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FACULTY OF ENGINEERING

CHEMICAL AND PROCESSING ENGINEERING

DESIGN AND CONSTRUCTION OF A MAIZE GRAIN CLEANER

By

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ABSTRACT

Maize (Zeamays) is the third most important cereal grain worldwide after wheat and rice. The importance of maize is centered on the large quantity of Carbohydrates and significant quantities of proteins, vitamins and fats, contained in the kernels, making it compare favorably as an energy source with root and tuber crops.Winnowing and cleaning of grain is usually done prior to storage or marketing if the grain is to be sold directly. For the majority of smallholder grain processors, this process is undertaken manually. It is relatively ineffective from a commercial perspective, since grain purchased from smallholders frequently requires screening to remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing, as there is usually no premium for quality; rather, there is every incentive to leave foreign matter in the grain, especially at the bottom of sacks, so that profits from sales can be maximized. Therefore, the objective of the study was to design, construct, test and carry out economic evaluation of a maize grain cleaner for small and medium scale agro- processing units. This would therefore, result in reduced bulk of the material by reducing the level of physical contaminants, thus reducing transport costs and optimizing storage space, safe and longer storage, more out-turn of better quality milled products.

The design of the various machine parts was carried out by analyzing forces acting on them. Force analysis led to selection of proper materials to withstand the forces to avoid failure. Stainless steels of various grades were the main materials recommended to be used because they are food grade, strong and durable. Engineering drawings of the various components were drawn before the various components were constructed and then machine parts fabricated. A fully functional prototype resulted after all the above operations. Testing of the prototype was carried out and the figures revealed that the machine was 75.5% efficient. The maize grain cleaner has a total cost of $\mathbf{1,975,675}$ $\boldsymbol{UGX}$ which includes all the taxes, cost of material, machinery and hired labor to construct the machine plus overhead costs. The cost evaluation analysis of the project was based on the payback period method, the project was evaluated to breakeven in 3 months.

DECLARATION

I **AKAMPWERA AGATHA** declare to the best of my knowledge that this project report is as a result of my research and effort and it has never been presented or submitted to any institution or university for any academic award.

DATE : 31/05/2019

SIGNATURE:

APPROVAL

This project report has been submitted to the department Chemical and Processing Engineering for examination with approval from the following supervisors:

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LIST OF ACRONYMS

FAO - Food and Agriculture Organization

MAAIF - Ministry of Agriculture, Animal Industry and Fisheries

MOG - Materials other than grains

NAADS - National Agriculture Advisory Services

UBOS - Uganda Bureau of Statistics

WFP - World Food Programme

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter briefly describes the historical background of maize as a crop, the problems encountered during its cleaning and gives a justification for the design and construction of a maize grain cleaner in order to reduce on the cleaning losses by improving postharvest grain quality, labor, and increasing income for farmers. It also includes the objectives of the project and its scope.

1.2 Background

Maize (Zeamays) is the third most important cereal grain worldwide after wheat and rice (Golob, *et al.*, 2004). The importance of maize is centered on the large quantity of Carbohydrates and significant quantities of proteins, vitamins and fats, contained in the kernels, making it compare favorably as an energy source with root and tuber crops (Ambrose *et.al*, 2011). Furthermore, maize is referred to as the cereal of the future for its nutritional value and utilization of its products and by-products (Choct, 1997.). Climatically, maize can be produced in most parts of the country except in the most arid parts of Karamoja. The districts with the highest production of Maize are Mubende (1,710,819 tones), Iganga (303,262 tones), Adjumani (47,264 tones) and Kabarole (91,318tones) respectively (*UBOS, 2015*).

However, effective demand of clean grains is gaining potential in the urban areas and the local market is available and it is growing due to increase in rate of urbanization. For grains to be utilized in any form they need to be cleaned which determines the quality, quantity of the cleaned grains as poor methods of cleaning lead to high loss and low quality of grains plus low market value (Ray, 2007).

The traditional methods of harvesting, threshing and postharvest handling of maize grains usually lead into contamination of the product with stones, sticks, chaff, dirt and dust. Materials obtained after threshing include long straws, chaff, small fragments of spikes, leaves and grains. Therefore maize grains, after threshing cannot be stored or used for consumption or as planting material due to the very fact that the presence of long straws, chaff, small fragments of spikes, leaves, dust, dirt and other foreign materials in the grain will accelerate deterioration, thus lead to poor physical condition and the quality of grain becomes eminent. Grain primary processing usually improves grain condition and quality and the process is a vital and necessary link between production, storage and distribution. As a result, farmers are compelled to do additional work of separating and cleaning grains from undesirable materials that will otherwise reduce the quality and the value of the product prior to storage, marketing, distribution and subsequent processing.

Most research on grains has focused on increasing yield, but issues of post- harvest losses, value addition and market accesses have been minimally addressed (Wright, B.D, 2009). This study therefore seeks to address the issues of grain cleaning so as to reduce losses and increase quality.

1.3 Problem Statement

Winnowing and cleaning of grain is usually done prior to storage or marketing if the grain is to be sold directly. For the majority of smallholder grain processors, this process is undertaken manually. It is relatively ineffective from a commercial perspective, since grain purchased from smallholders frequently requires screening to remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing, as there is usually no premium for quality; rather, there is every incentive to leave foreign matter in the grain, especially at the bottom of sacks, so that profits from sales can be maximized (Rosegrant, 2015). The cleaning process is undertaken manually and large equipments are available for large scale processing. This leads the cleaning process to be time consuming and tedious on the side of small scale farmers, therefore there is need to develop a machine that will reduce the level of physical contaminants at an affordable cost and positively enhance the safety of maize grains together with derived products and even be able to cope up with the increasing demand for the clean grains.

1.4 Purpose of the Study

The purpose of the study is to design and construct a maize grain cleaning system that will reduce the level of physical contaminants and positively enhance safety of maize grains and their derived products. The study also aims at increasing production levels of quality grain and reducing drudgery usually associated with farmer's methods.

1.5 Objectives of the Study

1.5.1 Main Objective

To design and construct a maize grain cleaning system by April 2017

1.5.2 Specific Objectives

i. To design the different components of a maize grain cleaning system
ii. To fabricate and assemble the components of a maize grain cleaning system
iii. To test the performance of the grain cleaner for efficiency of clean grain expected to be about 95% clean grain and 5% chaff.
iv. To carry out economic analysis of the grain cleaner.

1.6 Scope of the Study

The scope of the study is limited to designing, fabricating, testing and carrying out economic evaluation of a maize grain cleaner to be used by small scale and medium farmers.

1.7 Justification of the Study

In Uganda, grains are produced and milled by small- scale farmers and local grain processors using cottage mills. This study seeks to develop a small scale and cost effective maize grain cleaning system for value addition in small- scale grain processing. The use of a maize grain cleaning system would result in reduced bulk of the material by reducing the level of physical contaminants, thus reducing transport costs and optimizing storage space, safe and longer storage, more out-turn of better quality milled products. It will also lead to improved grain quality which fetches higher prices on market. The improvement of the farmer earnings through sales of higher quality grains will enhance poverty alleviation among the rural farmers hence improving the livelihoods of their families.

CHAPTER TWO: LITERATURE REVIEW

This chapter includes relevant literature related to cleaning of maize, the existing cleaning methods and the developed models in the area of maize grain cleaning.

2.1 Maize Production and Consumption in Uganda

Maize is the most important cereal crop in Uganda. The cereal is planted on about 384,000 ha, which is 7% of total area planted with crops, and produces about 527,000 metric tons annually (UBOS, 2000; Kasenge, et al., 2001). Maize production in Uganda has been increasing due to its increasing demand both in the country and the region, particularly in Kenya, Congo, Rwanda, and Tanzania. The cereal is one of the major cash crops in the east and orthern regions of Uganda. In these regions, about 75-95% of maize produced is sold (Vinlaw Associates, 1997).

While home consumption remains the main reason for producing maize, small farmers depend upon maize among other crops for a substantial source of farm income. It is estimated that about 0.2 pounds of rough maize is consumed per person per day by Ugandan farm families (Vanegas & Ngambeki, July 1991).Therefore, maize comprises a significant part of the diet of many of the region's inhabitants. Per capita total maize consumption ranges from 28 kilogrammes a year in Uganda to 125 kilogrammes a year in Kenya. However, the yields remain low, fluctuating around 1.5 tonnes per hectare. Maize was mostly used as a food crop for domestic consumption but after 1981 the Government began to promote it as an export crop in an effort to diversify Uganda's sources of foreign exchange. About 1% of the total maize produced in Uganda is consumed by the household on the farm and the rest of the crop is sold meaning that maize is now produced mainly for sale (NARO, 2015). The majority of farmers also retain a portion of their produce for grain. Reliance upon purchased grain is not yet common and because of its excellent storage properties, maize is often saved for future use in case of drought or food shortage.

2.2 Post-Harvest Handling of Grains

When the grains have matured and ready for harvest, harvest is done using pangas, knives, hand picking and sickles. After harvesting, the crop is spread out on bare ground to dry. Significant losses due to poor post- harvest handling and storage facilities have forced farmers to sell their produce quickly irrespective of the price. This has resulted in dumping of produce on the market causing drastic price depression. Post-harvest losses can be substantially reduced with improved storage and processing methods. When dried, the crop is threshed by beating with sticks to remove the grain. The grain is separated from the chaff by winnowing, (Grains Sub sector Study report, 2007).

Most farmers in Uganda use open sun as a drying method for drying their maize on bare ground, tarpaulins, plastic sheeting, and concrete drying yard. During drying, moving wind blows foreign material like sand, stones, among others which come into contact with the spread maize and contaminates them (Bank, 2011).

