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Design, Fabrication and Testing of a Rice De-Stoning Machine

Usman, M, Balogun, A. L. and Oyebanre, O. D.

Department of Agricultural and Bio-Environmental Engineering Technology
Institute Of Technology, Kwara State Polytechnic, P.M.B. 1375, Ilorin, Nigeria

Abstract – A motorized Rice de-stoning machine was designed, fabricated and evaluated for optimum performance. The rice de-stoning machine consists of the hopper, vibrating sieves, machine frame, pulley, belt, eccentric shaft, rice channel, electric motor and blower. The parameters investigated were Impurity Level (IML), Rice Separation Efficiency (RSE), Stone Separation Efficiency (SSE) and Tray Losses (TL) after the separation operation. Three varieties of locally produced rice (Bukola, Alhaji Aba and Kodogiche) were used for the test. 500 g of each variety was used with 30 g of stone added to each to make a mixture of rice and stone for the test. The result of the evaluation reveals that Alhaji Aba variety has the highest RSE and SSE of 81.0% and 77.3% respectively with the least IML and TL of 6.5% and 14.5%, respectively. While Bukola variety has the highest IML of 7.8% with the least SSE of 72.6% and Kodogiche variety has the highest TL of 14.8% with the least RSE of 79.0%. The machine is powered by the electricity using the electric motor. The machine, after the test, is found capable of de-stoning different varieties of locally produced rice but performed better with the long rice grain than with short rice grain which implies that the size of rice grain is a factor determined the efficiency of this machine. This work is a contribution to the improvement of the quality of Nigerian rice.

Keywords: Design, De-stoning, Fabrication, Machine, Test

1.0 Introduction

The popular cereal crops of the world include wheat, barley, oats, rice, maize, sorghum and millet, but the major cereals of the developing countries are rice, maize, sorghum and millets (Olugboji, 2004). Rice (*Oryza sativa*) is a leading cereal crop grown in all the continents of the world. It is often considered to be a tropical crop although it is grown in the temperate zone Asia, North America, and southern part of Europe.

Rice had been part of the staple diet in eastern countries for thousands years. It was first eaten in China some 5,000 years ago (Akintunde, 2007). Japanese rated rice very highly, as reflected in the many thousands of shrines which may be seen across the country side. The growing of rice and the success or failure of crop affected the history, art, literature, ceremonials and the very way of life of the people of India, China and Japan for centuries (Akintunde, 2007).

Asian countries were the world largest producer of rice in 2002. Typically, China and India together produce about 50% of the world rice. In 2000, United States exported about 37% of 8.7 million tons it produced and Pakistan exported about 28% of the 7.2 million tons it produced while Thailand exported significantly more rice than any other country (Dannson, 2004).

Many rice importing countries include Nigeria, Cote d' Ivoire, Philippines, Saudi Arabia and Indonesia. Some rice importing countries buy rice when drought, floods or any other condition reduces the yield of their own rice crop but Nigeria imports rice on a regular basis. Nigeria is currently the largest rice importer in the world. Nigeria imported rice to the tune of 1.8 million dollars alone in 2002, 1.3 trillion on rice importation in 2007. The importation of rice as a staple food in Nigeria has risen dramatically in the last four decades. Today, rice is hawked on the streets of all cities and villages in the country and for many families; it is a daily item on the menu. Therefore, there is need to carry out research on the improvement of locally produced rice. Reasonable quantities of rice are produced yearly from different fields in Nigeria, but many Nigerians preferred imported rice. This is partly attributed to the fact that about 80% of rice produced locally in Nigeria contains stones. This is because most of rice produced locally is processed manually or with insufficient methods. The greater part of stones in Nigerian rice is introduced during threshing, parboiling, drying, milling/ dehusking and winnowing

Harvesting and post-harvest handling methods introduce contaminants such as stones, sticks, chaff and dust into grains which need to be cleaned. Jekayinfa *et al.* (2003); Adejuyigbe and Bolaji (2005); Bolaji *et al*. (2008) have reported that, for mechanization of agriculture in Nigeria to succeed, it must be based on indigenous designs, development and manufacture of most of the needed machines and equipment to ensure their suitability to the crops as well as to the farmers technical and financial capabilities

In Nigeria, most of the agro-allied products are consumed or exported unprocessed. This has negative effects on the economy of our nation. The separation of grains from stone and other impurities before consumption or further processing into various products is one step necessary to improve agro-allied industries. This step will ensure the quality and hygiene of products, thus increasing the commercial value of the final exported products.

