscuits and confectioneries (Sidi, 2005).

However, along with this positive effect of cassava flour production, some negative impacts on the environment have also been caused. Cassava processing, especially in areas where the industry is highly concentrated, is regarded as polluting and a burden on natural resources (FAO, 2007). In order to ensure sustainable environment, there is a need for determining appropriate processing technologies devoid of environmental degradation, which is the main thrust of this study. The objective of the study was to identify and quantify potential environmental impacts associated with cassava flour production in Southwest Nigeria, especially activities that have the largest impacts and then suggest improvement options or impact reduction strategies towards the sustainability of the system.

METHODOLOGY

Life cycle assessment

Worldwide, environmental awareness increases as part of the wider sustainable ethos, and for that, industries and businesses have started to assess how their activities affect the environment. One tool for identifying quantitatively environmental impacts of products/process is life cycle assessment (LCA) method.

The Society of Environmental Toxicology and Chemistry (SETAC, 1993) defined the LCA as an iterative process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and waste released to the environment; to assess the impact of those energy and material used and released to the environment; and to identify and evaluate opportunities to effect environmental improvements. Gordon (2006) further defined life cycle assessment as an environmental management tool, which attempts to consider the resource and energy use and the resultant environmental burdens over the entire life cycle of a package, product or service from extraction of the raw materials through manufacture/conversion, distribution and use to recovery or disposal. As a process it can be considered as a systematic and phased approach,

which consists of four components: goal definition and scope, inventory analysis, impact assessment, and interpretation (United Nations Environment Programme, 2002).

Goal definition and scope

Goal definition and scope is the phase of the LCA process that defines the purpose and basis of the study. The goal of this study was to identify and determine the degree of environmental burden associated with cassava flour production in Southwest Nigeria. The scope of LCA consists of functional unit, system boundary, data requirements, any assumptions and limitations (ISO, 1997), and they are subsequently discussed.

Functional unit: The functional unit defines what precisely is being studied, and quantifies the service delivered by the product system. It also provides a reference to which the inputs and outputs can be related. For this study, the functional unit chosen was 1000 kg of cassava tuber processed.

System boundary: The system boundary of the cassava flour production is shown in Figure 1. In the figure, different types of energy and raw materials go into cassava processing as input, while after the processing operation there were outputs such as; wastes, emissions and desired product(s)

Inventory analysis and data collection

In the life cycle inventory (LCI) phase of LCA, all relevant data is collected and organized. Without an LCI, no basis exists to evaluate comparative environmental impacts or potential improvements. The data sources that were used for this study were both primary and secondary data sources. Primary data is site specific and was obtained by visitation to a cassava flour producing factory at Shagamu-Benin Express way near Ijebu-Ode, Ogun State Nigeria in the year 2014. Data were collected during site visitation with the use of structured questionnaire. The inventory of material input and output is presented in Table 1. Secondary data required to convert resources input into their energy equivalent were collected from literatures and relevant LCA database (IPCC, 2006; NPI, 2002).

Life cycle impact assessment (LCIA)

A LCIA provides a systematic procedure for classifying and characterizing the environmental effects. LCIA for this study was done in accordance with the procedure of International Standard Organization (ISO) for conducting an impact assessment entitled ISO 14042, (ISO, 1998), which states that impact category selection, classification, and characterization are mandatory steps for an LCIA. The inventory data for this study was grouped into the environmental impacts of global warming, eutrophication, and acidification.

RESULTS AND DISCUSSION

Results presented in this work are related to two aspects; the energy use in the production of cassava flour and the environmental impacts of the product system boundary.