2.2.1 Physical and Engineering Properties of Cereal Crop Grains.

Identifying the physical and engineering characteristics of cereal crop grains is very important to optimize the design parameters of agricultural equipment used in their production, handling and storage processes. So, it is essential to determine and recognize the physical and engineering (aerodynamic and mechanical) properties of agricultural products because these properties play an important role in designing and developing of specific machines and their operations such as sorting, separating and cleaning, also to determine the optimum in seed metering device in pneumatic planter and precision sowing machine to suite every size of these grains. Kochhar and Hira (1997) reported that to design equipment and facilities for handling processing and storage, the physical properties of crop grains must be known.

Sitkei (1987)reported that the functioning of many types of agricultural machines (sifters, sowing machines, pneumatic transport systems, etc.) is influenced by the physical properties of the objects participating, and so in order to study a given process they must be described accurately. Also the quality of processing (in chopping and milling) may be characterized by a products mean size and mean standard deviation, or these data may be used to organize a technological process or in designing certain structural elements (mesh dimensions of sifters or dimensions of screen holes).

In general, to specify the shape of a food material it is necessary to identify three basic dimensions, namely, length, width and thickness, aerodynamic properties of the food material includes the terminal velocity and mechanical properties of maize grains includes; Angle of repose and Friction coefficient.

2.3 Grain Cleaning

2.3.1 Role of Grain Separation and Cleaning

It is well recognized that grains are the most important input for agricultural production and they carry important genetic information of which the desirable types can be expressed under well-organized production knowhow. However, the benefits of good crop varieties cannot be realized without the availability of clean seeds to farmers. Furthermore, clean seeds of improved varieties need to be maintained under specific conditions to produce quality grains by farmer.

The function of grain separation is to remove/separate grain from unwanted materials such as broken and yet short straw, pieces of broken ears (cobs) and chaff. The function of grain cleaning is to eliminate foreign or undesirable material such as twigs, leaf and soil particles, empty and weed seeds, dust, chaff and the like to reduce bulk, improve storability and make grains easier to handle during subsequent processes. The ideal cleaned grain is free from any other materials. The degree to which this is achieved is called the purity (cleaning efficiency), usually measured in percentage (Schmidt, 2000). Cleaning refers to separation of contaminants from produce and complete removal of the contaminants so that the cleaned produce is free from re-contamination (Kajuna, 2001).

Separating process fraction the grain lot into two categories, one category containing the grain and the other containing inert matter like stem, leaves, dust, dirt, chaff, etc. to be discharged. There are methods that may separate the grain lot into several fractions with various purities. Intermediate fractions typically contain both grains and inert matter and must be further cleaned (Schmidt, 2000). Basically, undesirable material can be separated from the grain if it differs in its physical characteristics such as size, shape, weight/mass and density or specific weight. And the more similar the impurities are to the grains, the more difficult they are to remove/separate. Variation in grain size and morphology of the grain adds another constraint to grain cleaning: The larger the variation in the grain lot, the more difficult it is to clean. Eliminating/taking out inert matter without eliminating grains with different sizes is difficult for many species (Schmidt, 2000).

2.4 Separating and Cleaning Devices

The objective of using a separating and cleaning device is to separate grain from materials other than grain (MOG). Such devices may make use of differences in surface characteristics of the grains. There are many types of separating and cleaning device namely: aerodynamic, mechanical, combination of aerodynamic and mechanical, specific gravity table method etc. (Arfia, 2006). Many commercial cleaners incorporate more than one of these cleaning methods (Hauhouot et al., 2000).

2.4.1 Aerodynamic Separator and Cleaner

Nagesh and Lakshminarasimhan (2014), pointed out that threshed grains require considerable additional cleaning before it can be used as food, whole or ground and even as grain. Pneumatic (aerodynamic) cleaning is the process of using air to lift light, chaffy and dusty materials out of the grains while heavier materials move downward. For aerodynamic separation to occur, the particles in a mixture must be accelerated as free dispersed bodies and not as a mat. Aerodynamic separation depends upon the existence of a differential between suspension velocities (terminal velocity) of the components to be separated.

Aerodynamic separator and cleaner use air as a medium to lift light materials such as chaff and dust out of mixture of grain and undesirable materials; i.e. heavier materials moving downward while light materials are blown away. Air current, either to blow or suspend lighter materials, is generated by natural or mechanical fan. However, the limitation of natural air current as a means of separation is the unpredictability in direction, speed and continuity of the air current (wind), and the high labor requirement and rather imprecise degree of separation (Aguirre and Garry, 1999). Aerodynamic separators and cleaner are basically of two types, namely the vertical air stream and horizontal air stream separators (Goria and Callagham, 1990). In the vertical air stream separator, air stream is flowing vertically against the injected mixed product such that heavy particles drop through the air (counter current flow) while the light materials move upward and are carried along by the air (concurrent flow). In the horizontal air stream separator, air is blown horizontally or at an inclined angle to the horizontal against mixed product injected along the vertical plane. The mixed products are displaced along the horizontal plane at various distances based on their aerodynamic properties (Gloria and Callagham, 1990).

2.4.2 Mechanical Separation

In mechanical separation mixed materials are moved over a perforated and oscillating surface with openings of specified shape and size. Mechanical or sieve separation is a process separating the desired material/grain from undesired materials on the basis of differences in sizes and shapes. Multi sieve separators are used for classifying grains to size grades.

Nonetheless, presence of short straws creates problems by blocking sieve openings and thereby reduces the quality of final product. Segregation and separation take place along the sieve length as grain and MOG are being transported over the sieve. The thickness and looseness of the grain and MOG layer on the sieve influences separation (Gloria and Callagham, 1990). The process of separation is ensured by the relative movement of layers of grain and undesired materials caused by the oscillation of plain sieves (Wang et al, 1994).

2.4.3 Combination of Aerodynamic and Mechanical Separation

Combined air and sieve system, used to separate grain from undesired materials, employs terminal velocity, size, shape, and density as a means to segregation and separation. The method is advantageous and effective than the others methods of separation. The primary method of grain separating and cleaning, at the moment, is the air-sieve separator (OARI, 2006/7). According to Simonyan et al. (2006) the physical parameters affecting the separating and cleaning process are grouped into two: (i) crop factors that include crop variety, maturity stage, grain moisture content, straw moisture content, bulk density of grain, bulk density of straw, stalk length, terminal velocities of particles (both grain and other materials), grain size and (ii) machine factors such as frequency of sieve oscillations, amplitude of oscillation, sieve slope, length of sieve, width of sieve, sieve hole diameter, fan speed, angle/direction of air flow from the fan.

2.5 Existing Cleaning Machines and their Principle of Operation

2.5.1 Manual Cleaning by Winnowing

In Uganda, manual winnowing of grains using baskets and power of wind are often used. During manual winnowing of grains using baskets and power of wind, the operator holds the basket having the grains in one hand, rise it up and pours such that the chaff can be removed by moving wind. The manual winnowing method using wind and baskets is a highly tedious, labor intensive and time consuming process that is also accompanied by high quantitative and qualitative losses. So there is a lot of health problem to the operator and limited quantities of cleaned grains with this method.

Figure 1: Manual cleaning by winnowing

(FAO Annual report, 2015)

2.5.2 Mechanical Cleaning

Mechanical cleaning of grains involves use of mechanical tools to clean off the chaff from the grains. This is a mechanized means of cleaning suitable for cleaning of large number of threshed grains at a time. There are a variety of mechanical cleaners designed to suit the cleaning of grains depending on the mechanism that is incorporated into the cleaning system. Mechanical cleaners are manual or hand operated while others are motorized.

2.5.2.1 Manual Double Screen Cleaner

Operation Principle of the manual double screen cleaner

It is a manually operated equipment used to sieve the grains for cleaning. Batches of 5-10 kg can be loaded at a time. It consists of mainframe scalper/grading screen, draper rod, handle, shutter etc. Eyelets are provided the top to hang the unit thereby eliminating the weight of the unit coming on the arms of the worker. After filling, it is operated by swinging action. It separates impurities like stubbles, chaff, and dirt from maize.

Figure 2: Manual double screen cleaner

Advantage

It is used to separate dust, impurities from grains.

Disadvantage

There is a problem of drudgery and it is time consuming.

2.5.2.2 Grain-Grain Scalper- With Air Separation.

Operation Principle of the Grain-Grain Scalper- with Air Separation Cleaner.

The grain-grain scalper is designed for cleaning all kinds of grains. The unit consists of frame, body, feed hopper, eccentric drive, variable speed unit, screens, travelling screen brushes, air separation chamber, and spouts for screens and drive system. The air separation system removes light impurities before the grain is subjected to screening process. It has two oscillating screens; one for removing coarse material and second screen removes the fines.

Figure 3: Grain-grain scalper- with air separation

Advantage of the Grain-Grain Scalper- with Air Separation Cleaner.

It is used for cleaning of all type of grain and grains

The disadvantage

It's complicated to design and expensive

2.5.2.3 Precleaner

The pre-cleaner is used in modem grain handling and storage systems for preliminary cleaning of all kinds of grains, cereals, and legumes which undergo further processing before consumption. The equipment consists of a sturdy frame, body, centrifugal fan, expansion chambers, magnetic separator and sieving assembly as shown below.