This work therefore aims to design, fabricate and evaluate rice de-stoning machine with vibrating sieve using locally sourced materials for the purpose of removing stones and other impurities from locally produced rice. This paper also presents the results of the testing and performance evaluation of the machine.

2.0 Materials and Methods

2.1 Design consideration

Physical and mechanical properties of various variety of rice and stone was considered. These include volume, density, terminal velocity, moisture contents, weight, angle of repose, gravitational force, size, shape, colour, brittleness, appearance, strength, toughness,

2.2 Material selection

The particular conditions under which the various parts of rice de-stoning machine are subjected to make it necessary to select a very good material for fabrication. In the choice of material, their properties such as mechanical, physical, chemical, thermal, durability and all add availability and cost are considered. In this design, the strength, cost, availability and serviceability of materials were put into consideration. Mild steel and aluminum was considered suitable and selected for the fabrication of this machine.

2.3 Design of machine components

Design of hopper: The hopper design is based on the volume of cuboids which is obtained as follows:

$$V = Lbh \tag{1}$$

Where L = length of cuboid (m), b = breath of cuboid (m), h = height of cuboid (m), V = volume of the cuboid (cm^3)

$$\begin{aligned} V &= Lbh \\ &= 10 \times 10 \times 10 \\ &= 1000\ cm^3 \end{aligned}$$

Therefore the volume of the hopper is calculated to be 1000 cubic centimeters.

The recommended angle of repose for gravitational discharge of rice ranges from 15º to 30º (Eugere and Theodore, 1986). In order to allow free flow of rice, a hopper slant angle of 30º was considered. This is 10º above the angle of repose.

Design of power required to drive the blower: Power required to drive the blower is given by Adejuyigbe amd Bolaji (2005) as:

$$P = TV = \acute{\omega}rV \quad (2)$$

Where T = torque (Nm), w = weight of the blower blade (N), r= radius of blower, V = angular velocity (rad/s)

The mass and angular velocity rating of blower with required air supply width are 5.7 kg and 26 rad/s respectively.

From eqn (2) Power required = 0.37 kW

Angular velocity is given as (Hall *et al*., 1988)

$$w = \frac{2\pi N}{60}$$

Where N= angular speed (1400 rpm).

Therefore, an electric motor of 0.37kW and 1400 rpm are considered suitable for the power transmission.

Design of vibrating sieve: The degree of the vibrating movement depend on the number of vibration per seconds (frequency) and on the shaking distance. Vibration of the sieve causes separation of grains of different weight. The sieve is designed to operate by the work of an electric motor and the vibrating movement loosens a mixture of grain and at the same time transport the brain along the inclined sieve of angle 30º. The sieve design consists basically of the determination of sieve diameter "d" (Akintunde, 2007).

$$d = \sqrt{\frac{D^2(3\pi - 2C_o)}{C_o}}$$

Where D= maximum diameter of rice grain size (3 mm), C = coefficient of opening (3.5)

Therefore,

$$d = \sqrt{\frac{2.3^2(3 \times 3.147 - 2 \times 3.5)}{3.5}}$$

$$d = \sqrt{\frac{5.29(9.425 - 7)}{3.5}}$$

$$d = \sqrt{\frac{5.29(2.425)}{3.5}} = \sqrt{\frac{12.8271}{3.5}}$$

$$d = \sqrt{3.666488} = 1.914387$$

$$d = 1.9\ mm$$

Electric motor power = 0.37kW

Motor speed = 1400 rpm

Velocity of motor $v_1 = \frac{\pi d_2 N_2}{60}$

$= \frac{3.142 \times 0.77 \times 1400}{60}$

Velocity of the motor=5.645 m/s

Since the pulley on the motor has the same diameter as that of the vibrating sieve.

