Department of Bioresource Engineering

McGill University

BREE 490: Design 2 & 3 – Winter 2013:

Design Report:

Design of a Winnowing Machine for West African Rice Farmers

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1. ABSTRACT

Current basket winnowing methods utilized in Lafia, Nigeria are inefficient in cleaning impurities from rice paddy harvested from the field. To address the issue, a design was created which combined the technology of a dual-combine sieve and Chinese winnowing machine with the emphasis of creating the prototype from accessible and recycled materials. The design underwent a series of system developments from theoretical concept to first prototype, leading to the adjustment of key components. Performance of the machine was determined through testing, and future improvements were suggested based off the performance results. The relative cost of the machine and feasibility of implementation was found in relation to Lafia, Nigeria. Ultimately, the first prototype was a successful proof of concept, and shows promise in being an effective solution for improving the efficiency and quality of winnowing.

2. INTRODUCTION

Reducing rice post-harvest losses is a necessary step toward ensuring greater global food security as increased future demand will require increased production efficiency. Winnowing is a process of cleaning chaff from paddy initially harvested from the field, and is conducted by using wind separation to blow lighter chaff and debris from rice paddy mixture dropped from a height. (Okunola and Igbeka, 2009). Currently, developing communities in West Africa utilize antiquated winnowing baskets which depend heavily on natural wind for cleaning; there is a reported 1-5% total global rice loss from cleaning processes alone as winnowing baskets have limited efficiency in separating rice from debris (Ogunlowo & Adesuyi, 1999). Consequently, rice winnowed by this method also has a reported reduction in quality. This is a significant problem; low-quality rice is not only unsuitable for export, local West African consumption and demand is also low (Hall, 1972). The use of winnowing baskets is labor intensive and inefficient, requiring women workers who traditionally winnow rice to input full eight hour work days. Because the performance of winnowing baskets is contingent upon natural wind, the rice output quantity suffers from paddy separation losses and is also low-quality.

The previous focus was to conduct a literature review of winnowing technology utilized in industrial processes to adopt that technology in design suitable to Lafia, Nigeria. The objective of this report is twofold: to explore the implementation challenges of creating a design which improves the efficiency and quality of rice winnowing, while simultaneously prioritizing the accessibility and ease of design replication. As such, the prototype developed for this report takes into consideration a number of key constraints and parameters determined for Lafia, Nigeria.

There are several constraints which are highly relevant in the prototype of a winnowing machine. Accessibility of parts and the cost of obtaining parts are related; the two constraints highly influence what materials will be used for construction of the prototype. An assumption is that Nigerian women will be operating the winnowing machine as they are traditionally entrusted with the job, a factor which will influence the physical dimensions and direct physical labor inputs needed of the prototype. The local capacity of Nigerians to upkeep a winnowing machine and the availability of local fuel sources are also important constraints in determining the sophistication of the machine, and the source of power used to drive the prototype. Lastly, human health and well-being is of the utmost concern, which influences the overall design when incorporating safety factors and measures undertaken to reduce debris inhalation. Ultimately, the goal is to adequately address the relevant local constraints, in hope that the prototype is well-received and adopted.

3. DESIGN ANALYSIS & SPECIFICATIONS

The chosen design integrates a double combine sieve with the traditional Chinese winnowing machine. The rice paddy-debris mixture enters the machine via a trapezoidal hopper. The mixture passes through a horizontal wind stream of 4 to 6 m/s that is produced by the fan. The lighter debris, such as dust and straw, is blown out of the machine by the wind current, while the heavier rice paddy and impurities fall toward the sieve system. The impurities such as rocks that are larger than the rice paddy are collected by the upper sieve and vibrated out of the machine into a collection vessel. The rice paddy then falls onto the lower sieve, where it is vibrated into a collection vessel underneath the sieve system, while the impurities that are smaller than the rice paddy but too heavy to be removed by wind are collected in their respective collection vessels underneath the lower sieve.

Figure 1: 3D representation of the chosen design (left), finished prototype (right)

3.1 Hopper

The hopper is trapezoidal in shape and constructed from plywood. For testing purposes the outlet area of the hopper was adjustable to allow for the testing of different feed rates of rice paddy into the machine.

3.2 Motor

A 1.5 HP motor that is running at 1725 revolutions per minute powers the entire system. The motor is connected to the fan via a 2-pulley v-belt system.

3.3 Fan

The fan provides a wind stream at an average rate of 5.46 m/s (see *Table 1: Wind velocity trials* in appendix A). It is an axial impeller fan enclosed in a casing (also known as a squirrel cage fan). The fan is a recycled furnace fan of 11-inch diameter and 12.5-inch blade length and was donated by Turner Heating in Pointe Claire. The fan's 0.5-inch shaft is connected to a 10-inch diameter pulley that reduces the fan's speed to roughly 250 revolutions per minute.

3.4 Pulley-v-belt system(s)

The original fan shaft was replaced with a shaft extension to support pulleys on either side of the fan. The motor shaft holds a 1.5-inch diameter pulley that is connected by a 42-inch 4L v-belt to a 10-inch diameter pulley mounted on the fan shaft. A 1.75-inch pulley is mounted on the opposite end of the fan shaft and transfers torque to a 3.25-inch pulley that is connected to the shaft that powers the drive arm of the sieves. This connection is made by an 80-inch 4L v-belt. The shaft that is driven by the 3.25-inch pulley is mounted on two pillow block ball bearings to allow for a smooth rotation.

3.5 Drive arm

The drive arm is comprised of two main components: the actual arm that connects to the sieve system and the rotating mechanism. The 11.5-inch length of the drive arm is constructed from 0.25-inch steel flat bar that is bolted to an aluminum piece. The mechanism of rotation is crafted from an aluminum piece that is set-screwed around the shaft whose rotation of roughly 120 revolutions per minute is driven by the 3.25-inch pulley. The radius of gyration for the drive arm is 1-inch.