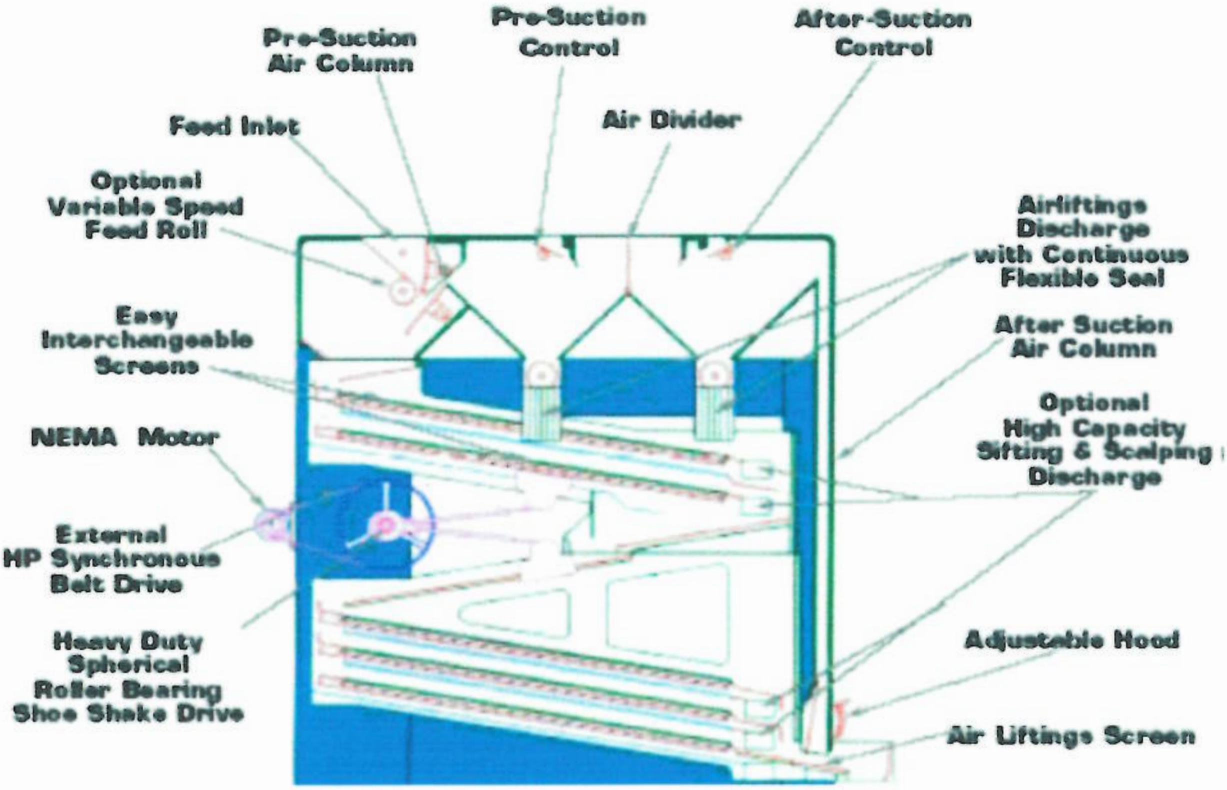


Figure 4: The pre-cleaner

(http://www.Virgiliorodriguez.com, 2011)

Operation Principle of the Precleaner

The precleaner is used in modem grain handling and storage systems for preliminary cleaning of all kinds of grains and cereals. It is especially suitable for cleaning of cereals and other grains, which undergo further processing in maize, and flour mills. The equipment consists of a sturdy frame, body, centrifugal fan, expansion chambers, magnetic separator and sieving assembly. The magnetic separator removes ferrous impurities like nails, pins, screws etc. from the grains before it enters the cleaning system. The centrifugal fan removes dust, chaff, immature grains and all other light impurities from the grain. An aspiration box collects the immature grains and delivers them through seal gate flap for bagging. The unit has dual aspiration at entry and exit, which ensures thorough cleaning and also creates a dust free atmosphere in the working area. The triple sieving mechanism removes stones, clay lumps, straw, leaves, sand and other impurities from grain. A beater-type cleaning device prevents sieve clogging and maintains a high sieving efficiency. These sieves are replaceable and can be selected according to type of grain.

It is used for cleaning maize and other grains, which undergo further processing in the mills. And this method requires further cleaning methods which makes it more costly and ineffective (Tamil, 2011)

Therefore the motorized grain-cleaner which is able to remove most of the contaminants from the maize including sand, stones, metallic materials and that can clean a variety of beans by running the grains once through the machine without requiring any skilled labour at an affordable price is preferred for farmers and local maize grain processors.

CHAPTER THREE: METHODOLOGY

3.1 Methodology.

This chapter presents the step by step procedures and methods that were used to achieve the specific objectives of the study which included the design, fabrication, assembling the different components of the maize grain cleaner prototype, testing the performance, efficiency and carrying out economic evaluation of the maize grain cleaner prototype.

3.2 Design of Different Components of a Maize Grain Cleaner

3.2.1 Design Considerations

Some of the design considerations that were taken into account include the availability of design and construction materials, the loading capacity per unit cleaning operation, cost of the materials, ergonomic, environment, gender, shape and size of maize among others.

3.4 Functional Units of the Maize Grain Cleaner

The maize grain cleaner consists of different functional units and these include; inlet unit (hopper), cleaning unit (blower and screen sieves), outlet unit, and the motion transmission unit.

3.4.1 The inlet Unit

The inlet unit mainly consists of a hopper and a regulator that controls the flow rate of maize. This hopper receives the maize and directs it to the cleaning chamber at a controlled flow rate.

3.4.2 Design of a Machine Hopper

Hopper design was based on a common criterion for it to function. The criterion is called the "Angle of repose". Angle of repose is the maximum slope at which a heap of any loose or fragmented bulk material will stand without sliding. It can also be called the angle of friction of rest (Eugene and Theodore, 1986). This type of hopper is a gravity discharge one and the recommended angle of inclination of hopper for agricultural materials is 8^0 or more, higher than the angle of repose (Micheal *et.al*, 1987). The angle of repose of maize is 27^0. (Richey, 1982).

3.4.2.1 Determination of the Capacity of the Hopper

The bottom perimeter was determined by the maximum maize diameter. The capacity of the hopper was determined from the mass flow rate method according to Johansson equation.

$M = \rho A \sqrt{\frac{Bg}{2(1+m)Tan\theta}}$ .... (3-1) (ASME, 1966)

θ= semi inclined angle of the hopper to the vertical.

m=discharge rate (kg/sec)

B= Average diameter of the grains

ρ= Bulk density (kg/m^3)

A= Outlet area of the hopper

Volume of the hopper, $V = \frac{1}{2}H(a+b) \times L$ .... (3-2) (*Beer, 2006*)

3.4.3 Cleaning Unit

3.4.3.1 Selection of the Screens

The basic sieve for cleaning elongated grain is a slotted top sieve and a slotted bottom sieve. In special separations it may be necessary to pass such grain through round-hole top sieve or over some sieve other than a slotted bottom sieve, but generally, slotted top and bottom sieves are used (USDA, 1968). AAMRC (2012) recommends different sieves for different crops. Recommended sieve openings sizes for different grains.

Table 1: Sieve sizes

No.	Crop	Screen opening in mm		
		Top Screen	Middle Screen	Bottom Screen
1.	Wheat	10r, 9r, 8r,6.5r	4s,4.5s,6.35r	2s,2.25s
2.	Barley	14r,10r	4.5s, 3.5s	1.7s, 1.4s
3	Soybean	12r	8r	2.5s
4	Sorghum	6r,7r	4.25s, 4.5s	1.7s, 2s
5	Haricot bean	10r	6.5s	2.75s
6	**Tef**	**2r**	**1s**	**0.56s, 0.5s**
7	Maize	14r	12r,10r	8r, 6r
8	Rape grain	4r	2.5s	1s

Source: AAMRC, 2012; where r stands for round, s stands for slotted

Material screening on sieves with oscillatory motion is a complex process, influenced by a wide range of factors, related both to the physical properties of the material subjected to screening, as well as to the geometry of the separation system and its kinematic and functional parameters. Thus, the understanding of the angle of internal and external friction of grains on the separation surface, their density, shape of material particles (of grains), grains size, content of impurities in grain mixture, etc. are important (Yan et. al, 2010).

The diameter of the maize grains will be determined using equation

$d = L\,W\,T^{1/3}$ .... (3-3) (Mohsenin 1986)

Where; d - diameter of the maize grain

L - Length of the maize grain

W - Width of the maize grain

3.4.4 Design of the Fan and the Fan Housing

Fans are machines with relatively low pressure rises that move air or gases or vapors by means of rotating blades or impellers and change the rotating mechanical energy into pressure or work on the gas or vapour. Loren Cook Company (1999) classifies fan into centrifugal and axial fans. Centrifugal fans discharge air perpendicular to the axis of an impeller rotation. It was indicated that a precise determination of air flow velocity and outlet pressure are the most important parameters in the design and/or selection of a fan. The choice of fan type for a given application depends on the magnitudes of required air flow. For a given fan type, the selection of the appropriate impeller depends on rotational speed. Speed of operation varies with the application. For agricultural applications, fan speeds are recommended to be between 450 and 1000 rpm (Adane, 2004). As cited by Adane (2004), (Bosoi *et al* 1991) indicated that the initial data required for the design of a fan are the mean velocity of air stream flow at its exit (Cheam), the volume flow rate (V).

