Physical Science International Journal

26(6): 29-38, 2022; Article no.PSIJ.92979
ISSN: 2348-0130

Design and Development of a Low Cost Laterite Sieving Machine

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/PSIJ/2022/v26i6749

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/92979

Original Research Article

Received 15 August 2022
Accepted 19 October 2022
Published 09 November 2022

ABSTRACT

Sieving has been an essential process in the use of laterite for building, agriculture, etc. However, manual laterite sieving results to drudgery, fatigue, and time wastage during the processing. The method of laterite sieving is still being done manually in some parts of the country and therefore labour intensive. This is because a lot of Small and Medium Scale Entrepreneurs cannot afford the existing sieving machines because of their cost implications and availability. The simple aim of this paper is to develop a laterite sieving machine that will enhance the efficient sieving of laterite sand to be used in the construction/housing sector and also to reduce drudgery. This paper presents the design of an efficient laterite sieving machine that was developed with locally sourced materials with ease of maintenance amongst other advantages. The machine motion was designed with the concept of crank and slider mechanism. The machine is powered with a 2.43kW, 2600 RPM diesel engine and with the appropriate pulley ratio, the machine operated at a speed of 440RPM with an operating rate of 300kg/hour. The machine component parts include prime mover, Hopper, driving/driven pulley, belt guard, sieving unit and the machine frame. Several fabrication techniques such as welding, machining, etc. are adopted for the fabrication of the machine. Dry laterite sample was tested with the machine for operational effectiveness and the result shows that the machine has a sieving capacity of 300kg/hr and sieving efficiency ranging from 92 - 97%. The fabricated laterite sieving machine performed well with high sieving efficiency, reliability, durability with an estimated cost of 646, 684.00 Nigerian Naira.
The study was carried out in Akure, Ondo State, Nigeria. A performance evaluation was carried out on the machine and the sieving efficiency is 96% was achieved.

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Keywords: Sieving machine; laterite sand; fabrication techniques; Nigeria.

1. INTRODUCTION

Sieving has remained a necessary operation used to reduce lumps into fine particles (undersize) after making the lumps pass through a screen. It is also used to separate the coarse unwanted particles (oversize) which are discarded after each batch of sieving. The craftsmen accomplished this using a cane or raffia screen in a traditional setting, with an arbitrary guess of the screen / aperture size without considering the effect the size will have on sieving speed and the operators' comfort [1]. Sieving operation using traditional technology involves the followings:

i. A receptacle
ii. The raffia sieve or screen
iii. Laterite to be sieved
iv. Human power

The receptacle

A container that receives the fine sieved particles (undersize) able to pass through the screen as the laterite is creased against it.

The sieve

This is made of cane, raffia palm or palm frond material and is usually square or rectangular in shape.

The siever

The siever is a person using his/her two palms. The palms serve two purposes; the first, lifting the lumps of the mash onto the sieve and the second compressing and shearing the lumps against the sieve.

1.1 Improved Traditional Sieving Technology

Improvement has been made on this traditional technology; the material used for making the sieve has undergone serious changes. Improved versions have been made from synthetic material, metal strips and aluminium (Fig. 3). These improved sieves are known for their durability making their choice preferable compared to sieves made of raffia palm which are also still available [2].

1.2 Drawback of the Traditional and Improved Sieving Technology

The traditional and improved traditional sieving materials are both with the following flaws:

- The sitting position of the operator combined with the bending and stretching needed to carry out the sieving leads to waist pain.
- Irritating sensation resulting from friction of rubbing the palm against the sieve with the laterite sample
- "The process is time consuming. For instance, to sieve a 30 kg worth of laterite may take about 60 to 90 min. This can translate to several hours in case of large scale production" [3].
- Possibility of inhaling of poisonous dust-like particles.
- Hygienic problems of the siever and the sieve's care.

According to Uthman (2011), the traditional method of lump breaking and sieving of laterite is time wasting and energy consuming which invariably leads to low production.