Figure 2: An aerial view of the drive arm mounted on a shaft that is supported by pillow block ball bearings.

3.6 Double sieve system

The upper sieve is longer than the lower sieve, spanning almost the entire length of the machine. This sieve has larger perforations and is intended to filter the debris that is larger than the rice paddy and too heavy to be blown away by the wind stream. The lower sieve has perforations that are too small for the rice paddy to fall through. This sieve is intended to catch the rice paddy and redirect it toward a catchment vessel, while the impurities that are smaller than the rice paddy, but too heavy to be blown away in the wind stream, fall through the sieve into their respective collection vessel. The sieves are connected on at two points along their length by arms of 0.25-inch flat bar. These arms rotate around 0.5-inch that are driven through their center. These shafts are mounted in sheets of plywood to hold the sieve system at an incline of 12.5°. The rotation of the sieve system is driven by the drive arm, which is attached to the pulley system.

3.7 Frame

The frame of the prototype is constructed from 2x4 planks and sheets of plywood.

3.8 Body casing

Polyethylene sheeting was stapled to the frame of the machine to contain the airflow, debris and rice paddy. It is slanted inward above the sieve system to direct the rice paddy into the upper sieve and mitigate paddy losses at the edges of the sieves.

4. SYSTEM DEVELOPMENT

The following is a detailed discussion of the major pieces/sections of the winnowing machine. It outlines their development from the beginning of the design process to the end.

4.1 The Fan

4.1.1 Bought vs. Built

Initially, there were many discussions about whether the fan should be built or bought. It was decided to purchase a centrifugal fan, as it is relatively simple in design, easy to build or repair, and quite accessible in Lafia (Dr. Michael Ngadi, Department of Bioresource Engineering, McGill University, personal communication, January 2014). The fan used for this experiment was donated by Turner Chauffage – Heating Inc. Subsequent to procurement of this fan, the frame of the machine was designed around it (see section 3.2).

4.1.2 Optimal Fan Wind Speed and Corresponding Required rpm

The first order of business was to figure out what the optimal wind speed would be for the fan to blow at. The sought after wind speed should be strong enough to blow away the lighter, less-dense debris out of the paddy mixture, while not indiscriminately blowing the clean paddy away as well. It was found that the optimal wind speed for this application was 800 – 1300 ft/min, or 4.1 – 6.6 m/s (Kashayap and Pandya, 1965; Kashayap and Pandya, 1966). In order to achieve this wind velocity, a specific rotational speed (rpm) would be required of the shaft of the centrifugal fan. This was calculated using the fan affinity law:

$$\frac{n_1}{Q_1} = \frac{n_2}{Q_2}$$

Where: Q_1 = first air flow rate (m^3/min)
n_1 = rotational speed corresponding to Q_1 (rpm)
Q_2 = second air flow rate (m^3/min)
n_2 = rotational speed corresponding to Q_2 (rpm)

The variable to be solved for in this case was n_2. Based on information provided by Turner Heating (personal communication, February 2014. Pointe-Claire, Qc.: Turner Chauffage – Heating Inc.), the air flow rate (Q_1) at the fan outlet was known, as well as n_1. However, a new Q_1, corresponding to the rotational speed n_1 9" (0.23 m) from the fan outlet (where the paddy would fall), was used; it was obtained by measuring the wind speed at this distance. Q_2 was easily calculated because Q = (cross-sectional area)(wind velocity), and the cross-sectional area could be measured, while the desired wind speed was already pre-determined to be 4.1 – 6.6 m/s; a wind velocity of about 5 m/s was used. Using all these values, the required rotation of the fan shaft, n_2, was calculated to be 248 rpm.

4.1.3 Fan Power Requirement

To find the power requirements of the fan, total pressure of the airflow in the fan and the cubic flow rate of the air leaving the fan are required:

$$P = \frac{p_t * Q}{\mu_b \mu_f \mu_m}$$

Where: Q = Air flow rate (m^3/min)
p_t= total pressure (Pa)
μ_b= belt efficiency
μ_f= fan efficiency
μ_m= motor efficiency

The power requirement of the fan requires the total pressure, however a part of total pressure requires static pressure:

$$Total\ Pressure = p_t = p_s + p_d = p_s + \frac{\rho v^2}{2}$$

Where: p_t= total pressure (Pa)
p_s= static pressure
p_d= dynamic pressure
ρ = density of fluid
v = velocity

Usually the static pressure is given on a chart provided by the fan manufacturer, since the fan was donated, most of the information needed to calculate the power needed for the fan was not provided, and therefore the power requirements for the fan could not be determined. However when testing the fan with a new set of pulley attachments, the motor on top of the fan was able to provide enough power to supply torque to the fan and to the sieves.