Energy use

The processing of cassava flour was divided into eight

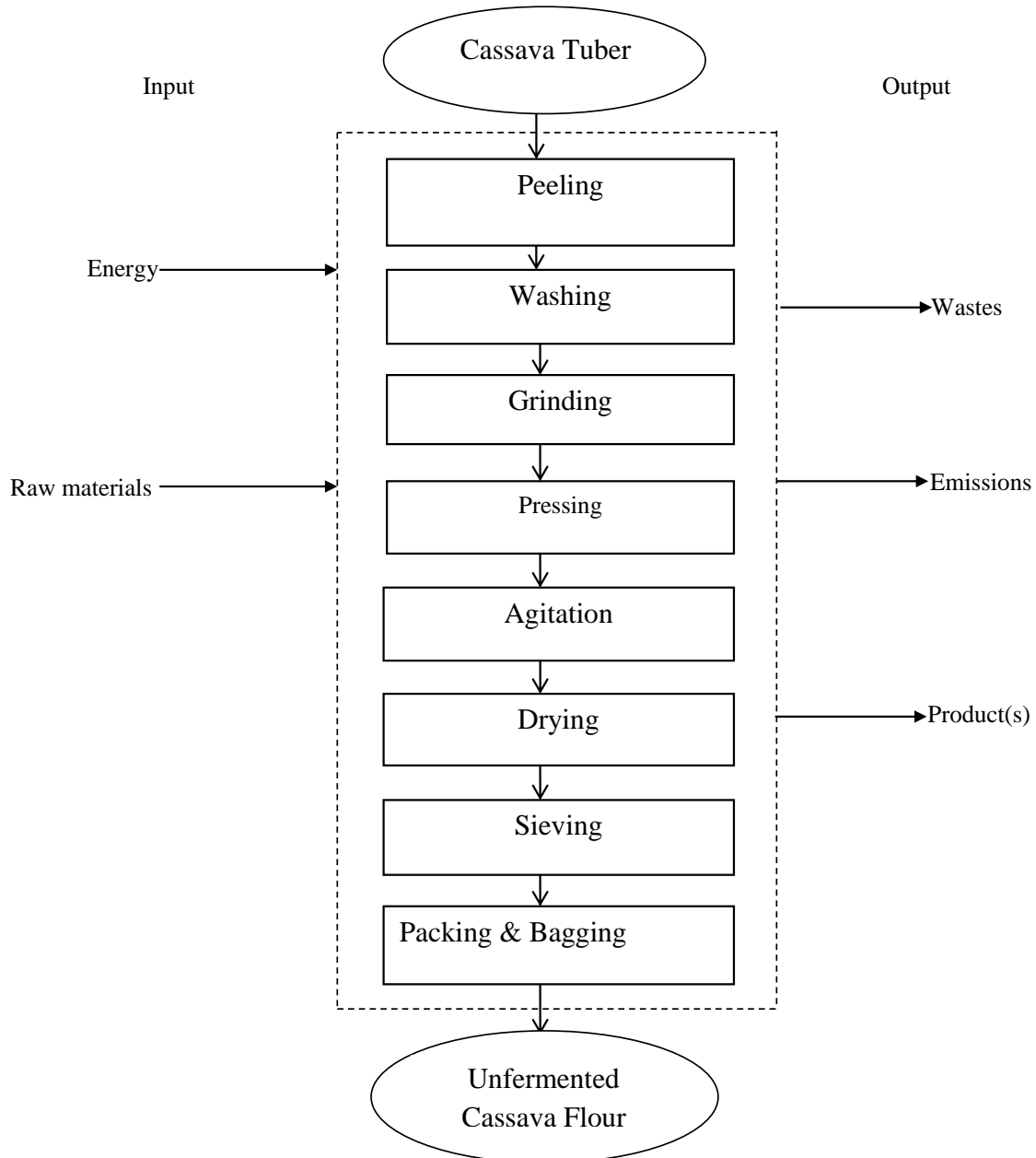


Figure 1. System boundary of unfermented cassava flour production.

unit operations excluding power generation and the total energy used was grouped into manual, thermal, electrical and chemical energy.