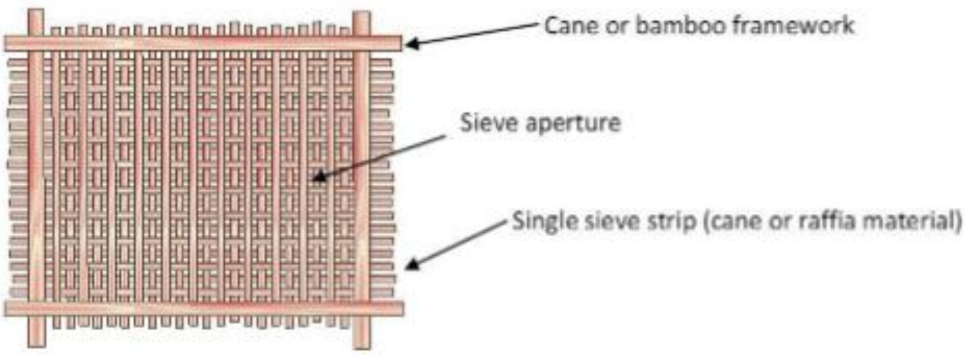

Fig. 1. Traditional raffia sieve

1.3 Mechanized Sieving Technology

In a bid to reduce human effort and time expended in sieving operation, mechanized sieves have been conceived and developed. Orojinmi (1997) developed "a laterite siever, his study showed a performance evaluation on the machine with an efficiency of 76% and output capacity of 69.12 kg/h. He recommended that the machine be improved so as to increase the efficiency and capacity and to lessen the hectic aspect of the sieving operation". Suleiman and Adigun (2008) fabricated "a laterite siever with locally available materials such as mild steel, stainless steel, etc. but they however never carried out a comprehensive performance evaluation in terms of the efficiency and throughput capacity on the machine. They suggested that the machine should be constructed with stainless steel materials so as to prevent corrosion and allow hygienic operation". Alabi (2009) in his study developed a motorized laterite sieving machine but also made the following recommendations; an outlet provision for unsieved materials, a cover for the pulley and electric motor for the protection of the operator and also, a cover for the hopper. Kudabo et al. [4] developed and evaluated "a motorized laterite siever, with power source an electric motor. The machine dimension was put at 915 mm × 455 mm × 630 mm. Test result of this study showed that the siever has efficiency of 93.3% at 26% moisture content at sieving speed of 410rpm and output capacity of 135 kg/h". Jackson and Oladipo (2013) developed "a motorized laterite siever at the National Centre for Agricultural Mechanization (NCAM) which was evaluated to determine the effects of operating speed on its sieving efficiency". The operating speed was varied four times for the study, the speed used are, 450, 500, 600 and 650 rpm. The machine was used to sieve 15 kg of laterite sample at each of the speed, and the time used for the sieving operations of the 15 kg laterite sample at all the tested speeds were noted and recorded. This study showed a sieving efficiency of 86.5% at an operating speed of 650 rpm while the lowest efficiency achieved was at 75.5% while operating at a speed of 450 rpm and output of 200kg/h. Looking more closely at Kudabo et al. [4] and Jackson and Oladipo (2013) who both made more comprehensive reports, it is observed that while Kudabo et al. [4] "used a 410 rpm to develop a sieving machine with 93.3% efficiency and an output of 135 kg/h" while Jackson and Oladipo (2013) on the other hand ,"using a slightly higher rpm of 450, developed a siever with an efficiency of 75.5% and an output of 200kg/h. Even though both designs and the others were silent on the sieve aperture sizes that were used to produce the speeds, outputs and efficiencies, the contrast here is that the machine using 450 rpm and producing an output capacity of 200 kg/h is 75.5% efficient whereas the one using 410 rpm is 93.3% efficient (Bourman RP, 2010). However, unlike the grating and sieving operations which are presently mechanized, and are in the market and reducing farmers' drudgery; the sieving machines for laterite are yet to be seen in the market. No doubt the concept may not have been perfected so as to produce affordable and reliable sieving machines" [5].

Fig. 2. Assemblage of Materials for traditional sieving arrangement

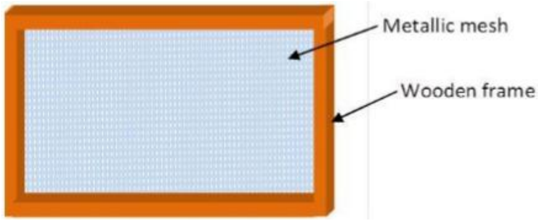

Fig. 3. Improved traditional sieve

1.4 Methods of Sieve Analysis

According to Adamson D (2011), there are different methods for carrying out sieve analyses of Laterite and this depends on the material to be measured.