4.2 The Frame

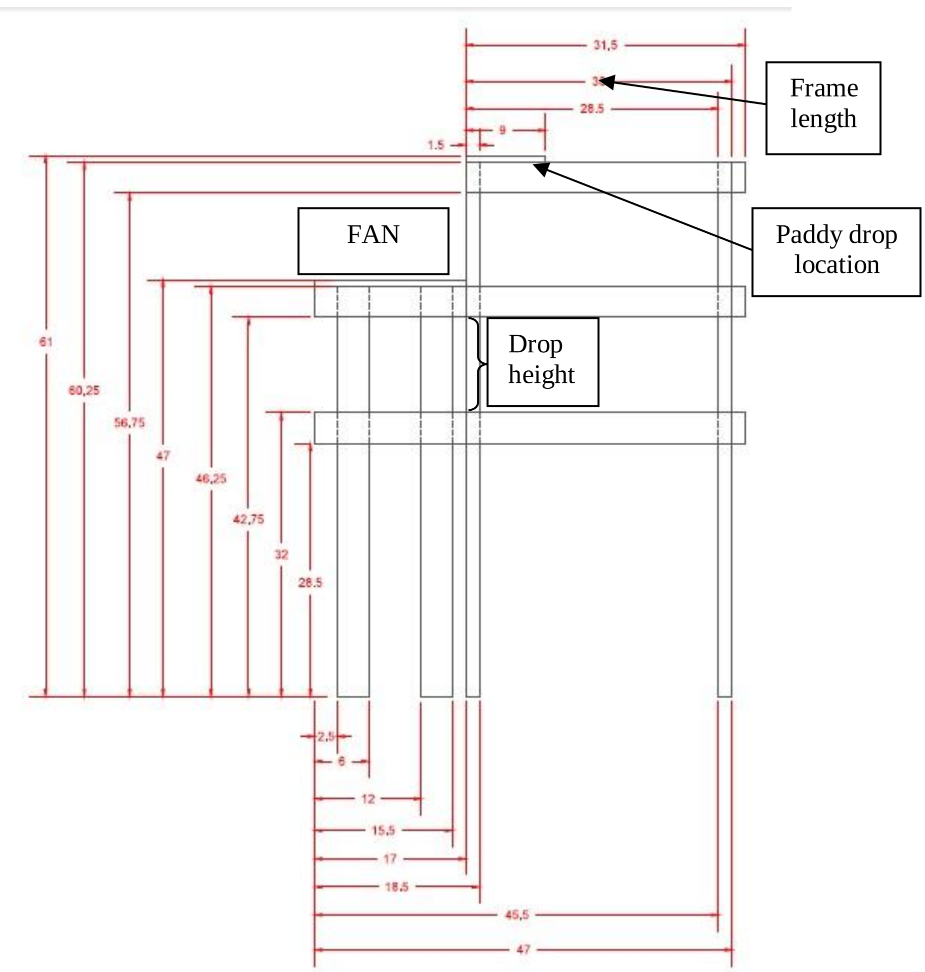

Figure 3: Side elevation view of the frame

4.2.1 Paddy Drop Location

The frame was designed so that the paddy would fall at a distance of 9” (0.23 m) from the fan outlet, as can be seen in Figure 1. This distance was chosen after having consulted an article by Kashayap and Pandya (1966), in which a similar winnowing system was used.

4.2.2 Height of Freefall below the Air Stream

The first major dimension that needed to be ascertained was the paddy drop height between the bottom of the fan’s air stream and the sieve system (see Figure 1). This distance has to be large enough to allow for sufficient exposure between the paddy mixture and the lighter debris that are separated out by the blowing air from the fan. If the drop height is not large enough for the lighter debris to clear the sieve system, then re-contamination of the paddy with this debris will occur when they contact the sieve. While a significant drop height would need to be incorporated into the design for this reason, this must be balanced with the goal of trying to keep this machine as compact as possible.

To address the issue of balancing the two competing aims, a plot relating horizontal resolved distances between various particles as a function of different drop heights. The data was obtained from Table III of Kashayap and Pandya (1965), which relates fall heights below the air stream with resolved distances between paddy, as estimated by particle 1 in Table I of Kashayap and Pandya (1965), and various chaff/debris (particles 2 through 6 of Table I). The first order of business was to calculate which particle in Table I best represented the debris reported from Lafia, Nigeria (see Appendix I), and to check the validity of the assumption that the dimensions of the Lafian paddy (see Appendix I) were well represented by particle 1 from Table I. After investigating this, it was concluded that the paddy and debris would be best represented by particles 1 and 5 respectively, from Table I, and the resolved distances between the two particles, as reported in Table III, was plotted with respect to various drop heights; this plot can be seen in Figure 2 below. The MATLAB program created to obtain this plot can be seen in Appendix II.