The results is shown in Figure 2, and it could be observed that drying consumes the largest energy during the processing of cassava into flour using 64.86% of the total energy and this is due to the combustion of coal to generate heat for the drying process. The next operation that consumes large energy is grinding using 17.45% of the total energy. This is followed by sieving, packing and bagging contributing 5.54 and 5.38% respectively. Therefore, effort must be made to reduce the energy

consumption during drying. However, other means of generating heat should be considered for the drying operation such as biogas which is domestic and environmentally sound renewable fuel (Cilliers, 2006; Papong and Malakul, 2010; Strehler, 1998).

Environmental impact based on LCA methodology

The emissions from the system boundary have been grouped into impact categories of global warming, eutrophication and acidification as shown in Table 2 with

Table 1. Inventory data of cassava flour production.

Parameters / energy input	Measurement units of inputs	Values of Inputs and outputs per 1000 kg of cassava
Diesel	MJ	3.942E+02
Stationary engines	MJ	9.180E+03
Coal	MJ	3.879E+03
Sulphur	MJ	1.360E+00
Environmental output emission from fuel combusted		
CO ₂	Kg	7.883E+02
CH ₄	Kg	0.122E+00
N ₂ O	Kg	2.167E-03
Emission from stationary engines		
CO	Kg	2.199E+00
SO ₂	Kg	4.272E+00
NO _x	Kg	1.876E+00
Emission from coal		
CO ₂	Kg	1.025E+04
SO ₂	Kg	4.187E+00
Emission from sulphur		
SO ₂	Kg	1.551E-03
Products		
Cassava flour	Kg	3.120E+02

Table 2. Characterization results for emissions in the production of cassava flour.

Environmental impact category	Emissions	Amount (kg)	Characterization factor ^a	Units
Global warming	CO ₂	1.104E+02	0.0010	Kg CO ₂ -equivalent
	CH ₄	0.122E+00	0.025	
	N ₂ O	2.167E-03	0.3200	
	CO	2.199E+00	0.0020	
Acidification	SO ₂	4.272E+00	0.0010	Kg SO ₂ equivalent
	NO _x	1.876E+00	0.0007	
Eutrophication	NO _x	1.876E+00	0.0014	Kg NO ₃ –equivalent
	N ₂ O	2.167E-03	0.0028	

the respective characterization factors. The total scores for each of the selected environmental impact categories are presented in Table 3. It could be observed that global warming potential has the highest impact score with 1.105E+01 Kg CO₂ equivalent followed by acidification and eutrophication potentials respectively. These results compare with the findings of other authors such as; Ntiamoah and Afrane (2008) who found that Cocoa beans processing in Ghana contributed predominantly to photochemical ozone creation potential, global warming potential, acidification potential and abiotic depletion potential. Also, Papong and Malakul (2010) discovered

that the ethanol conversion stage contributed mostly to the environmental impacts due to the use of coal for power and steam production in the bioethanol plants.

Characterization factors are obtained from Kasmaprueet et al. (2009) and Frischknecht et al. (2004). The units are obtained from Kasmaprueet et al. (2009), Ntiamoah and Afrane (2007).