The flowrate of desired air stream is determined from the concentration of the material entrained by the air, μ given as ratio of Gm to Ga and has a value between or equal to 0.20 and 0.30. The volume flow rate of air required to make separation between grains and materials other than grains was estimated from the equation given below;

$$V = \frac{G_a}{\mu} = \frac{G_m}{\mu\rho} \quad \text{(3-4) (Adane, 2004)}$$

Where:

V = volume flow rate (m^3/s)

G_a= the mass flow rate of air (kg/s)

G_m = the quantity of material removed by the air stream per unit time (kg/s);

μ = coefficient of concentration (unit less),

ρ = density of air (kg/m^3).

3.4.5 Design of Power Transmission

The power transmission systems used in the design of machine are belt and pulleys, sprocket wheels and chain, shaft, gears, universal joints and clutches. Among flexible machine elements, perhaps V-belt drives have the widest industrial application. Hence, one or more V-13 belts was used on a drive, as required, to transmit power because of their simplicity and ease of design, selection, installation, maintenance and repair and their low cost. The standard V-belt sections are A, B, C, D and E. The Table below contains design parameters for all sections of V-belt. The kW rating given for a particular section indicates that belt section selection depends solely on the power to be transmitted, irrespective of number of belts used. If the required power transmission falls in the overlapping zone, then one has to justify the selection from the economic view point also (RPPC, undated).

3.4.5.1 Selection of Pulleys and Belts

The driving system consisted of a machine pulley and the motor. The ratio of the driver pulley to the driven pulley expression was given by (Kurmia and Gupta, 2008)) as;

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \qquad \text{(3-5) (Khurmi and Gupta, 2008)}$$

Where: N_1 - Motor speed in rpm

N_2 - Shaft pulley speed in rpm

D_1 - Diameter of motor pulley

D_2 - Diameter of shaft pulley

The diameter of the machine/shaft pulley was obtained from equation (3-5)

The load carrying capacity for both pulleys was given as:

$$C = e^{\left(\frac{\mu\theta}{sin\left(\frac{\propto}{2}\right)}\right)} \qquad \text{(3-6)}$$

Where: μ - coefficient of friction

θ - Contact angle

$\propto$ - groove angle

Determination of Pulley Weight

$$V = \pi r^2 h \qquad \text{(3-7)}$$

Where V- volume in cubic metres

r- Radius of the pulley in metres.

h- Width in metres.

Weight, W_P= Density x Volume

Selection of the Transmission Belt

Type A, V-belt was chosen to transfer the drive from the motor to the power transmission shaft with the aid of the pulley. The factors considered during selection of belts were; Speed of the driving and the driven shaft, Speed reduction ratio, Power to be transmitted by the belt, and Centre distance between the pulleys.

The length of the belt (L) was determined from; -

$$L = 2C + 1.57(\frac{D_1 + D_2}{2}) + (\frac{D_2 - D1}{4C}) \quad \text{.......... (3-8) (Shigley, 2008).}$$

Where

D_1 = diameter of the motor pulley (m),

D_2 = diameter of the cleaning unit pulley (m),

C = the center distance between the motor pulley and the cleaning unit shaft pulley.

Centre distance between the two pulleys was;

$$C = A + \sqrt{(A^2 - B)} \quad \text{.......... (3-9), as given by Shigley } et\ al\text{, 2011}$$

Where: $A = \frac{L_P}{4} - \pi(\frac{D_2 - D_1}{8})$ And $B = \frac{(D_2 - D_1)^2}{8}$

Where: L_p - Pitch length of the belt selected from the table

Angle of wrap (Θ); - angle of contact the belt makes with the pulleys

Let Θ_1= angle of wrap of the small pulley

Θ_2 = angle of wrap of the larger pulley

Angle of contact of the belt with the motor pulley was given as;

$$\theta_1 = 180 + 2\beta \quad \text{.......... (3-10)}$$

Angle of contact of the belt with the machine pulley was given as;

$\theta_2 = 180 - 2\beta$ .... (3-11)

Where $\beta = \sin^{-1}[(R-r)/C]$

Where: R - radius of the shaft pulley

r - Radius of the engine pulley

β - wrap angle

Ratio of Belt Tensions:

$\frac{T_i}{T_j} = e^{\mu\theta}$ .... (3-12) (R.S. Khurmi & J.K. Gupta, 2005)

Where μ- Friction coefficient

Θ_1- Angle of Wrap on a small pulley (rads) Hall et al, (2001)

T_i - Tension in the tight side of the belt

T_j - Tension in the slack side of the belt

3.4.6 Determination of Shaft Diameter

The shaft diameter to withstand the loads was determined from the maximum shear stress theory.

Assumptions:

- Weight of the shaft is negligible.
- The shaft is straight.
- Effect of stress concentrations is negligible.
- Shaft material is homogeneous and perfectly elastic.
- Material used is mild steel.

$\tau_{max} = \frac{16}{\Pi d^3}\sqrt{(M_b)^2 + (M_t)^2}$ .... (3-13) Khurmi and Gupta (2005)

Where: τ_{max} - allowable design shear stress for bending and torsion

M_b - bending moment

M_t - torsional moment

d - Diameter of the shaft

3.4.6.1 Determination of Minimum Shaft Diameter.

Diameter determination will be based on the strength, where both bending moment and torsion force are required.

$$D = \left(\frac{10.2N}{S_y}\sqrt{(K_m M)^2 + (K_t T)^2}\right)^{\frac{1}{3}} \text{.............................. (3-14) Khurmi and Gupta (2005)}$$

Where, S_y = Tensile yield strength (N/m²); T = Shaft Torque (Nm); D = Shaft diameter (m); T = Applied torque (Nm); M = Applied bending moment (Nm); K_M = Shock fatigue factor for Moments; K_t = Shock / fatigue factor for Torques; N=Factor of safety

3.4.7 Determination of Power Required by the Machine

The power required to operate the cleaning machine was considered to be the sum of powers required to drive the fan assembly, the drive assemble, the sieving system including the grain and chaff on the sieves, power required to oscillate the sieves and the loads on them and power required to overcome frictional resistance. The total power (P) required for the cleaning and separating processes was determined by using the Equation given by (Nduka et al, 2012).

$P_r = P + 10\% P$ (10% is possible power loss due to friction drive)

Where:

P_r= total power required to drive the machine,

P = the sum of $(T_i - T_j)$V for fan and sieve oscillation,

T_i = tight side tension of belt

T_j = slack side tension of belts

3.5 Fabrication and Assembly of the prototype

This work was done from Munyengera Agro-machinery ltd in Maude and assembled at Busitema University mechanical workshop. The construction of the prototype involved the selection of suitable materials and fabrication processes that were used to come up with the prototype.

3.5.1 Selection of Materials

Different components of the machine were constructed using materials whose properties are suitable for the conditions of operation of the machine. The following factors were considered when selecting the materials that were used in the fabrication of the prototype and they included; material strength, ductility of the materials, legislation, safety during handling.

3.5.2 Mechanical Properties of the Materials

These are properties associated with ability of the material to resist the different forces and loads applied on the material. The mechanical properties that were considered included; strength, ductility, toughness, elasticity, and machinability of the materials. Moreover, the materials which are readily available on market were preferred since the timeframe given to complete the project was limited and the funds not readily available.

3.5.3 Material Cost

Materials that are efficient and relatively cheaper in terms of cost were used in the fabrication of the prototype such that the cost of the completed machine is affordable to local farmers dealing in maize grains. The following aspects were considered when selecting the material for fabrication of the designed maize grain cleaner.

Table 2 : Selection of materials for fabrication

Part	Selection criteria	Possible material
Hopper	Strength, rigidity, weight cost, availability.	Stainless steel, mild steel and aluminium alloy steel.
Sieves	Strength, rigidity, weight cost, availability.	Stainless steel, mild steel and aluminium alloy steel.
Cam	Wear resistance, strength, resistance to both torsion, force and stress.	Alloy steel, plain carbon steel, mild steel, low carbon steel.
Pulley	Strength, machinability and Resistance to wear.	Aluminium alloy steel.
V-belt	Strength and durability	Rubber
Fan housing	Strength, rigidity, weight, cost and availability.	Stainless steel, mild steel, Aluminium alloy steel.
Shaft	Wear resistance, machinability strength, resistance to both torsion, forces and stress	Alloy steel, mild steel, low carbon steel.
Frame	Strength, rigidity and cost.	Mild steel hollow, square bars, L-shaped angle bars.
Bearings	Strength to withstand axial and rotational forces and availability	Pillow bearings, journal bearings.

3.6 Fabrication processes, methods, and assembly of the prototype

Various processes and methods of fabrication with their corresponding tools and equipments were used to come up with the machine prototype. These processes included;

Shaping process; this was used in preliminary shaping of the machine components and the methods that were used in this process included marking, bending, and cutting.

Machining that was used to give the machine component its final shape according to planned dimensions and the methods that were used in this process included drilling, boring, grinding among others.

Surface finishing that provided a good surface finish of the machine components. Polishing was used to obtain the required surface finish of the different components.

Joining process was used for joining different machine components to come up with the machine prototype.

Welding and screw fastening were the mostly used methods in this process.

The different methods that were employed were accomplished by using various tools and equipments as shown in the tale below.

Table 3: Operation, tools and equipment

Operation	Tools / equipment that were used
Cutting	Hack saw, angle grinder, and cutting disc.
Measuring	Tape measure, tri-square, vernier caliper, steel ruler.
Machining	Lather machine, Centre drill.
Marking out	Centre punch, tri-square.
Grinding	Angle grinder, grinding disc.
Welding	Welding rods, welding mask.
Drilling	Drilling machine, drilling bits.
Tightening	Alien key, spanners, screw driver, and an adjustable spanner.