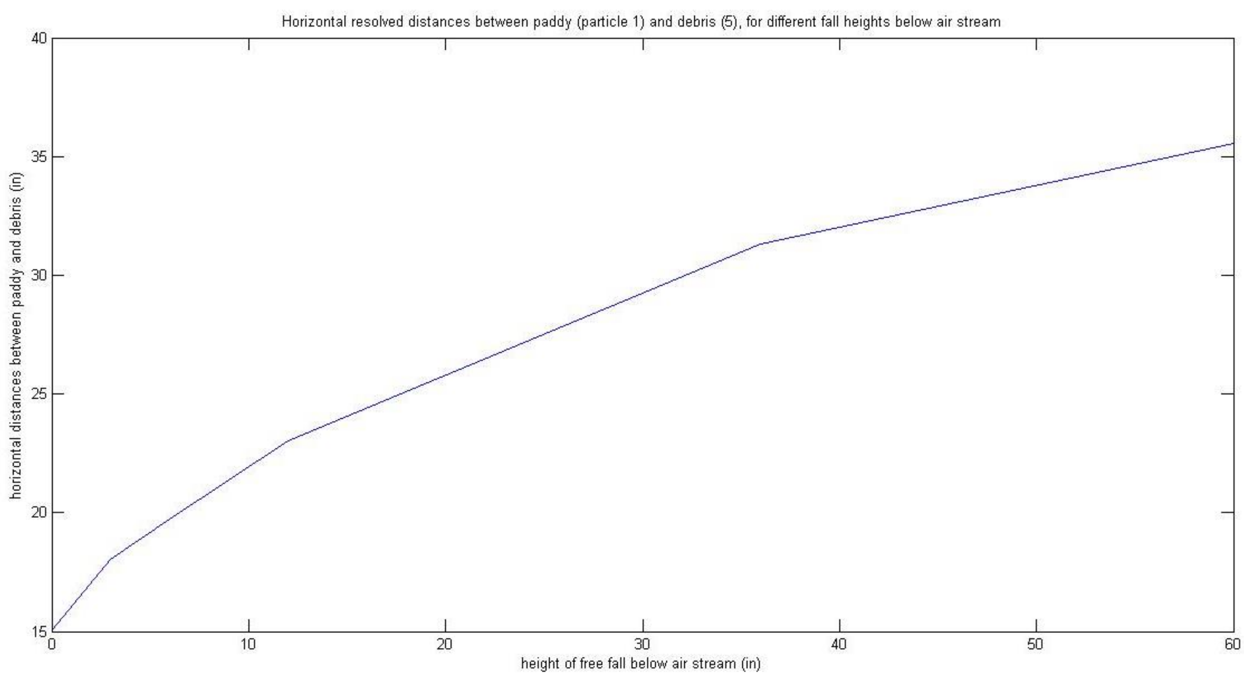

Figure 4: Horizontal resolved distances between paddy (particle 1) and debris (particle 5), for different drop heights below air stream (Kashayap and Pandya, 1965)

Looking at Figure 4, it initially seemed like a fall height of 35” (0.89 m) would be the optimal drop height, as it shows the last point where there is a rapid increase of y-axis values before it is subject asymptotic behavior assumed to be a diminishing return to the increase of drop height. However, after discussion, it was deemed that this drop height was too large and would result in a machine that would be too high. After some investigation, it was realized that the 35” (0.89 m) mark seemed ideal in the graph because of the lack of data points between the 1 and 3 ft drop heights (0.30 m and 0.91 m drop heights respectively). After further analysis, keeping in mind design compactness and where the most data points were sampled, it was found that the best drop height would probably occur at the 20” (1.67’ or 0.51 m). This was deemed a reasonable distance that would not result in too bulky a machine, and incorporated into the design.

4.2.3 Length of Frame

The second major dimension to be determined was the length of the frame (see Figure 3). This was determined by considering two factors. The first one being that the paddy would be falling 9” (0.23 m) from the fan outlet. The second factor to be considered was the amount of distance needed to allow for sufficient horizontal wind exposure between the falling paddy mixture and the lighter debris being blown away, as discussed in *4.2.2*. This was determined by looking at the y-axis value of the plot in Figure 2 corresponding to the decided-upon 20” (0.51 m), which could be seen to be about 26” (0.66 m). By adding the 9” (0.23 m) and 26” (0.66 m) of the two considered factors, a required frame length of 35” (0.89 m) was found. This was later brought down to 30” (0.76 m) after considering safety factors (see Figure 3).

4.2.4 Overall Height of Frame

The overall height of the frame of 61” (1.55 m) (see Figure 3) was calculated after considering all these factors together: the fan outlet height, required paddy drop height, and approximate height of the sieve system and collection system.

4.3 Sieve system

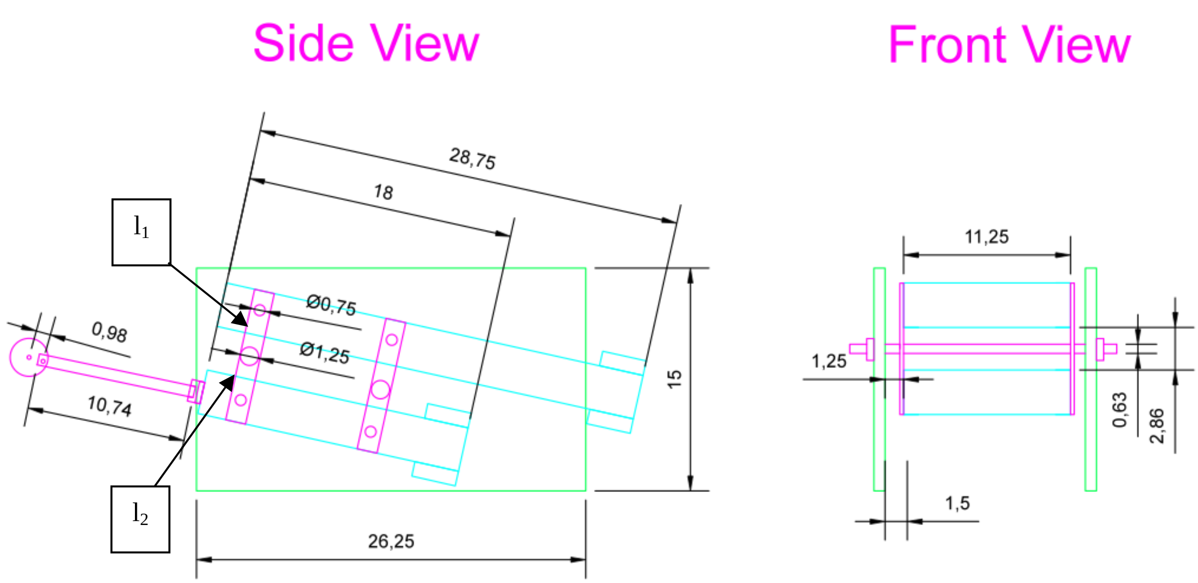

Figure 5: Side elevation view of sieve system (left); front elevation view of sieve system (right)

The sieve system was perhaps the most arduous component to design and build. Figure 5 shows elevation views of this system, separated from the rest of the frame. The green rectangles are ¾" (0.02 m) plywood pieces, and these would be fastened to the legs of the frame below the horizontal 2x4 wood pieces bordering the bottom of the drop height in Figure 3.