Global warming

As shown in Figures 3 and 4, the major contribution to

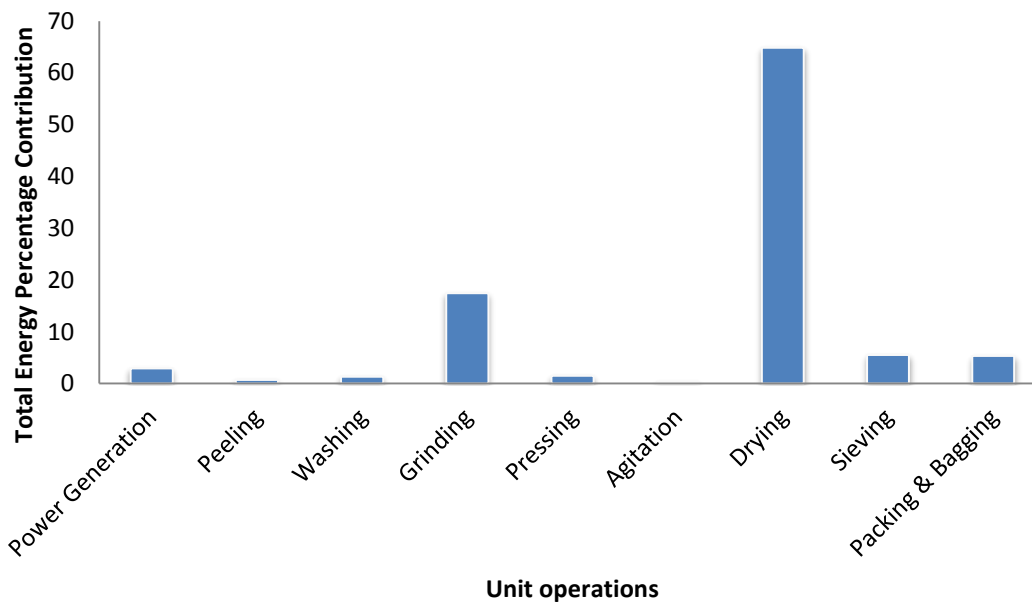


Figure 2. Percentage of total energy used in cassava flour production per unit operation.

Table 3. Characterization results for the production of cassava flour.

Environmental impact category	Total impact score	Units
Global warming	1.105E+01	Kg CO ₂ equivalent
Acidification	5.585E-03	Kg SO ₂ equivalent
Eutrophication	2.632E-03	Kg NO ₃ - equivalent

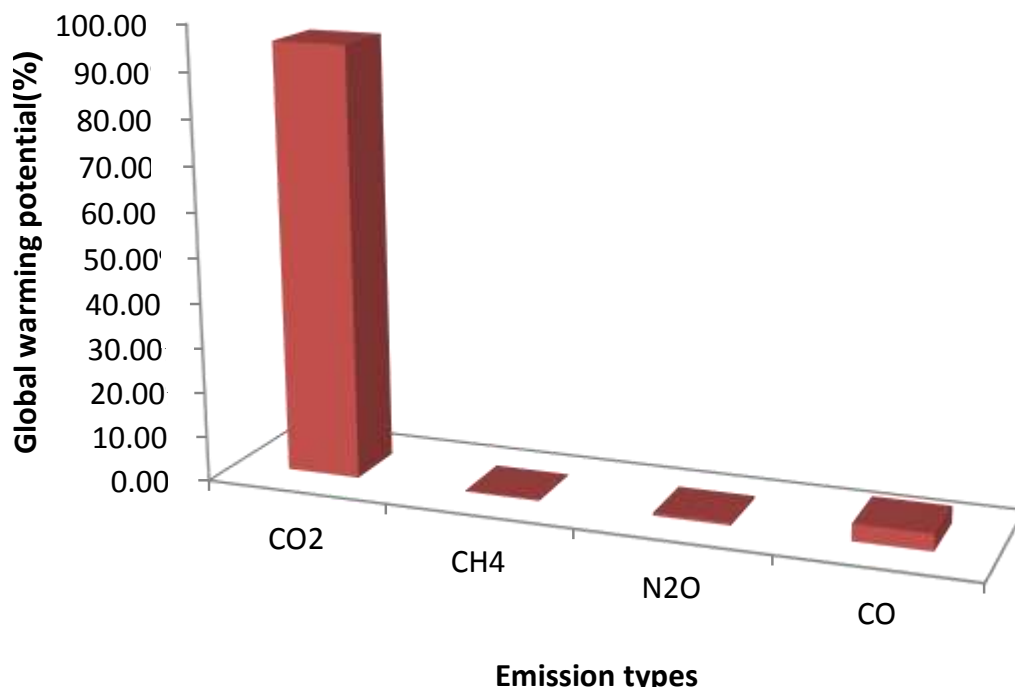


Figure 3. Emission types' contribution to total global warming potential in cassava flour production.