i.e $d_2 = d_2 = 0.77\ mm$

$v_2 = v_1 = 5.645\ m/s$

$= 5.65\ m/s$

Design of blower: The theoretical air flow rate (Q_T) is given as (Hall et al., 1988)

$$Q_T = vD_p w \tag{3}$$

Where v= Velocity of air flow (m/s), D_p = Depth of air (m), w= Width over which air is required

The actual air flow rate (Q_A) required will be higher than the theoretical and obtained using equation (4) (Hall *et al*., 1988).

$$Q_A = \frac{Q_r}{h} \tag{4}$$

Where h = efficiency of blower.

V= 5.6 m/s is chosen so that it is higher than 5.3 m/s the terminal velocity of rice (Ogunlowo and Adesuyi, 1999). Considering a depth of air of 0.42 m, air width of 0.42 m and blower efficiency of 80%, therefore from eqn (3) and (4), = 0.988 m^3/s and = 1.23 m^3/s.

Design of torque on the shaft: The torque on the shaft according to McGraw-Hill, 2006 is given by

$$P = T_r \times w = T_r \times \frac{2\pi N_2}{60}$$

$$370 = T_r \times \frac{2 \times 3.142 \times 1400}{60}$$

$$T_r = \frac{370 \times 60}{2 \times 3.142 \times 1400} = 2.5234\ N.m$$

Minimum diameter of vibrating sieve shaft is given by,

$$T_r = \frac{\pi}{16} \times t_{max} \cdot d^3$$

The yield stress for mild steel rod is 180 mN/m^2, therefore the maximum allowable shear stress using a factor of safety of 2 is given by,

$$T_{max} = \frac{T_y}{2} = \frac{180 \times 10^6}{2} = 90 \times 10^6 N/m^2$$

Hence,

$$2.5234 = \frac{3.142 \times 90 \times 10^6}{16} \times d^3$$

$$d^3 = \frac{2.5234 \times 16}{3.142 \times 90 \times 10^6}$$

$$= \sqrt{0.00000014329}$$

$$= 0.005233\, m$$

$$d = 5233\, mm$$

Power Transmission and stresses in the belt: Since the power of the electric motor is just 0.37kW, the A-type is suitable to transmit this kind of power (Khurmi and Gumpta, 2005).

Using a groove angle; $2\beta = 34°$ (Khurmi, 2005)

$$2\beta = 34°$$

$$\beta = \frac{34}{2} = 17°$$

From $tan\beta = \frac{x}{t}$ (Khurmi, 2005)

$$tan\ 17° = \frac{x}{3}$$

$$x = 8\ tan\ 17° = 2.4458\, mm$$

$$x = 2.4\, mm$$

Cross sectional area of the belt is given as: Area of rectangle ABCD× Area of rectangle ADE

$$A = 13(8) - 2\left(\tfrac{1}{2} \times 2.4 \times 8\right)$$

$$= 104 - 19.2$$

$$= 84.8\, mm^2 or\ 0.0000848\, m^2$$

The maximum tension in the belt is given by

$T = \sigma_b \times A$ (McGraw-Hill, 2006 and Khurmi, 2005)

Where T = maximum tension in the belt, σ_b= maximum allowable stress in the belt = 2 mN/m^2, A = cross street sectional area

$$T = 2 \times 10^6 \times 0.0000848$$

$$= 169.6\, N$$

Centrifugal tension is given by

$T_c = mv^2$ (McGraw-Hill, 2006 and Khurmi, 2006)

Where M = mass of density per unit length of the belt material = 1.06kg/m (Khurmi, 2005), V = velocity of the belt

$T_c = 0.106 \times 5.645^2$

$T_c = 0.106 \times 31.866025$

$T_c = 3.378\ N$

Tension in the tight side of the belt is given by

$T_1 = T - T_c$ (Khurmi and Gumpta, 2005 and Olugboji *et a*l., 2014)