4.3.1 Power Requirement and Sieve Vibration Frequency

The first thing that needed to be investigated was the required vibration frequency of the sieves, as well as the required energy input. The former was important to ascertain so as to properly select the pulley ratios in order to achieve the desired frequency. The power requirement was also important to derive so that a proper motor/engine could be acquired for the system; one that would be able to power both the sieve system and the fan.

The vibration frequency was initially set to 480 rpm, based on an article from Okunola and Igbeka (2009). Eventually, after consultation with Sam Sotocinal (personal communication, March 2014. Sainte-Anne-de-Bellevue, Qc.: McGill University), it was decided to bring the frequency down to 120 rpm in fear of shaking the frame too much.

To determine the power requirement of the sieve system, a MATLAB program was created to ascertain the maximum power requirements for various lever ratios between l_1 and l_2 (see Figure 3). This MATLAB program can be seen in Appendix III, with iteration when l_1 was set equal to l_2. The program was initially run for various lever ratios. It was found that while $l_1 = l_2$ required the most power in comparison to the other lever rations, with a maximum of 389 W, the extra required power was deemed negligible when one considers the size of the motors/engines on the market and the estimated minute power requirement for the fan system. Therefore, when considering this, and the added benefits of having a system that is simpler to construct and that would potentially run into significantly less complications, in keeping with the objectives of this machine, it was decided to keep $l_1 = l_2$.

4.3.2 Sieve Tilt Angles

Sieves can be tilted to specific angles from the horizontal so as to achieve maximum efficiency in separating paddy from impurities. Okunola and Igbeka (2009) had published optimal tilt angles for the top and bottom sieves of a double sieve system similar to that being discussed in this report. They reported that the optimal tilt angle for the top sieve is 8^o, while that of the bottom sieve is 20^o (Okunola and Igbeka, 2009). However, after some discussion with Scott Manktelow (personal communication, March 2014. Sainte-Anne-de-Bellevue, Qc.: McGill University), it was deemed that having different tilt angles for the top and bottom sieves would complicate the design and construction of the system, as well as add additional strain on certain sections of the system. Keeping its construction as simple as possible is important when one considers the objective of trying to make this system as easy to build and replicable as possible. Furthermore, it was deemed highly unlikely, prior to construction that the angles at which the sieves would be placed would be so accurate that paying attention to the different angles for the top and bottom sieves would matter. Therefore, it was decided to keep both sieves at the same tilt angle.

Next, it was important to determine the approximate sieve angle for both sieves to clean the paddy of Lafia, Nigeria (see Appendix I for the dimensions of the paddy). While the literature reported certain optimal angles, it may not be representative data for the paddy from Lafia. So it was decided to run experiments with the prototype to try to establish the best angle for the paddy in question. An elaborate sieve system was designed in order to test the cleaning efficiency of the paddy at various sieve angles; it would be similar in design to Figure 5, but more complex. The whole system would be able to pivot from a single point, notably the drive shaft. The ¾” (0.02 m) plywood walls of the sieve assembly (green rectangles in Figure 5) would be attached to other ¾” (0.02 m) plywood outer walls, which would themselves be attached to the legs of the frame seen in Figure 3. The sieve plywood walls would be attached to the outer walls by means of 2 bolts each; a series of holes along the outer wall would allow for the bolts to be inserted and the sieve to be oriented at different angles. To change the angle of the sieve system, the 4 bolts would need to be undone, the sieve assembly would be moved up or done from the pivot point, and then the bolts would be re-inserted into a new set of holes on the outer plywood. It should be noted that while there would be a series of holes along the outer plywood, the plywood wall of the sieve assembly itself (green rectangles in Figure 5) would only have one set of holes where the bolts could be attached.

After some discussion amongst group members, it was decided to not build the elaborate system just discussed, but to decide on a fixed tilt angle for both sieves, and build the system permanently set at this angle. This was decided because building a complex system would run into problems, there would be insufficient time to run these tests, and it would be extremely complicated and difficult, which would not be in keeping of the objectives of the design to develop a cheap, reproducible prototype. Furthermore, it was important to remember that the purpose of building a prototype was to build a model that would reflect as close as possible the eventual final design of the winnowing machine, and not build an experimental apparatus. Designing for a fixed angle sieve system would satisfy all these aforementioned concerns. Therefore, both sieves were set to be placed at an angle of about 14^o, which is the average of the optimal tilt angles for top and bottom sieves as reported by Okunola and Igbeka (2009). This was justifiable with the belief that the accuracy with which the sieves would be placed for this system would not be so precise that it would make a difference whether they would be placed at 14^o or at an angle determined from the aforementioned experimental procedure. Also, since the paddy used in the experiments by Okunola and Igbeka (2009) were from a similar region of Nigeria as Lafia, it could be reasoned that the optimal tilt angles that would be obtained from the experiment described in this report would not vary greatly from 14^o.

4.3.3 Sieve Screens

Initially, the exact size and shape of the screen holes that would be needed was being ascertained through the use of various calculations presented by Okunola and Igbeka (2009), using the paddy dimensions in Appendix I as the basis. It was thought that after this would be accomplished, that screens with these specific characteristics would be ordered from companies that specialized in screens for crop sieving. However, due to time constraints, this approach was abandoned, and instead, a new approach was adopted for screen acquisition: scrap extended metal and perforated sheets were used for the screens for the two sieves. To select suitable pieces, simple criteria were used: the holes for the screen of the top sieve needed to be bigger than the paddy's dimensions, so that the entire paddy would fall through, while those of the bottom sieve needed to be smaller than the paddy's dimensions, so that none would fall through. This selection criterion is consistent with the intended functioning of this sieve system, as discussed in the Design Analysis & Specifications. Of course using the scrap sheets would not result in a final paddy product of as high a quality than if the screens would be purchased from specialized companies, but it would be more in keeping with the objectives of the design of this report. Using readily available materials, such as scraps, and using such a simple choosing methodology would result in reduced costs, increased accessibility to materials, easier system construction, and an overall improved winnowing process as compared to the current process in Lafia.