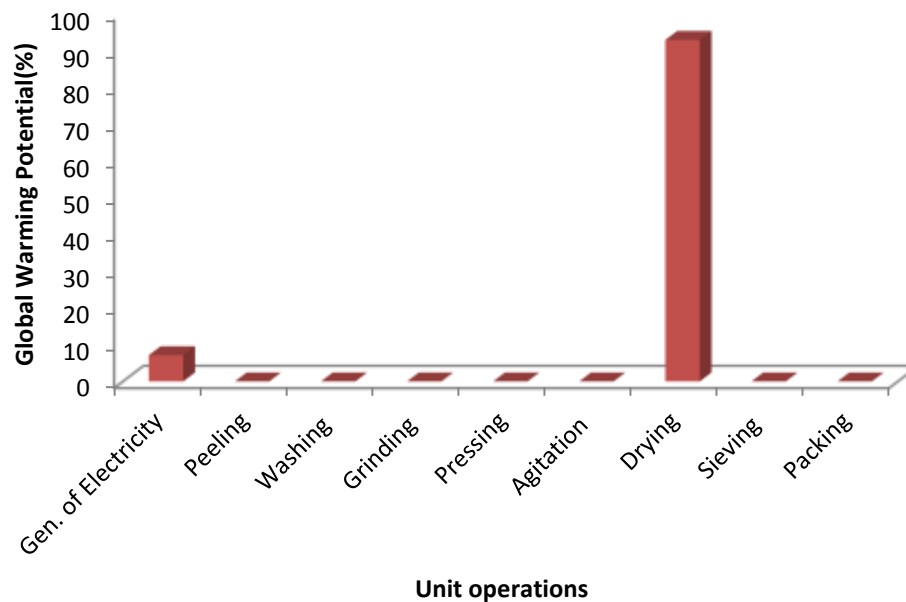


Figure 4. Contribution of unit operations to global warming potential in unfermented cassava flour production.

global warming is the carbon dioxide (CO_2) emission from combustion of fossil fuel (coal) for drying operation and combustion of diesel use in the generator to operate the electrical motor during the production operation. 93% of CO_2 is emitted from the burning of coal which is used majorly for drying operation while 7% of the total CO_2 emission is from the diesel generator. N_2O and CH_4 emissions from the combustion of diesel fuel and CO emission from coal combustion also contributed to global warming potential. Thus, the drying method involved in cassava flour production in the studied factory using fluidized bed drier and coal as energy source is contributing noticeably to the total global warming in Southwest, Nigeria.

Acidification

The acidification emission of the various processes in cassava flour production is presented in Figure 5. The total acidification in this study is $5.585\text{E}-03$ kg SO_2 equivalent. The drying process has the largest contribution to acidification emission (67.71%) followed by the grinding process (15%), sieving (7%) and packing (6.7%) of the total acidification emissions. The acidification potential was caused mainly from the drying operation due to the atmospheric pollution arising from emission of nitrogen oxides (NO_x) and sulphur oxide (SO_2) from the combustion of coal which was used to generate heat for the fluidized bed dryer. NO_x reacts with hydrogen to produce nitric acid (HNO_3) which has an acidifying effect on soils and freshwater (Charterjee, 2005).

Furthermore in order to enhance whitening during cassava flour production, fumes of heated sulphur is channeled into water which is used for washing and grinding of Cassava tuber, and this form H_2SO_3 (sulphurous acid). The waste water generated during washing and pressing is channeled into an earth reservoir which is unlined. Thus, the waste water leaches into the soil. H_2SO_3 lowers the soil pH making the soil unsuitable for planting due to the presence of H^+ ions which damage root cell membranes. Also, sulphur can be found in the air in many different forms. It can cause irritations of the eyes and the throat when the uptake takes place through inhalation of sulphur in the gaseous phase (Charterjee, 2005).