- Throw-action
- Horizontal Sieving Method
- Tapping sieving
- Wet sieving
- Air Circular Jet Method

1.5 Aim of the Project

The aim of the project is to develop an efficient Laterite Sieving Machine.

List 1. Traditional way to abstract the sand

Areas of use of laterite	Applications of sieving	Advantages of sieving
• Agriculture • Building blocks • Road building • Water supply • Waste water treatment	• In food Industries • In Agriculture • In Oil Industries • For domestic purpose	• Getting more output • Required less time • Required less manpower • More reliable • Required less electric consumption • Unit is portable • Technology is simple

(Source: Abbas A., [6])

1.6 Objectives of the Project

The objectives of this project are to:-

- develop an efficient Laterite Sieving Machine
- carry out a performance evaluation of the machine developed in order to determine its functional requirements

1.7 Justification

The problems associated with the existing process of sieving laterite are enumerated thus:-

- The old method of laterite sieving is extremely time-consuming with little output and labor intensive.
- Cost of buying imported machines is high.

Therefore, the project is to provide an alternative means to the problems highlighted above while still placing emphasis theon Efficiency of the machine.

2. MATERIALS AND METHODS

The design of a machine such as the laterite sieving machine requires careful consideration of the choice of materials to be used. The materials used for each part of the machine were selected based on the physical and chemical properties of the laterite to be sieved, machinability of the material, availability of the material, corrosion resistance and cost.

2.1 Design Considerations

The considerations contained in this work are based on the logical necessity of design parameters. The selection of materials for various parts of machine is based on the following factors. The design of the machine was based on the following consideration:

a. Availability of the materials locally to reduce cost of production
b. Properties of material to be processed
c. Choice of materials
d. Choice of design for specific parts and selection of some standard parts of the machine
e. Strength of the material and rigidity of the machine,
f. Availability of the material locally and ease in obtaining them,
g. Durability
h. Corrosion under various uses and weather condition to which its exposed,
i. Economy / feasibility
j. Ease of fabrication

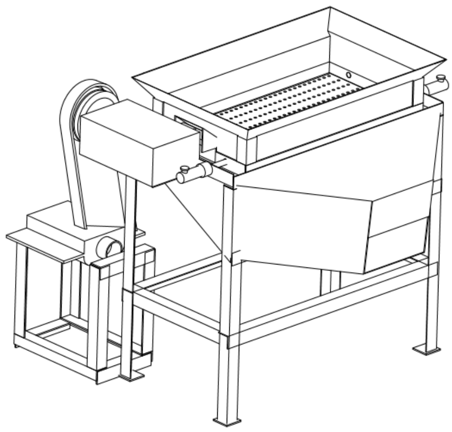

Fig. 4. Model of the laterite sieving machine

2.1.1 Prime mover

The Prime mover was selected based on the speed and power output required for the machine.

The specifications of the prime mover used.

Table 1. Materials selection procedure

S/N	Machine Component	Criteria for Selection	Most Suitable Materials	Materials actually Selected	Reason for Selection
1.	Shaft (Sieving Unit, guide)	Strength, machine, surface finish, weight, cost, availability.	Mild steel, cast iron	Mild steel	High strength and light weight
2.	Pulley	Weight, good wearing property, availability	Mild steel cast iron, cast iron	Mild steel	Availability and weight
3.	Belt Guard	Strength, machinability, surface finish, weight	Mild steel, carbon steel	Mild steel	Surface finish, light weight
4.	Sieving Unit	Weight, good wearing property, availability	Mild Steel, Galvanised Steel	Mild Steel	Availability and weight
5.	Bearing	Strength, machinability, surface finish, weight	ball bearing	Ball bearing Roller bearing thrust bearing	Strength, machinability, Type of load, surface finish
6.	Cam guard	Weight, good wearing property, availability	Mild Steel, Galvanised Steel	Mild Steel	Availability and weight
7.	Hopper	Weight, good wearing property, availability	Mild Steel, Galvanised Steel	Mild Steel	Availability and weight
8.	Frame (Sieving Unit stand and Diesel Engine stand)	Strength, Ability to withstand impact load/stress, availability, welding ability, machinability	Mild Steel, Galvanised Steel	Mild Steel	Strength, Ability to withstand impact load/stress and availability, welding ability
9.	Cam	Strength, machinability	Mild steel	Mild steel stainless steel	Strength, cost
10.	Reciprocatin g rod	Strength, machinability, cost, availability	Mild steel	Mild steel stainless steel cast iron	Strength cost and machinability