$T_1 = 169.6 - 3.378$

$= 166.222\ N$

$sin\ \alpha = \dfrac{r_1 - r_2}{x}$

Where $r_1 - r_2 = 38.5\ mm$

$\sin\alpha = \dfrac{0}{530} = 0$

$\alpha = sin^{-1}\ 0 = 0$

Angle of contact between the belt and pulley is given according to Khurmi and Gumpta (2005) as

$\theta = (180 - 2x)\dfrac{\pi}{180} rad$

$= (180 - 2(0))\dfrac{\pi}{180}$

$\pi rad = 3.142\ rad$

Thus the tension in the belt according to Olugboji *et al*. (2014) and Khurmi (2005) is expressed as

$log_e \dfrac{T_1}{T_2} = \mu cosec\beta$

Where $T_1 =$ Tension on the tight side of the belt, $T_2 =$Tension on the slack side of the belt, $\mu =$ Coefficient of friction between belt and cast iron pulley which according to Khurmi (2005) is taken to be 0.28 for leather belt and dry cast iron pulley.

$2\beta -$ Groove angle of the pulley, carefully taken as 34º and β = 17º

Where $sin\alpha = \dfrac{r_1 - r_2}{x}$

$log_e \dfrac{166.222}{T_2} = 0.28 \times 3.142 \times cosec\ 17°$

$= 0.28 \times 3.142 \times 3.42$

$= 3.009$

$$log_e \frac{166.222}{T_2} = e^{3.009}$$

$$\frac{166.222}{T_2} = 20.267$$

$$T_2 = \frac{166.222}{20.267} = 8.20\ N$$

Power transmitted per belt according to Agidi *et al*. (2015) and Khurmi (2005) is given by

$$P = (T_1 - T_2)V$$

$$= (166.222 - 8.2) \times 5.645$$

$$= 158.022 \times 5.645$$

$$= 892.03\ W or\ 0.892\ kW$$

Number of belt required: The number of belt required is given by

$$n = \frac{TotalPowerTransmittedbythemotor}{PowerTransmittedPerBelt}$$

$$= \frac{370\ W}{892.03\ W} = 0.415$$

This implies that a single belt of the given standard is sufficient for power transmission.

Determination of amplitude and frequency of vibration: According to Anderson (1987), for a system of force vibration with a single degree of freedom, the amplitude is given as:

$$\gamma = \frac{F/k}{\left[\left(1 - \left(\frac{w}{w_n}\right)^2\right)^2 + \left(2\varepsilon\left(\frac{w}{w_n}\right)\right)^2\right]^{0.5}}$$

Where F = magnitude of excitation force, k = stiffness of spring (suspension reed), γ = amplitude of steady state vibration, m = mass of system, ε = coefficient of damping, w = frequency of excitation force given by $w = \frac{2\pi N}{60}$, w_n= natural frequency of vibration of the system, given by $w_n = \sqrt{\frac{k}{m}}$, Frequency of vibration f of the system is therefore, $f = \frac{w}{2\pi}$

2.4 Assembly of machine and description of major components

The frame of the machine was put together using electric arc welding joining technique. The de-stoning unit was mounted in the frame and the hopper was fixed to the top of frame. The frame carries every other components of the machine. It is fabricated from 38 mm ×38mm×5mm thick mild steel angle iron-welded together. The four legs of the frame form the machine stand. The overall length, width and height of the machine frame are 700mm, 400mm and 1350mm respectively. The hopper is the unit through which the machine is fed with impure rice with stones. It has a square cubic base. The hopper was made of 1.5mm thick galvanized metal sheet. The curves are formed on the anvil to the design shape and welded together. The centrifugal fan blower made up of mild steel plate. It was measured and marked out with scriber into diameter 170 mm ×180mm width with the length 250mm. This machine has mechanical sieve constructed from 2mm galvanized metal sheet. The length, breadth and height are 243 mm × 210mm × 100mm respectively. The size of the sieve were made in such a way that it will allow stones of smaller size to pass through them into the collecting tray under the sieves. The de-stoning machine uses electricity as a source of power. The machine require only one operator since it is made simple to operate.

2.5 Testing and evaluation of the machine

The machine was tested and evaluated for high efficiency and reliability. The machine requires single operator since it is easy and simple to operate.