4.4 Power and Pulley V-Belt System

The motor on top of the fan is rated at 1725 rpm, which has a torque that needs to be transmitted to the shaft connected to the fan and then to the shaft connected to the vibrating sieves. In order to transmit torque from the motor to the fan and the vibrating sieves, four pulleys connected by a V-belt is required. In order to transmit torque from the fan shaft to the shaft connected to the vibrating sieves, an extended shaft with a length of 24" (61 cm) was installed inside the fan in order to place a pulley on the other side of the fan and connect it to the bottom shaft connected to the sieves.

4.4.1 Pulley Diameter

To size the correct dimensions of the pulley, a ratio between RPMs and pulley diameter was used:

$$n_1 d_1 = n_2 d_2$$

Where: d_1 = diameter of driver pulley (cm, in)
n_1 = rotational speed corresponding to d_1 (rpm)
d_2 = diameter of driven pulley (cm, in)
n_2 = rotational speed corresponding to d_2 (rpm)

Given that the fan needed to run on a shaft speed of 248 rpms to produce a wind velocity of 6 m/s and the motor runs at a shaft speed of 1725 rpms, a 1:7 pulley diameter ratio was needed to meet the required shaft speed of the fan. The pulley diameters that were available to meet the 1:7 pulley ratio was a 1.5" (3.8 cm) driver pulley attached to the motor shaft and a 10" (25.4 cm) driven pulley attached to the fan shaft. However, the pulley diameter ratio changed from a 1:7 ratio to a 1:6.6 ratio, which consequently had the fan shaft spin at 258 rpms instead of 248 rpms. In consideration to using the fan affinity law, the wind velocity immediately exiting the outlet changed from 6 m/s to 6.2 m/s.

Since the fan shaft was spinning at 258 rpms, the shaft connected to the vibrating sieves needed to slow down to a shaft speed between 200-100 rpms. Thus, a 1.75" (4.45 cm) diameter driver pulley attached to the other side of the fan shaft and a 3.25” (8.25 cm) diameter driven pulley attached to the last shaft connected to the sieves were used to slow down the revolutions of the vibrating sieves to 139 rpms.

4.4.2 Belt Length

After sizing the 4 pulleys, the length of the V-belts between the motor and fan shaft and between the fan shaft and the shaft connected to the sieves were calculated by finding the angle of contact between each pulley. The Angle of contact was found using the following equations:

$$Angle\ of\ Contact\ of\ Small\ Pulley = \theta_d = \pi - 2\sin\left(\frac{D-d}{2C}\right)$$

$$Angle\ of\ Contact\ of\ Large\ Pulley = \theta_D = \pi + 2\sin\left(\frac{D-d}{2C}\right)$$

Where: D = diameter of large pulley (cm, in)
θ_D = Angle of contact of large diameter pulley (rad)
d = diameter of small pulley (cm, in)
θ_d = Angle of contact of small diameter pulley (rad)
C = Length between the pulley centers.

When the angle of contact was found between the two pulleys, the total outer length of the belt was calculated using the following equation:

$$Length\ of\ Belt = \sqrt{4C^2 - (D-d)^2} + \frac{1}{2}(D\theta_D - d\theta_d)$$

The length of the first V-belt between the first pulley attached to the motor and the second pulley attached to the fan shaft and the length of the second V-belt between the third pulley attached to the fan shaft and the fourth pulley attached to the shaft connected to the sieves were found to be 42” (107 cm) and 80” (203 cm) respectively.

4.5 Final Comments on Winnowing Machine Development

When the prototype was actually being constructed, slight imperfections in the materials made it so that slight modifications had to be made from the designed dimensions. Seeing as the objective was to make this system as accessible, cheap and reproducible as possible, and inherently improve the current winnowing process by using easy-to-obtain materials, most of these materials were cheap and obtained from scrap pieces, and imperfections were unavoidable. This problem would undoubtedly be encountered when this system is rebuilt in the future, and so a certain amount of adaptability is required in those that undertake the machine’s construction in the future.

5. Testing: Methods, Results and Analysis

5.1 Wind stream velocity

The wind stream velocity was measured using an anemometer. Readings were taken 5-inches directly below the hopper outlet. The average wind speed over five readings was found to be 5.46 m/s. The recorded data for each trial can be found in *Table 1*.

Table 1: Measured wind speed velocities at 5-inches below hopper outlet in m/s.

Trial	**Anemometer reading (m/s)**
1	4.5
2	5.4
3	6.2
4	6.0
5	5.2
Average wind velocity, $(\sum readings\ (\frac{m}{s}))\ /(5\ trials)$	5.46

5.2 Paddy sample composition

The rice paddy was found to be by roughly 88% rice paddy, 4% heavy impurities and 0.6% dust and small impurities by mass before winnowing. The methods for calculating this composition were as follows.

The complete sample of rice paddy mixture was weighed. The sample was run through the machine and the components were collected in containers as four separate components: light impurities (straw, chaff, dust etc.), large heavy impurities (rocks, small sticks etc.), clean rice paddy and smaller heavy impurities (tiny rocks). The contents of each container were weighed and examined to determine the percent mass composition of the rice paddy.

It was observed that roughly 50% of the contents of the light impurities container were escaped rice paddy. Roughly 95% of the small heavy impurities were also rice paddy. These observations were made by eye. The contents of the clean rice paddy container contained some large heavy debris; these were removed by hand and their weight was recorded and added to the mass of heavy debris and subtracted from the mass of clean rice paddy. Similarly the heavy impurities contained significant masses of rice paddy; the large impurities were removed by hand to determine the mass of rice paddy and that of the heavy impurities. The following table has been modified to account for these observations. **It is important to note that some rice was lost to the exterior of the machine. It is for this reason that the percentages of the components do not sum to 100%. It is also important to consider that the discrepancies in percentage composition can be attributed to the fact that impurities are not distributed evenly throughout the batch of rice paddy. Modifications were made throughout the trials.