Table 2. Prime mover Specifications

Description	Data
Power	2.43Kw
Speed	2600 rev/min

2.1.2 Slider crank mechanism

A slider-crank linkage is a four-link mechanism with three revolute joints and one prismatic, or sliding, joint. The rotation of the crank drives the linear movement the slider (the sieving unit). It is mainly used to convert rotary motion to a reciprocating motion or vice versa [7].

Full rotation of the crank is possible if the eccentricity, c, is less than the difference between the connecting rod and the crank lengths and the crank length is less than the connecting rod length. This mechanism that has a very wide usage in machine design. There are two types of slider-cranks: in-line and offset.

a. In-line: An in-line slider-crank has its slider positioned so the line of travel of the hinged joint of the slider passes through the base joint of the crank. This creates a symmetric slider movement back and forth as the crank rotates. This type of slider crank was used for the Laterite Sieving Machine and it worked perfectly well.

b. Offset: If the line of travel of the hinged joint of the slider does not pass through the base pivot of the crank, the slider movement is not symmetric. It moves faster in one direction than the other. This is called a quick-return mechanism.

2.2 Design Calculation and Considerations

For the evaluation of pulley diameters, the speed ratio of the driving and driven shaft is given by:

$$\text{Speed ratio} = \frac{\text{Speed of driving shaft}}{\text{Speed of driven shaft}} = \frac{\text{Diameter of driven pulley}}{\text{Diameter of driving pulley}} \quad (1)$$

The speed ratio of 6:1 was chosen in order to reduce the speed of the driving pulley which is to the desired speed. The service factor which is determined by the service condition is 1.

$$\text{Design Power} = \text{Power transmitted x Service factor} \quad (2)$$

i. Diameter of the driven pulley, D_1 is 490mm.

From equation (1), the diameter of the driving pulley D_2,

$$D_2 = \frac{490}{6} = 80\text{mm}$$

Note: The centre distance, c must not be less than the diameter of the larger pulley

ii. The Peripheral Speed, v of the belt can be determined from equation (3) below:

$$v = \frac{\pi D_1 N_1}{60} \quad (3)$$

Where N_1 is the Speed of the driven shaft

iii. The angle of contact on the larger and smaller pulleys (θ) are determined below respectively from the relations:

$$\theta_1 = \left(180^o + 2\sin^{-1}\frac{R_1 - R_2}{c}\right)\frac{\pi}{180^o}. \quad (4)$$

Where R_1 is the radius of driven pulley and R_2 is the radius of the driving pulley

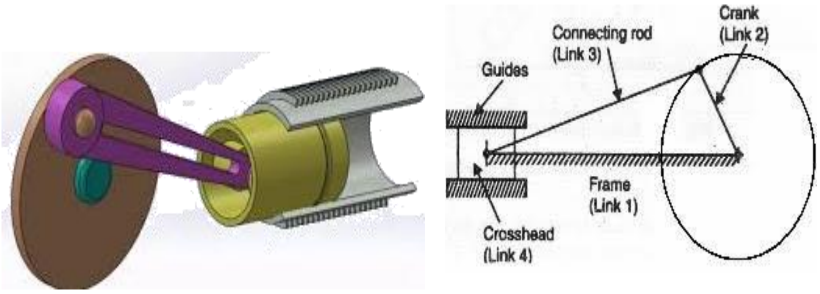

Fig. 5. Slider-crank mechanism
(Source: Adzimah SK, [8])