2.6 Experimental materials

Three different varieties of rice are obtained from the major rice producing areas (Lafiagi and Patigi) of Kwara State. The three varieties are called; **Bukola, Alhaji Aba and Kodogiche**

2.7 Sample preparation

The three varieties of rice was separated and their physical properties such as size, length, moisture content, density, terminal velocity et al. were measured with appropriate measuring devices. Then, each variety are weighed into 500g in three replicate using digital weighing balance and Stones of 30g was also measured and mixed with each 500g sample of rice.

2.8 Experimental procedure

The machine was switch on and allowed to run at no load to ascertain its condition. Then, the sample prepared was fed into machine through its hopper and operating time was noted using the stop watch. The clean rice was collected from rice outlet of the machine while the Stones were collected from the Stone outlet. Tachometer was used to measure the operating speed of the machine. . As the motor operates it vibrates the sieves and the grains mixture flows from the hopper to the first sieve where larger stone particles are retained while rice and smaller stone particles passed to the second vibrating sieve .then ,the second sieve retained some smaller stone in rice while rice with the remaining stones particles passed through the rice channel to the last vibrating sieve where the blower supplies air stream across the flowing mixture giving them a velocity that changes their directions and causes them to experience different projectile motion. The range of projectile motion of rice grain is greater than that of stones due to their difference in density weight. The machine was tested with three variety of local rice. The machine was loaded with 500g of each variety of rice grain mixed with 30g of stone through the hopper making the total load of feed mixture of rice and stones to be 530g. The output parameter measure was based on impurity level after separation (IML), Tray losses (TL), Rice Separation Efficiency (RSE), Stone Separation Efficiency (SSE). According to Ogunlowo and Adesuyi (2009), impurity level of rice grain is determined by:

$$IML = \frac{mscr}{mcr + mscr} \times 100$$

Where, $mscr$ = the mass of stone in clean rice after separation (g), mcr = mass of clean rice (g)

Rice Separation Efficiency (RSE) is determined by

$$RSE = \frac{mcr}{mrm} \times 100$$

Where mcr = mass of clean rice, mrm = mass of rice in the mixture

Stone Separation Efficiency (SSE) is determined

$$SSE = \left[1 - \frac{mscr}{msm} \times 100\right]$$

Tray Loss (TL) is determined by:

$$TL = \frac{mcr}{mrm} \times 100$$

Where mcr = mass of clean rice (g), mrm = mass of rice in mixture before separation process**:**

3.0 Results and Discussion

The mean values of the results obtained are presented in table 1

Table 1 Average values of data obtained from the experiment.

Varieties	IML (%)	RSE (%)	SSE (%)	TL (%)
Bukola	7.8	80.3	72.6	14.7
Alhaji Aba	6.5	81.0	77.3	14.5
Kodogiche	7.5	79.0	74.0	14.8

Table 1 reveals that the impurity level (IML) after separation process for the three varieties of local rice used is known to be 7.8% for Bukola variety, 6.5% for Alhaji Aba and 7.5% for Kodogiche. The table shows that rice separation efficiency of the machine was found to be 80.3% for Bukola, 81.0% for Alhaji Aba and 79.0% for Kodogiche. Also from the table, stone separation efficiency of the machine is known to be 72.6% for Bukola, 77.3% for Alhaji Aba while 74.0% for Kodogiche. The table also reveals that the tray losses value obtained during the test are: 14.7% for Bukola, 14.5% for Alhaji Aba and 14.8% for Kodogiche.

These result shows that Bukola rice variety has the highest impurity level of 7.8% while Alhaji Aba has the lowest impurity level after separation. The result also reveals that the machine has the highest rice separation efficiency of 81.0% with Alhaj Aba while with Kodogiche, rice separation efficiency is low (79.0). From the table, it is found that stones separation efficiency (SSE) is high with Alhaji Aba while with Bukola variety stones separation efficiency is low. The table also reveals that the tray loss (TL) during the separation is high with Kodogiche while with Alhaji Aba a tray loss is low. But the tray losses for the three varieties of rice is almost the same

The results in the table reveals that impurity level of rice after separation depend on the stones separation efficiency of the machine. Bukola variety has the highest impurity level following the lower stone separation efficiency of the machine during its separation which might be in turn due to its short grain length similar to that of stones length making their separation difficult. Alhaji Aba having long grain length produced the highest rice separation efficiency and stone separation efficiency which could be due to its long grain length that makes separation easier.