Table 2: Components of sample rice paddy by mass (g)

Trial $m_{totalin}$ (g)	**$m_{smallheavyimpurites}$ (g)**	**$m_{lightimpurities}$ (g)**	**$m_{ricepaddy}$ (g)**	**$m_{largeheavyimpurities}$ (g)**
a) 166.6	0.105	0.9	93.07	23.68
b) 174.53	0.146	1.1	48.55	12.23
c) 515.35	0.37	3.3	492.22	11.96
d) 862.41	0.355	2.9	707.84	35.7
e) 725.31	01.87	1.85	689.14	30.42
f) 722.96	0.925	2.035	640.763	27

The data of interest can be found in rows d, e and f, as these were collected without modification in between trials. These masses were divided by the mass of the total sample entering the system to produce estimates on the percent composition of the rice paddy. This yielded the following percentages:

Table 3: Percent composition of rice paddy

Trial	**Dust and small impurities (%)**	**Rice paddy (%)**	**Larger heavy impurities**
d	>0.6	82	4.1
e	0.6	95	4.2
f	0.6	89	3.7
Average over three trials	0.6	88	4

5.4 Percent loss

The machine was found to have a percent loss of roughly 15% of the rice paddy that entered the machine. These losses can be attributed to rice escaping the catchment containers or exiting the machine through the wrong pathway, such as being blown away by the wind or being caught by the upper sieve. To obtain this value a known mass of rice paddy was passed through the machine and the mass of the rice that fell into the clean rice paddy catchment was recorded to determine the percent loss of rice paddy as it passed through the machine. Three trials were conducted and the following data was collected:

Table 4: Percentage loss of rice paddy after one pass through machine (%)

Trial	***Mass in (g)***	***Mass out (g)***	***(Mass in – mass out)/(mass in) (%)***
1	*1000.73*	*856.7*	*14.39*
2	*1000.18*	*853.00*	*14.72*
3	*1000.3*	*837.00*	*16.33*
		Average percent loss	*15.15*

6. Cost Assessment

A budget of $500 was provided for the construction of the prototype. The total costs of materials totaled $316. As can be noticed on the materials price breakdown (*Table 5*), two major components of the system are missing due to the fact that they were obtained free of charge. These two components are the fan and motor combination as well as the sieve screens. If these materials would have had to been purchased it is probable that the allocated budget would have been surpassed. There are also a few other materials not included in the materials price breakdown such as metal arms. These items were also obtained free of charge from scrap piles at theworkshop.

Table 5: Materials purchased and their associated costs.

	Material list	No. Purchased	Unit Price (CAD)	Sub-Total (CAD)
1	3/8" Nylon Bearing, Flanged, 1/2" OD, pack of 5	2	$5.17	$10.34
2	5/8" SAE 841 Bronze Flanged-Sleeve Bearing, 3/4" OD	6	$1.56	$9.36
3	1/2" Stamped Steel Mounted Ball Bearing--ABEC-1, 2-bolt base mount	2	$12.03	$24.06
4	5/8" diameter, 18" length Hardend Precision steel shaft	2	$13.72	$27.44
5	1/2" diameter, 24" length Fully Keyed 1045 Steel Drive Shaft	1	$32.25	$32.25
6	3/4 " diameter, 24" length Fully Keyed 1045 Steel Drive Shaft	1	$36.49	$36.49
7	5/8" diameter One-Piece Clamp-on shaft collar. Black-Oxide Steel	1	$2.16	$2.16
8	10" OD, 3/4" bore, 4L Die Cast V-Belt Pulley	1	$33.59	$33.59
9	1-3/4" OD, 3/4" bore, 4L Die Cast V-Belt Pulley	1	$5.16	$5.16
10	1-1/2" OD, 1/2" bore, 4L Die Cast V-Belt Pulley	1	$4.92	$4.92
11	3/8" Steel Nylon Lock nuts	10	$0.34	$3.40
12	3/8" Steel Bolts	10	$1.49	$14.90
13	6", 1-1/5" length Wood Screws, 100 pieces	1	$5.49	$5.49
14	8", 3" length Construction Screws, 100 pieces	1	$8.64	$8.64
15	2"x4"x98" wood	11	$2.72	$29.92
16	1"x3"x98" wood	2	$1.61	$3.22
17	80 in 4L v-belt	1	$24.37	$24.37
18	43 in 4L v-belt	1	$8.09	$8.09
19	3/4"4'x8' Sheet of Plywood	1	$32.16	$32.16
			Total (w/o Taxes & other charges)	**$315.96**

The total material costs to build the prototype in Montreal would obviously differ from that in Nigeria. For this reason it cannot be established exactly how much the system would cost to build in Lafia without receiving further information from our contacts in Nigeria concerning the price of said materials. Regardless, in sticking with the portion of the design objective that includes building a winnower out of easily sources materials, it can be recognized that the materials chosen were not high end or specialized materials and thus reasonably assumed to be accessible and affordable to those in West Africa.

Including a winnower into the rice cleaning process would lead to large labour cost savings for the farmer as it would make the process much more time efficient and therefore not require the women to work as many hours. It however must be noted that this improved time efficiency of the process may not be regarded as a good thing from the workers perspective as it would be cutting jobs. Further investigation will have to be done concerning the machines public acceptance and consequence of its implementation along with how to mitigate the possible negative financial affects in has on the local population's salaries.