Fig. 6. Slider-crank of the developed machine

Belt Analysis

iv. Length of belt can be determined from the relations below:

$$L_p = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \quad (5)$$

Where L_p is the total length of belt, and
C is the centre to centre distance (assumed)
D_1 = Diameter of larger pulley
D_2 = Diameter of Smaller Pulley

$$A = b \times t$$

A=Area of v-belt
b=Top width of the belt and;
t=Thickness of the belt

v. Mass density of belt;

$$m = A \times l \times \rho \quad (6)$$

l=unit length of the v-belt
ρ=density of v-belt

vi. Centrifugal tension in the belt:

$$T_c = mv^2 \quad (7)$$

T_c is the Centrifugal tension in the belt

m is the mass density of the belt

And v is the peripheral speed of the belt

And maximum tension in the belt, T

$$T = \text{Stress} \times \text{Area} = \sigma \times a \quad (8)$$

$\therefore$ *Tension in the tight side of the belt*, T_1

$$T_1 = T - T_c \quad (9)$$

Tension in the slack side of the belt,T_2

$$2.3\log\frac{T_1}{T_2} = \mu\theta\text{cosec}\beta \quad (10)$$

μ is angle of contact
θ is the arc of contact
β is the angle of contact in radians

vii. Power Transmitted by belt:

$$P = (\mathbf{T_1} - \mathbf{T_2})v \quad (11)$$

Pulley Analysis

viii. Torque exerted on the larger pulley

$$T_l = (T_1 - T_2)R_1 \quad (12)$$

ix. Torque exerted on the smaller pulley

$$T_s = (T_1 - T_2)R_1 \quad (12a)$$

Shaft Analysis

x. Bending Stress developed in the shaft, σ_b;

$$\sigma_b = \frac{M}{z} \quad (13)$$

$$z = \frac{\pi d^3}{32} \quad (14)$$

z is the sectional modulus of the shaft

M is the Mass moment of Inertia

xi. The shear stress, τ developed in the driven shaft of radius r :

$$T_l = \frac{\tau J}{r} \quad (15a)$$

The shear stress developed is:

$$\tau = \frac{T_l r}{J} \quad (15b)$$

$$J = \frac{\pi d^4}{32} \quad (16)$$

where J is the polar moment of inertia

$$\tau = \frac{32 T_l r}{\pi d^4} \quad (17)$$

2.2.1 Machine features and description

The Laterite sieving machine as shown in Fig. 2 consists of the following major component parts; the frame, sieving unit, hopper, pulleys, bearing, prime mover frame, prime mover, sieving bushing, belt guard. The frame is the main unit of the machine of the machine on which all other components of the machine are supported. It was fabricated using mild steel of thickness to withstand vibration. The angle iron used was firmly joined with arc welding operation. The sieving unit was made of mild steel angle iron and 30mm diameter rod. The shaft is 28mm diameter. 410mm long and was supported at both ends with bearings. The bearings were bolted directly to the machine frame. The

Table 3. Design parameters

Parameter Solved FOR	Input parameters	Value
Speed Ratio	N_1 = 2600 rpm; N_2 = 450 rpm; D = 80mm	D = 490mm
Peripheral Speed	D = 0.4m, N_1 = 2600 rpm;	$v = 14.54m/s$
Angle of Contact	R = 40mm, R = 245mm, c = 500mm	$\theta_1 = 3.15rad$
Length of Belt	D = 490mm, d = 80mm, c = 500mm	$L_p = 1.754m$
Area of Belt	B = $13\ x\ 10^{-3}$, t = $8\ x\ 10^{-3}$	$A = 0.000104m^2$
Mass density of belt	$A = 0.000104m^2$, l=1.754m, $\rho = 1140kg/m^3$	$m = 0.208kg/m$
Centrifugal Tension in the belt	$m = 0.208kg/m$, $v = 14.54m/s$	$T_c = 61.67N$
Maximum Tension in the Belt	$\sigma = 2MPa$, $A = 0.000104m^2$	$T = 208N$
Tension in the tight side of the belt	$T = 208N$, $T_c = 61.67N$	$T_1 = 146.33N$
Tension in the slack side of the belt	μ=0.3, θ=2.823, β =20^o	$T_2 = 12.20N$
Power Transmitted by belt	$T_1 = 146.33N$, $T_2 = 12.20N$, $v = 14.54m/s$	$P = 1.95kW$
Torque exerted on the larger pulley	$T_1 = 146.33N$, $T_2 = 12.20N$, R=0.245m	$T_l = 26.826Nm$
Torque exerted on the smaller pulley	$T_1 = 146.33N$, $T_2 = 12.20N$, R=0.04m	$T_s = 5.365Nm$
Moment of inertia	D=490mm	$z = 6.28MPa$
Shear stress developed in the driven shaft	$T_l = 26.826Nm$, r=245mm, D=490mm	$\tau = 2.966MPa$

collection chamber was also made of mild steel and projected at an angle 45^o to the horizontal, for easy discharge of the sieved laterite through the outlet. The cam and follower mechanism ensures that there is a reciprocating motion for the sieving unit along a linear plane thus causing the fed laterite in the mesh surface to make round movement, so as to make the materials sieved [9].