4.0 Conclusion

The design, fabrication and testing of rice de-stoning machine was successfully carried out in the Department of Agricultural and Bio-Environmental Engineering, Kwara State Polytechnic, Ilorin with impurity level of, long rice grain after separation, 6.5%, rice separation efficiency of 81.0% , stone separation efficiency 77.3% and tray losses of 14.5%.

It was concluded that the rice de-stoning machine, after the testing, is found capable of de-stoning different varieties of locally produced rice but performed better with long rice grain than with short rice grain which implies that the size of the rice grain is a factor determined the efficiency of this machine.

5.0 Recommendation

Based on the testing result and conclusion drawn, this machine is highly recommended for utilization by the small and medium scale rice processors with long rice grain for optimum efficiency. Further research should be carried out on this machine to improve its efficiency, particularly on the vibrating sieve diameter. The diameter of vibrating sieve can be reduced to allowed easy separation of the mixture of short rice grains and stones.

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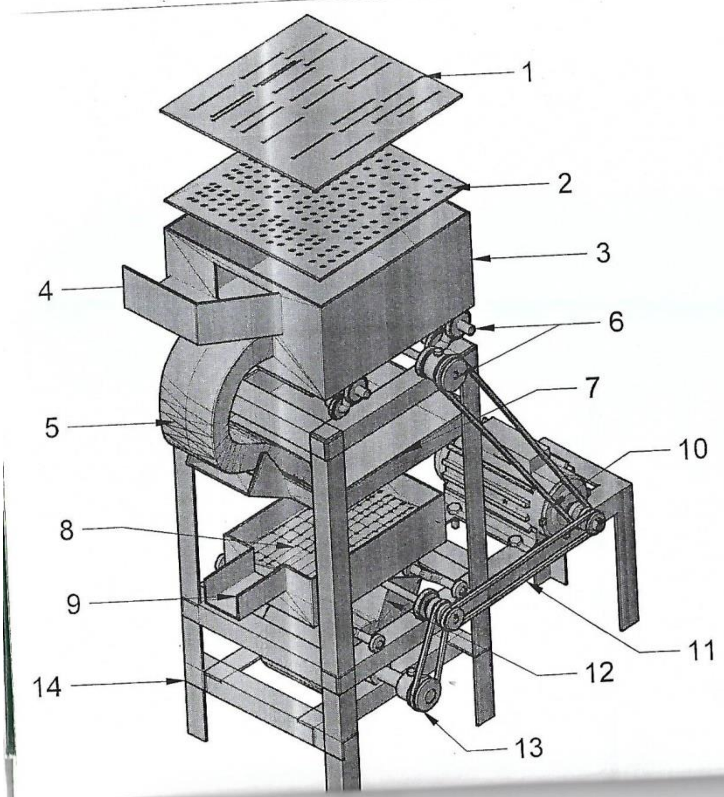
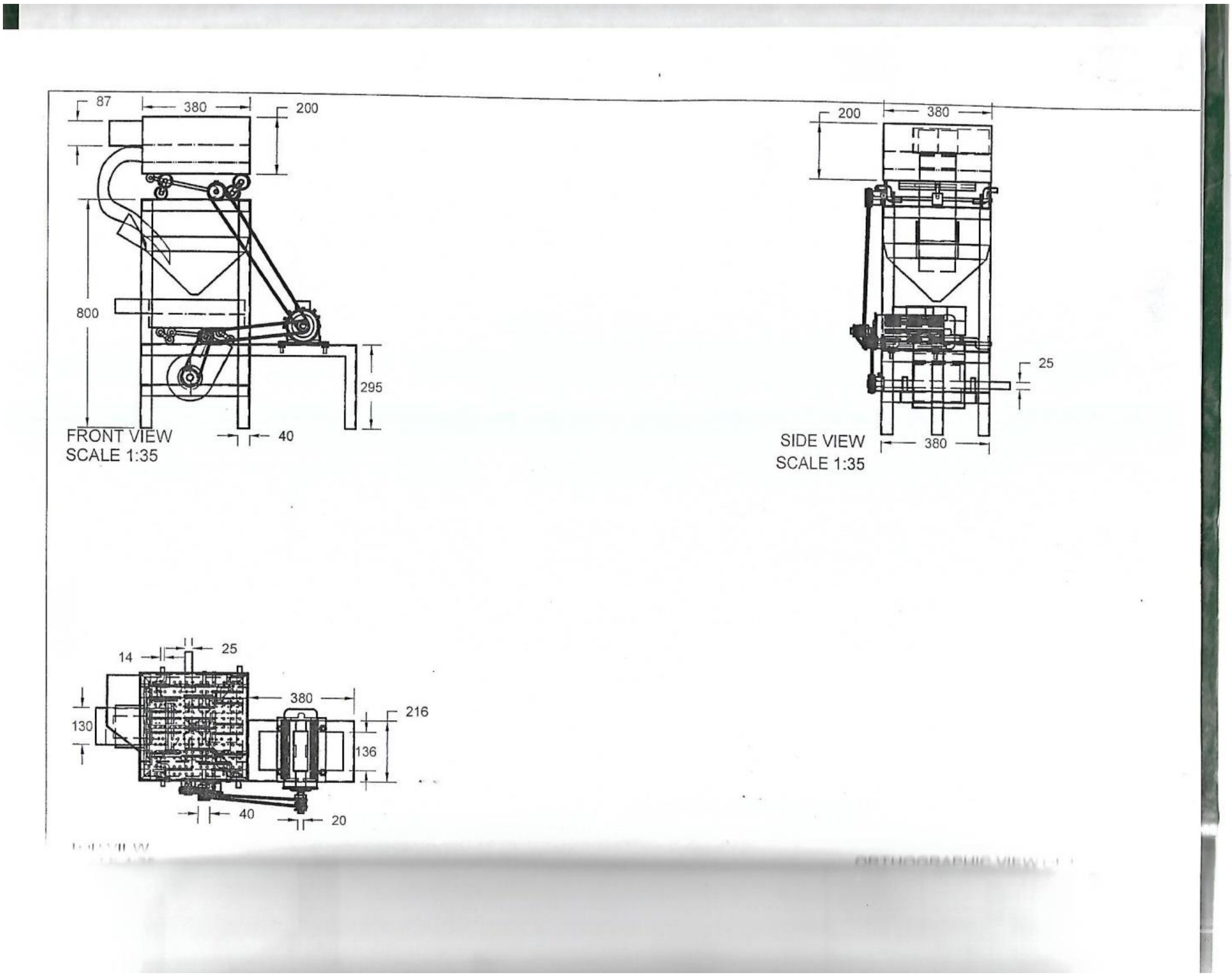


LEGEND OF RICE DE-STONING MACHINE

S/NO	COMPONENTS	MATERIAL	QTY
1	FIRST RECIPROCATING SCREEN	MILD STEEL	1
2	SECOND RECIPROCATING SCREEN	MILD STEEL	1
3	VIBRATING SIEVE	MILD STEEL	1
4	STONE OUTLET	MILD STEEL	1
5	RICE CHANNEL	MILD STEEL	1
6	ECCENTRIC SHAFT	MILD STEEL	2
7	HOPPER	MILD STEEL	1
8	LAST RECIPROCATING SCREEN	MILD STEEL	1
9	LAST VIBRATING SIEVE	MILD STEEL	1
10	ELECTRIC MOTOR	FINISHED PRODUCT	
11	BELT	RUBBER	3
12	BLOWER	MILD STEEL	1
13	PULLEY	-	4
14	MACHINE FRAME	MILD STEEL	-


87
380
200
800
295
40
FRONT VIEW
SCALE 1:35
200
380
25
SIDE VIEW
SCALE 1:35
380
14
25
380
216
130
136
40
20