3.6.1 Machine Operation

During operation, threshed grains were put in the hopper of the machine, the grain cleaner used air as a medium to lift light materials such as chaff and dust out of mixture of grain and undesirable materials; i.e. heavier materials moving downward while light materials were blown away. Air current to blow or suspend lighter materials was generated by natural or mechanical fan. Mixed materials were then moved over a perforated and oscillating surface (screen deck) with openings of specified shape and size. Segregation and separation take place along the sieve length as grain and Materials other than grains were being transported over the sieve. Different outlets were provided for both clean grains, chaff and dust, and other materials other than grains as shown in figure 5.

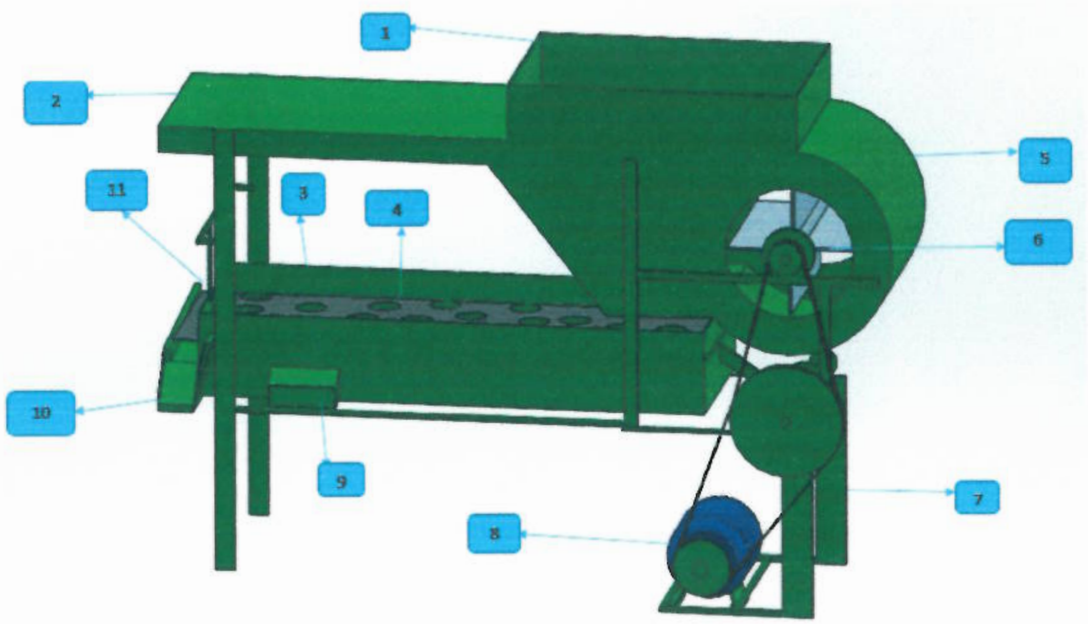


Figure 5: Assembly of machine parts

1. Hopper
2. Aspiration channel
3. Sieve frame
4. Sieves
5. Fan cover
6. Fan
7. Frame
8. Motor
9. Outlet for materials smaller than maize grains
10. Outlet for materials bigger than maize grains
11. Outlet for clean grains

3.7 Testing the Performance and Efficiency of the Prototype

Separation and cleaning process took place along the sieve length as grain and MOG were transported over the sieve. During each test run materials leaving through MOG outlet and those leaving through grain outlet were weighted using digital balance in order to determine the separation efficiency, cleaning efficiency, separation loss and cleaning loss. The performance evaluation of the separating and cleaning machine was made on the basis of the following parameters; cleaning efficiency, cleaning loss.

The cleaning efficiency and cleaning loss were calculated using the equations given by (Werby, 2010); Eq. (3-15 and 3-16).

$$CE = \frac{M_{css}}{M_{sbc}} \times 100\% \quad \text{(3-15)}$$

Where:

M_{css} = mass of clean grain sample (the mass of grains after separation and cleaning, kg),

M_{sbc} = mass of sample before cleaning (kg) and

CE is cleaning efficiency (%).

$$CL = \frac{S_1}{S_0} \times 100\% \quad \text{.......... (3-16)}$$

Where:

CL = cleaning loss,

S_1 = grain lost behind machine (M_{4-M_3}) in kg,

S_0 = grain output (M_3) in kg.

3.8 Economic Evaluation of the Constructed Prototype

This covered the computation and estimation of the different costs associated with the cleaner and the payback period to recover the invested capital to assess the viability of the investment.

3.8.1 Payback Period

This seeks to ascertain the period it takes to recover the invested capital.

$$\text{Payback period (month)} = \frac{\text{Total investment}}{\text{Expected revenue} - \text{total operating cost}} \quad \text{.......... (3-17)}$$

CHAPTER FOUR: RESULTS AND DISCUSSION

The machine was designed on the basis of the physical and aerodynamic properties of the grains knowing the thickness and width of the grains helped in choosing the perforation size required for the upper and lower sieves to make separation of the grains. The air velocity over the sieve unit was kept less than the terminal velocity of the principal grains under investigation. Physical and mechanical properties of maize grains are shown in the table below.

Table 4: Physical and mechanical properties of maize grains

Characteristics	Average value
Length, mm	10.5
Width, mm	8.1
Thickness, mm	5.1
Bulky Density, kg/m^3	720
Moisture content, %	12
Coefficient of friction	0.25
Angle of repose Θ, degrees	27
Terminal velocity of the grain, m/s	7.2
Terminal velocity of the chaff, m/s	3.2

4.1 Design of a Machine Hopper

The hopper was made in form of trapezoidal shape and the hopper base was slanted at the angle of repose of maize grains (θ) so as to ease the feeding of maize grains into the aspiration section.

4.1.1 Determination of the Capacity of the Hopper

The capacity of the hopper was determined from the mass flow rate method according to Johansson equation (3-1) as bellow,

$$M = \rho \cdot A\sqrt{\frac{Bg}{2(1+m)Tan\theta}}$$

$\theta = 63^0$

m=0 kg/sec,

B= 20mm

ρ = 720 kg/m^3

A= 0.0006mm^2

$$M = 720 \times 0.0006 \sqrt{\frac{0.02 \times 9.81}{2(1+0)Tan63}} = 0.0666\, Kg/s$$

Mass flow rate $M = 0.0666\, Kg/s$ was considered the capacity outflow of grains from the feeding hopper.

Volumetric flowrate

$$V = \frac{M}{\rho} = \frac{0.0666}{720} = 0.000093\ m^3/s$$

Since the required capacity of the grain cleaner is $250Kg/hr$, then the designed capacity of the hopper $M = 0.0666\ Kg/s$ was able to satisfy the cleaning chamber for its maximum cleaning. The assembly parts of the feed inlet hopper are shown in figure 6.

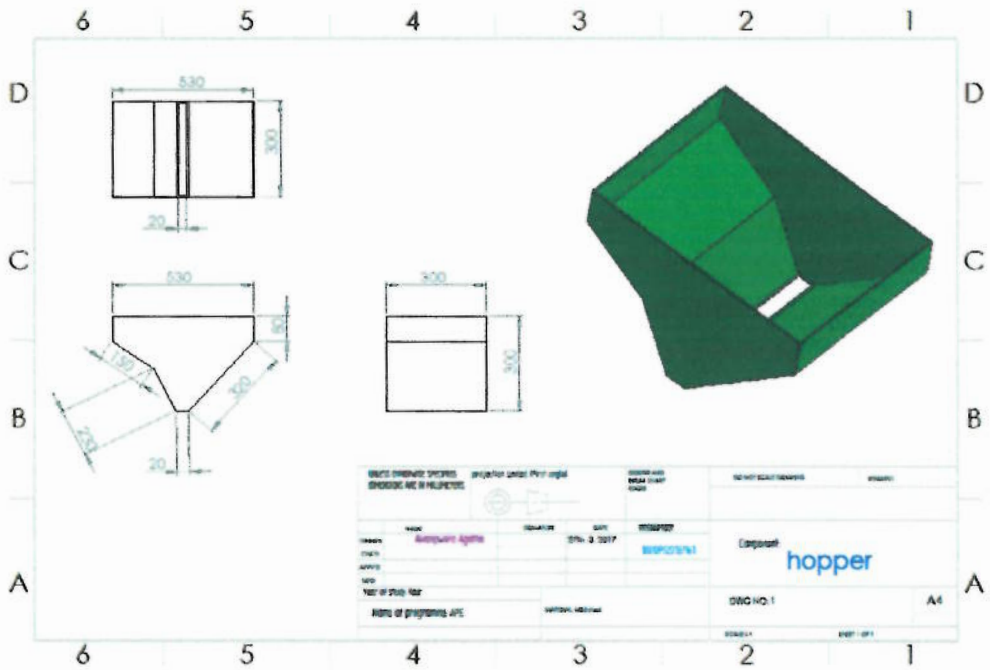


Figure 6: Assembly parts of the feed inlet hopper

4.2 Selection of the Screens

The diameter of the maize grains will be determined using equation (3-3) (Mohsenin 1986)

$$d = L\,W\,T^{1/3}$$

From table 4 above showing the physical and mechanical properties of maize grains;

$$d = 10.5 \times 8.1 \times 5.1^{1/3} = 141.6mm = 0.147m$$

The upper sieve perforations of diameter 0.145m and the lower sieve 0.07m were selected to allow the separation of grains from the admixture since the maximum diameter of maize grains is 10.5mm.

4.3 Design of the Fan

A centrifugal fan was constructed from a sheet metal of 1.50 mm thickness. The fan assembly has four radial blades. The fan blades are 260 mm in length and 112.5mm in width. The fan was operated at 500rpm.