2.2.2 Principle of the machine operation

When the prime mover is started, its input shaft rotates; the motion of the input shaft is transferred to the Cam shaft about the axis by the application of belt power transmission over a Pulley mechanism. The movement of the cam shaft and the slider crank mechanism which is connected to the shaft pushes the hoper unit which houses the screen and causes it to experience a linear motion along the path that has been created for it by the shafts moving within the confines of the path that has been created in form of bushing [10,11]. This linear motion and the speed with which it moves within the slider bushing causes the laterite that has been fed on the screen to be sieved.

Fig. 7. Fabricated laterite sieving machine

3. PERFORMANCE EVALUATION

"In the dry sieve analysis, a suitable quantity of laterite with a known weight is taken and sieved through a sieve and subject to a reciprocating motion. The amount of shaking depends on the shape and number of particles" [12].

Table 4. Result of tests carried out on the laterite sieving machine

Trials/Test	Mass of Laterite loaded on the machine (kg)	Mass of Laterite sieved by the machine (kg)	Time spent (Seconds)
1.	15.00	14.5	3.50
2.	20.00	19.0	4.20
3.	25.00	24.3	4.60
4.	30.00	29.2	5.10

The machine was tested using a 2.43kW, 2600 rpm prime mover at 15 kg loading rate each time. The quantity of laterite was weighed on the balance and weight was recorded. This was poured into the sieving unit and properly spread out. The machine was operated until the laterite was sieved leaving unsieved residue. The time taken was noted and recorded. Also, the sample collected (sand) from the sieve and the sieved residue were weighed and recorded. This procedure was repeated for three different times. The performance criteria tested for, were;

a. Sieving capacity (SC), and
b. Sieving efficiency (SE).

Sieving Capacity (SC): The sieving capacity is the rate at which the machine sieves in kilogram per hour and this was calculated as;

$$\mathrm{SC} = \frac{\mathrm{M}}{\mathrm{t}}$$

Where;

SC = Sieving Capacity (kg/hr)
M = Average mass of laterite loaded into the sieve (kg)
T = Average time taken to complete the sieving (hr.)

Considering the results obtained from the performance of the machine, the capacity of the machine (SC) is obtained as follows;

$$\mathrm{SC} = \frac{\mathrm{M}}{\mathrm{t}}$$

$$\mathrm{SC} = \frac{99.15}{19.40}$$

$$\mathrm{SC} = 5.11\mathrm{kg/min} \approx 5\mathrm{kg/min}$$

This means this machine has the capacity of processing 300 kg/hr of laterite which makes it a good machine for usage.

Sieving Efficiency (SE): This is defined as the ratio of sieved laterite sand to the mass of laterite loaded to the machine and is calculated as;

$$\mathrm{SE} = \frac{\text{average mass of sieved laterite}}{\text{average mass of laterite loaded}}$$

Where; SE=sieving efficiency
Average mass of sieved laterite=14.5kg
Average mass of laterite loaded=15kg

$$\mathrm{SE} = \frac{14.5\mathrm{kg}}{15\mathrm{kg}} \text{ x } 100\%$$

$$\mathbf{SE = 96.7}\%$$

4. CONCLUSION

A laterite sieving machine was developed and tested. Based on the results of the performance evaluation, it can be concluded that mechanical sieving of laterite can be done more conveniently than traditional method. The machine performed satisfactorily at 450 rpm, with 96.7% efficiency and 300kg/hr sieving capacity. The choice of locally available material for the construction of the machine makes it suitable for adoption in building and other industries of application, and the estimated unit cost is 646,684.00 Nigerian Naira as at May 2018.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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