Eutrophication

Eutrophication is a form of water pollution caused by NO_x emission from stationary machines used during the flour production process and from NO_2 emitted by the combustion of diesel used to generate electricity. Also waste water generated during washing and pressing operation of cassava tuber was discharged into an earth reservoir which is unlined. The waste water leached into the soil and result to eutrophication of the surrounding water bodies.

Conclusion

It has been shown from the case study that the production of unfermented Cassava flour in Southwest

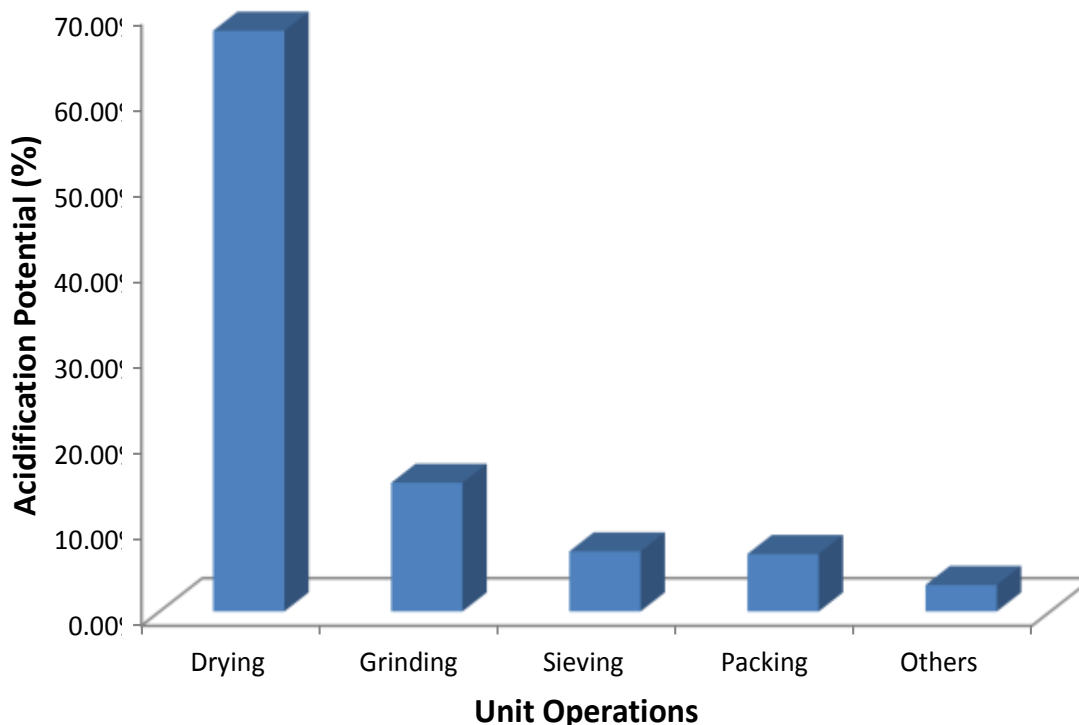


Figure 5. Contribution of unit operations to acidification potential in unfermented cassava flour production.

Nigeria is contributing to environmental degradation, due to emission of greenhouse gases into the environment from resources used. Particularly, the process has resulted in contributing to global warming potential, acidification and eutrophication impact in the region. Although, drying is an important process operation in the production of unfermented cassava flour, yet the combustion of coal during drying has contributed noticeably to the global warming potential. Furthermore, combustion of diesel fuel in power generation has also been found to impact the environment negatively through emission of harmful gases. The use of flash drying technology and alternative fuel such as biogas/biodiesel could reduce environmental impact associated with Cassava flour production in the region.

Conflict of Interests

The authors have not declared any conflict of interests.

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