According to (BEE India, 2004), the formula below was used to calculate the quantity of air;

$$V_a = \frac{G_a}{\rho}$$

Given that the terminal velocity of a maize grain is $7.2\, m^2/s$, therefore;

$G_a = V_a \times \rho = 7.2 \times 0.0006 \times 1.2 = 0.0052\, Kg/s$

Since the quantity of air $G_a = 0.0052\, Kg/s$ is smaller than the mass flow rate of maize grains $M = 0.0666\, Kg/s$ from the inlet hopper, then the air supplied was able to blow off light materials or chaff that had come along with the maize grains.

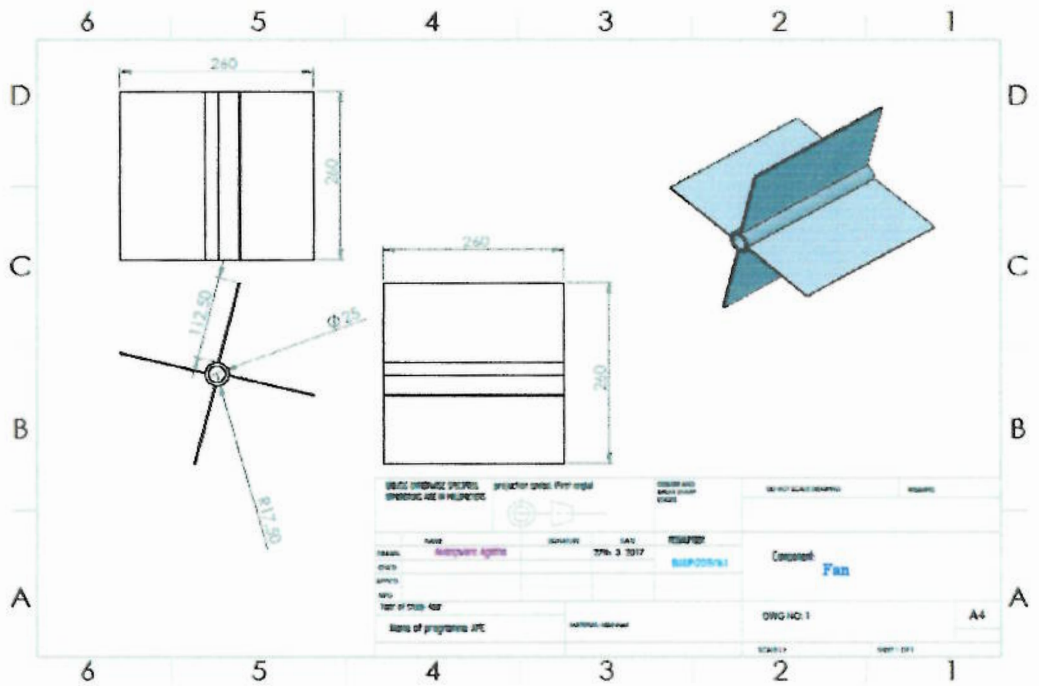


Figure 7: Fan and its dimensions

4.4 Selection of the Belt and the Pulleys

Factors considered during the belt selection include; Belt type, Belt width, and Initial elongation. For the calculation of a common two-pulley power transmission belt the following data are required:

PM= motor power or power to be transmitted [kW]

N_1 = number of revolutions of driving pulley [1/min]

N_2 = number of revolutions of driven pulley [1/min]

d_1 = diameter of driving pulley [mm]

d_2 = diameter of driven pulley [mm]

C = center distance [mm]

According to the V belt standards [Khurmi R S, Gupta, V-belt and rope drives, A text book of machine design, 2005]

Pulley diameter at sheave $d_2 = 232$ mm

Top width of v belt, b = 38 mm

Thickness of v - belt, t = 23 mm

$2\beta = 36^{o}$ (assumed)

For pulley

w = 32 mm; d = 33 mm; a=9.6 mm

c=23.4 mm; f= 29 mm; e=44.5 mm; No. of sheave grooves (n) = 20

For Cross section of V grooved Pulley, $N_2 = 500$ rpm (R S Khurmi & Gupta, 2005)

For belt:

Coefficient of friction = $\mu = 0.25$ (leather; σ all = 7 N/mm^2; $\rho = 1.2 \times 10^3\ Kg/m^2$

$N_1 = 1450$rpm

As we have $N_1/N_2 = d_2/d_1$

So $d_1 = 80$ mm

4.5 Shaft Design

4.5.1 Determination of Shaft Diameter

The diameter of the fan shaft and drive wheel shaft were determined using Maximum shear stress theory. Figure 8 and 9 show forces acting on fan shaft and drive wheel shaft, respectively

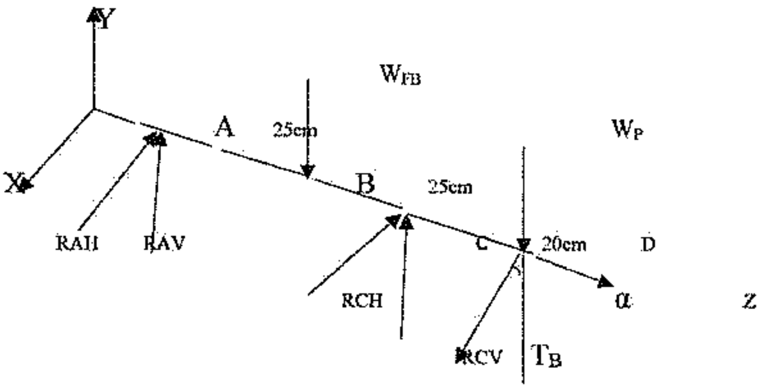


Figure 8: Forces acting on fan shaft and their locations

Where:

R_{AH} = horizontal bearing reaction force at A

R_{AV} = vertical bearing reaction force at A

W_{FB} = weight of fan blade

R_{CH} = horizontal bearing reaction force at C

R_{CV} = vertical bearing reaction force at C

T_B = total belt tension (T_i+T_j) at D

W_p = weight of fan pulley

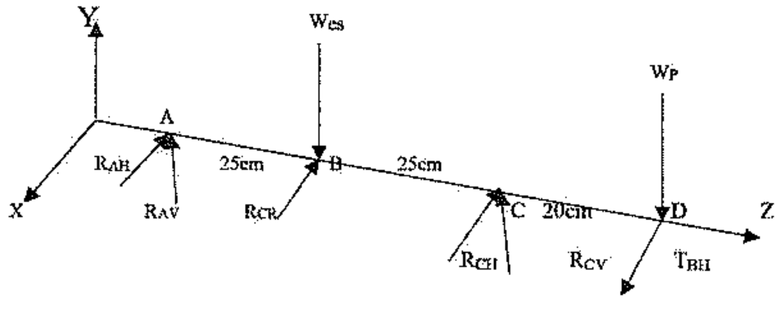


Figure 9: Force acting on eccentric drive wheel and their locations

Where:

R_{AH} = horizontal bearing reaction force at A

R_{AV} = vertical bearing reaction force at A

Wes = weight of drive

R_{CR} = horizontal force due to connecting rod at B

R_{CH} = horizontal bearing reaction force at C

R_{CV} = vertical bearing reaction force at C

T_{BH} = horizontal tension due to belt at D $(T_i + T_j)$

Step1: Determining the Direction Belt Pulls on the Fan Shaft

Sin $\alpha = \frac{opposite}{hyphotness} = \frac{26}{50} = 0.433$ and $\alpha = 31.33°$

Step 2: Determination of belt tensions (Ti and Tj) and torsional moment (Mt)

$T_{max} = \sigma a = 170.1N$

Where; σ and a= 2.1 N/mm²and 81mm² respectively

Using Eq. 9

$T_c = Mv^2 = 8.06N$ for both belts since they have almost the similar velocity.

Where; m= 0.108kg/min

V= 8.64m/s

Table 5: Some specification of A-Type V-Belt

Parameters	**Value**
Cross sectional area (a)	$81mm^2$
Maximum safe stress (σ)	$2.1N/mm^2$
Mass per unit length (m)	0.108kg/m
Groove angle	40^0

Source: Khurmi and Gupta (2005) Sharma and Aggarwal (2006)

Then using Equation below, the tight side tension (Ti) of both belts was calculated to be;

$$T_i = T_{max} - T_c = 162.04\ N$$

Slack side tension Tj was determined as 19.12 N and 18.17 N for fan/motor and drive wheel/motor belts; using Eq. (10):

$$\frac{T_i - T_c}{T_j - T_c} = e^{\mu\theta cosec\frac{\alpha}{2}}$$

Where:

μ = coefficient of friction between belt and pulley = 0.3(Appendix Table 8)

α = groove angle = 40°

θ = angle of wrap = 3.05 and 3.07 rad for fan-motor and drive wheel-motor belts respectively and were determined using Equation below (Khurmi and Gupta, 2005)

$$\theta = 180 - 2\left[sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)\right]$$

Where:

D_1 = 80 mm for motor shaft pulley,

D_2 =80 mm for fan shaft pulley and 232 mm for drive wheel pulley

C = 400 mm for between shaft and motor pulley and 249 mm for between drive wheel shaft and motor pulley.

Torsional moments (Mt) were calculated using Eq. (6).

$$M_t = (T_i - T_j)\frac{D_2}{2}$$

And found to be 11791 N-mm and 9927 N-mm for fan and drive wheel shaft respectively.

Where:

T_i= 162.04 N for both fan/motor and drive wheel/motor belts

T_j=19.12 N for fan and 18.17 N for drive

D_2 = 80mm for fan and 232 mm for drive.