7. Recommendations for Optimizing the Machine

7.1 Tilting the Fan

One of the biggest problems of the designed winnowing machine was that it was too tall to be operated easily by the women of Lafia, who are responsible for carrying out the winnowing process. The machine is 5'1" (1.55 m) according to Figure 3, while the average height of a Nigerian woman is 5'2" (1.57 m) (Wiki, 2014). Therefore, it was imperative to find ways to scale down the height of the machine. Perhaps the easiest way was to reduce the free fall height discussed in *4.2.2* between the air stream and the top sieve. It was found by Kashayap and Pandya (1965) that orienting the air stream/fan upwards 50 – 60^{o} from the horizontal would make it so that no free fall would be required below the air stream, thus eliminating the 1.67' (0.51 m) drop discussed in section *4.2.2*.

Tilting the fan and reducing the height of the machine would have more benefits than just reducing the machine's height to a more workable size for the Nigerian women. First of all, according to Kashayap and Pandya (1965), with an angled air stream, the optimal wind speed range of 800 – 1300 ft/min (4.1 – 6.6 m/s) could be slightly reduced to achieve the same results as before, thus saving energy. Although, the amount of energy saved would probably be quite negligible. More importantly however, reducing the free fall height would help solve another huge problem with the current design. At the moment, the air stream velocity is significantly altering the horizontal displacement of the paddy; this results in the paddy landing much farther along the first sieve than expected and, in turn, results in the paddy missing the second sieve as it falls through. Of course one solution would be to perhaps reduce the wind velocity exiting the fan, as it seems that the current wind speed, and thus the values reported in the literature, may be slightly too high. However, perhaps this would not even be required; if the drop height would be significantly reduced, as by eliminating the 1.67' (0.51 m) in question, then the gradual horizontal displacement of the paddy would be halted prematurely.

7.2 Sieve Orientation

Currently the power arm driving the sieve system is placed a certain distance below the fan and motor, and all the V-belts connecting the various pulleys are largely isolated to one location of the machine. The sieves are oriented so that the debris and paddy are shuffled into their respective collection bins on the opposite side of this power system. However, it was discussed that perhaps the system would be more efficient in its paddy cleaning if the sieves would be oriented so that the paddy (and by default, also the heavier debris) be shuffled in the opposite direction of the blowing air stream. This would ensure that no chaff and lighter debris get mixed in with the cleaned paddy as it moves. While this is a potentially useful recommendation, further brainstorming would be needed first to conceptualize how the engine/motor and V-belts would be placed with respect to the sieve driving arm and associated shaft. If an engine/motor would remain in its current location and the system setup would be similar to what it currently is, the V-belt that is attached to the shaft powering the sieve system would go across the whole system, and this would provide additional complications and safety concerns. However, this argument is hinged on the assumption that the power arm and shaft powering the sieve system would be on the opposite side as well. Perhaps the sieves can be rotated and deliver the paddy against the air stream direction, as has been discussed so far, while the power arm remains where it is currently. However this could pose yet another problem; the debris and paddy would be falling where the shaft and power arm would be. It is clear that no matter what is decided for this option, more brainstorming would be required first.

7.3 Sieve Holes

It was observed that the holes of the bottom screen were not ideal for the proper cleaning of the paddy; they were slightly too big and allowed significant amounts of paddy to be lost. While the criterion with which the screens were chosen, as discussed in *4.3.3*, would necessarily involve that some paddy is lost by the bottom screen, it is recommended by the authors that when the aforementioned choosing methodology is used for screens of the bottom sieve, that ones with smaller holes be chosen.

7.4 Safety Concerns with Shafts and Belts

The current machine has V-belts and shafts sticking out in the open, making it very easy for workers to walk into them unintentionally. Although the current speeds at which these components are moving is relatively slow compared to most machines, the system’s safety could be improved by placing some type of cage or safety bars to prevent workers from running into these moving components.

7.5 Future Considerations for Final Design

The materials used to construct the machine being discussed in this report, largely wood for the frame and polyethylene for the covering, were appropriate for a prototype. They were relatively cheap and allowed easy modifications as the system was being built. However, for the final design, changes would be necessary for it to be suitable for the workplace: materials from which the system is constructed would have to be much more durable. Thin sheets of fairly durable, non-rust, low-cost metal would need to be used for the covering (to replace the polyethylene), and a steel frame would be needed to replace the wood frame. Of course, this would increase costs of the system.

Other changes would also be needed in order for this machine to be used in the workplace of Lafia, Nigeria. One thing to consider is that it would be beneficial to install wheels that can be locked in place, on the legs of the frame, so that the machine can be moved from one work location to the next with ease. Another aspect to consider when using this machine in the workplace would be to use an engine as opposed to a motor that runs on electricity. A motor was used for the purposes of the prototype because it was donated by Turner Chauffage – Heating Inc. alongside the fan, and was powerful enough to run the fan and sieve system. However, an engine would be much more appropriate in Lafia because they have easy access to engines, to fuel, and they have the capacity to maintain and repair this technology (Dr. Michael Ngadi, Department of Bioresource Engineering, McGill University, personal communication, November 2014). The use of an electric motor is not appropriate, as it would not be practical to use in the workplace, and Lafia does not have a constant reliable source of electricity (Dr. Michael Ngadi, Department of Bioresource Engineering, McGill University, personal communication, November 2014).

8. CONCLUSION

In conclusion, the primary findings of this report suggest that the rice winnowing machine was a successful proof of concept. The rice was winnowed quickly and the quality of the rice paddy mixture was improved notably. Though the prototype shows promise, there are numerous areas of improvement for further development of the winnowing machine. In sum, this project has demonstrated that modern winnowing technology can be incorporated into a cheap and accessible machine which has the potential to improve the lives of those in Lafia, Nigeria and elsewhere.

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