Step 3: Analysis horizontal and vertical forces on fan shafts

To calculate bending moments on shafts it was necessary to know the horizontal and vertical forces acting on shafts.

- Forces acting on fan driving shaft - vertical (YZ) plane.

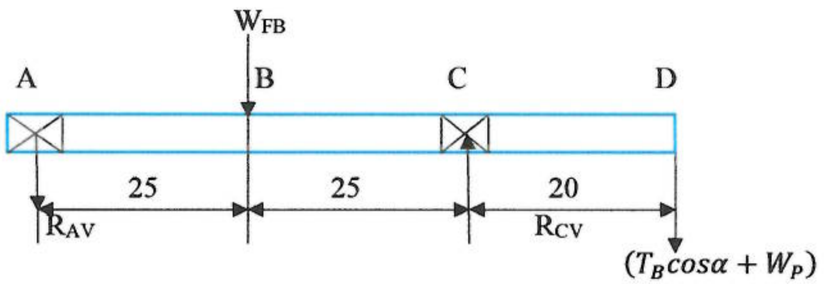


Figure 10: Free body diagram of the fan shaft on vertical (YZ) plane.

$T_B = T_i + T_j$ =162.04 +19.12=181.16 N

W_{FB}=11 N, W_P =15 N, α = 31.33°, $(T_B cos\alpha + W_P) = 170\ N$

In order to calculate reaction forces R_{AV} and R_{CV}, it was considered that

$$\Sigma BM_A = 0$$

$$50 * R_{CV} = 25 * W_{FB} + 70(T_B cos\alpha + w_p)$$

$$R_{CV} = 243.50N$$

$$\sum F_V = 0$$

$$R_{AV} + W_{FB} + R_{CV}(T_B cos\alpha + W_p)$$

$$R_{AV} = 62.50N\ downward$$

Forces acting on fan driving shaft on horizontal (XZ) plane

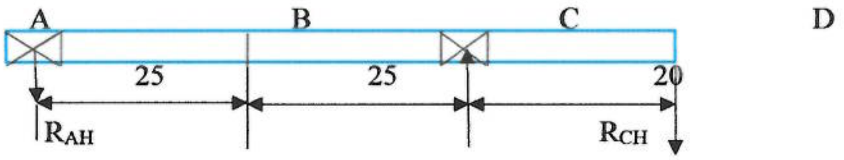


Figure 11: Free body diagram of fan shaft on horizontal (XZ) plane.

$T_B sin\alpha = 181.16 * sin31.33 = 94.2\ N$

$$\sum BM_A = 0$$

$$50 * R_{CH} = 70T_B sin\alpha$$

$$R_{CH} = 132\ N$$

$$\sum F_h = 0$$

$$R_{AH} + R_{CH} + T_B sin\alpha = 0$$

$$R_{AH} = 37.8N\ downward$$

Step4: Determination of the maximum bending moment for fan shaft

The maximum bending moment was found to be at point C of the fan shaft.

$$M_{max} = (M^2V + M^2H)^{1/2} = (18.4^2 + 18.9^2)^{1/2} = 26.38\ N - m$$

Following the same procedure, horizontal and vertical forces acting on drive wheel driving shaft were analysed as follows in figure 12 and 13.

Vertical forces acting on drive wheel driving shaft (XZ plane)

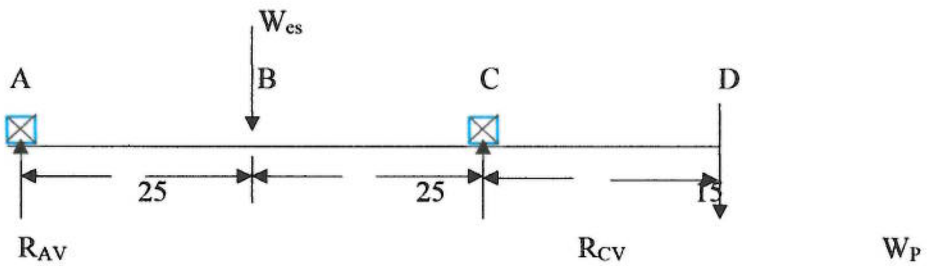


Figure 12: Free body diagram of the drive wheel shaft on vertical (YZ) plane

$$W_P = 5N, W_{es} = 10N$$

$$\sum BM_A = 0$$

$$50 * R_{CV} = 25W_{es} + 65w_p$$

$$R_{CV} = 11.5\ N$$

$$\sum F_v = 0$$

$$R_{AV} + R_{CV} + W_{es} + W_P = 0$$

$$R_{AV} = 3.5\ N$$

Horizontal forces acting on drive wheel driving shaft (XZ plane)

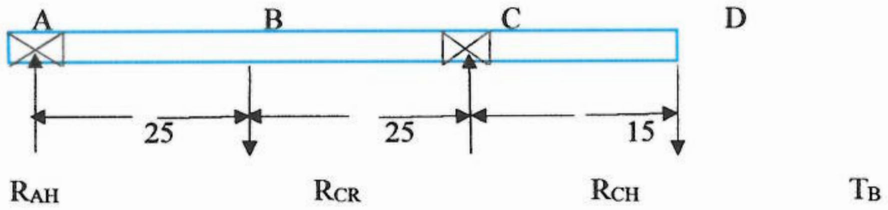


Figure 13: Free body diagram of the drive wheel shaft on horizontal (XZ) plane

Where $T_B = T_i + T_j = 162.04 + 18.17 = 180.21\ N$

$$R_{CR} = 20\ N$$

$$\sum BM_A = 0$$

$$25R_{CR} + 50R_{CH} + 65T_B = 0$$

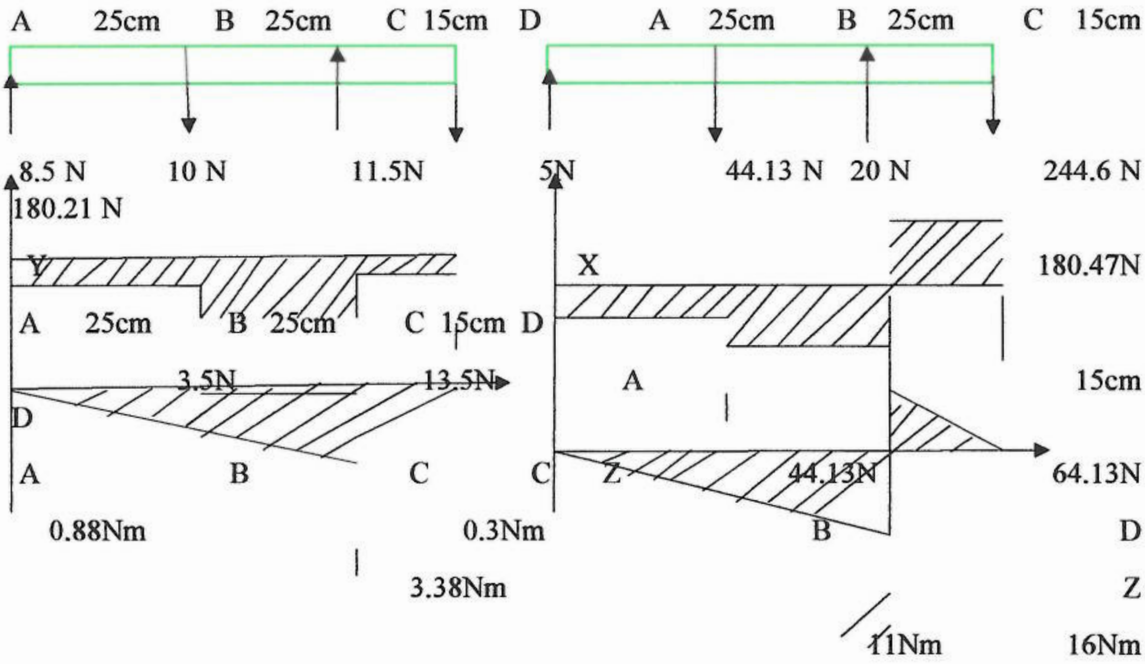
$$R_{CH} = 244.6\ N$$

$$\sum F_h = 0$$

$$R_{AH} + R_{CR} + R_{CH} + W_P = 0$$

$$R_{AH} = 44.13\ N\ downward$$

Based on the magnitude and location of all forces acting on the fan shaft shear force and bending moment on the horizontal and vertical plains containing the drive wheel were computed and plotted as follows in figure 14.



a) YZ plane (vertical)　　　　　　　　b) XZ plane (horizontal)

Figure 14: Shear force and bending moment diagram for drive wheel shaft.

From the diagram the maximum bending moment found at C

$$\boldsymbol{M_{max} = (M^2V + M^2H)^{1/2} = (3.38^2 + 27^2)^{1/2} = 27.2\ N - m}$$

The diameters of the fan shaft and drive wheel shafts were determined as follows

$$d^3 = \frac{16}{\pi\tau_{max}{}^{1}/_{fs}}\sqrt{(K_bM_b)^2 + (K_tM_t)^2}$$

For fan shaft M_t =11.79 N-m, M_b = 26.38 N-m, K_t= K_b = 1.5 and τ_{max}= 55 Mpa then

d =15.89 mm. Assuming a safety factor of 3, d = 15.87 x $\sqrt[3]{3}$ = 22.89 mm

∴ d = 25 mm

For drive wheel shaft M_t= 9.93 N-m, M_b = 27.20 Nm, K_t= K_b = 1.5, τ_{max}= 55Mpa

Then d = 15.9 mm. Assuming a safety factor of 3, d = 15.9 x $\sqrt[3]{3}$ = 22.93 mm

∴ d = 25 mm

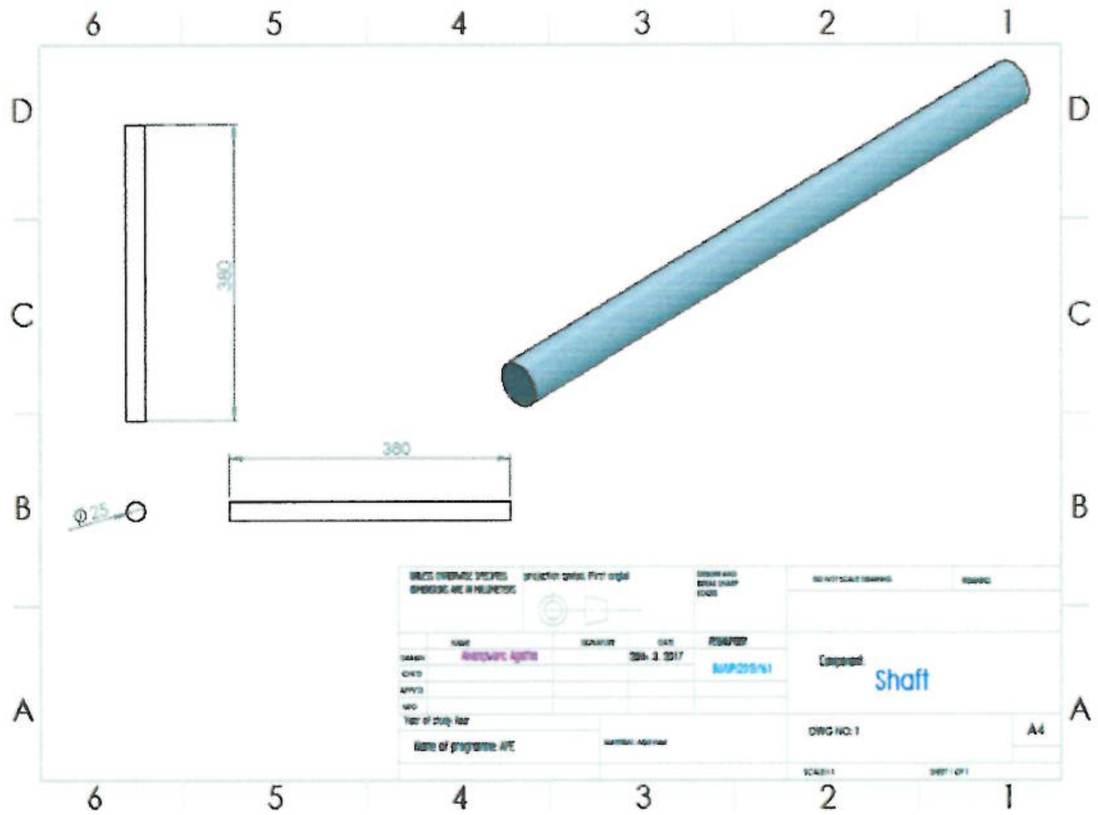


Figure 15: Shaft of the machine

4.6 Determination of Power

$P_r = P + 10\% \, P$ (10% is possible power loss due to friction drive)

Where:

P_r= total power required to drive the machine,

P = the sum of $(T_i - T_j)$V for fan and sieve oscillation,

T_i = tight side tension of belt, 162.04 N for both fan and drive wheel belts

And Tj = slack side tension of belts = 19.12 and 18.17 N for fan and drive wheel belts, respectively, and V = speed of belts = 8.64 m/s for both fan and drive wheel belt.

On the basis of the above, power required to drive the fan assembly,

Pf = (162.04 N - 19.12 N) 8.64 m/s = 1234.83 W

Accordingly, the power required to drive wheel assembly,

Pe = (162.04 N –18.17 N) 8.64 m/s =1243.04 W

The total power to operate fan and drive assembly;

P = Pf + Pe = 1234.43W + 1243.04W = 2477.87 W.

Overall total power P_T = = P + 10% of P = 2725.66W = 2.0 hp.

4.7 Testing the Performance of the Machine

The performance evaluation of the separating and cleaning machine was made on the basis of the following parameters; cleaning efficiency, grain loss and cleaning loss.

Table 6: Results obtained

Samples	Mass of uncleaned maize grains (kg)	Mass of cleaned maize grains (kg)	Mass of impurities (kg)	Cleaning time (s)	Grain loss	Cleaning Efficiency (%)	Cleaning loss (%)
1	5	3.388	0.839	58	0.734	67.8	14.7
2	3	2.028	0.592	33	0.330	76.0	11.0
3	2	1.648	0.338	24	0.011	82.4	0.55
Total	10	7.064	1.769	115	1.075	75.4	8.75 %

The cleaning efficiency and cleaning loss was calculated using the equations given by equation (3-23) and (3-24) respectively.

$$CE = \frac{M_{css}}{M_{sbc}} \times 100\%$$

$$CE = \frac{3.388}{5} \times 100\% = 67.8\%$$

$$CL = \frac{0.734}{5} \times 100\% = 14.7\%$$

$$\text{Operation capacity} = \frac{mass\ of\ cleaned\ maize}{time\ ttaken} = \frac{7.064}{\frac{115}{60}} = 3.68 kg/min$$

$$\text{Operation capacity} = 3.68 \times 60 = 220.8 \approx 221 kg/hr$$

The cleaning efficiency depends on the amount of cleaned and uncleaned maize in a way that if the few maize grains are cleaned and collected while a large amount of uncleaned maize pass through the machine un-cleaned then the efficiency of the machine is very low as it depends on the weight of cleaned and the uncleaned maize.

4.7.1. Effect of Feed Sample on the Performance of the Machine

Cleaning Efficiency decreased with increasing feed sample while the cleaning loss increased with increasing feed sample. Increasing the feed sample from 2 to 3 kg/sec decreased the cleaning efficiency from 82.4 % to 67.6 % while cleaning loss increased from 0.55% to 11.0% and 11.0% to 14.7% on increasing the feed sample from 3 to 5 kg. The low cleaning efficiency and the high cleaning loss with the increasing feed sample was due to the thick layer of material (matting of grains and chaff) formed on the sieves that constrained penetration of grain through the mat of materials on the sieves. Hence, effect of the feeding sample could be seen as increasing of the thickness of mixture of grain and chaff layer on sieve. Above all, with higher feed samples, it takes a long duration of time for the grain to be separated from the materials other than grains (MOG) due to the denseness of the MOG that made diffusion of the grain through the MOG sluggish.

The relation between cleaning efficiency and cleaning loss with feed sample are shown in the figure below indicating the variations in the parameters.

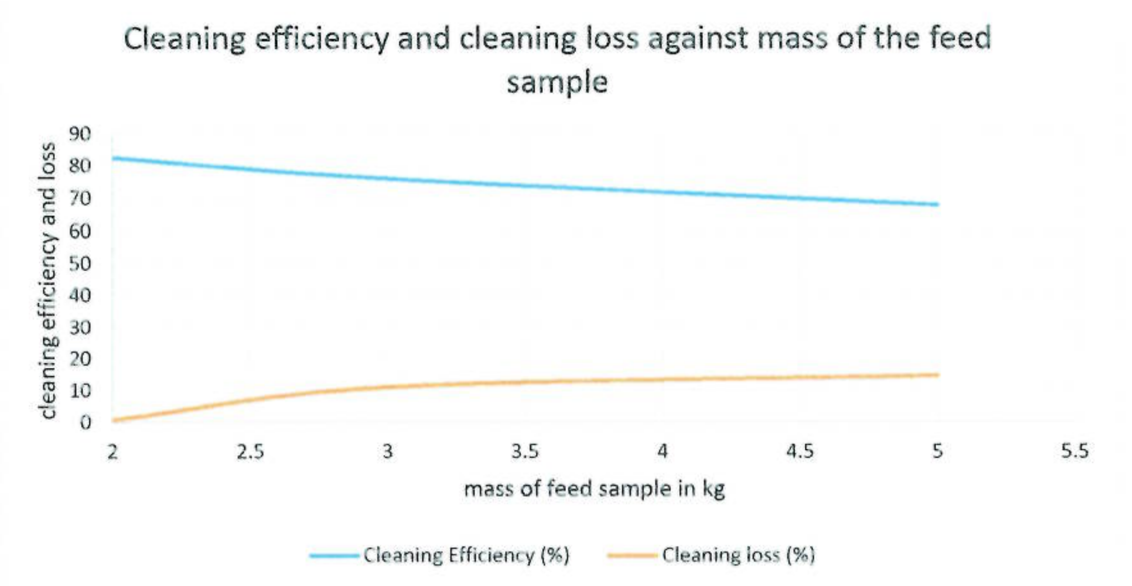


Figure 16: Cleaning Loss and Cleaning Efficiency

4.7.2 Effect of the Sieve Slope on the Machine Performance

The sieve slope at 5^0 affected the cleaning efficiency of the machine when high feed samples were used. This was due to the plugging effect of the sieve perforations at this low slope, which resulted in permitting some of straw and immature seeds to move out with main grains and other grains remaining in the machine. I learnt that increasing the slope to 10^0 would increase the cleaning whereas increasing the slope beyond that would increase the cleaning loss. This was done for low feed samples that improved the efficiency to 82.4%.

4.8 Economic Evaluation

4.8.1 Pay Back Period.

The cost involved in the separating and cleaning machine has been evaluated in terms of raw material cost and production (machine and labour) cost only. Materials wastage and overhead costs are estimated from raw material and production cost.

Total Initial Investment

. The cost of materials that were used during construction and fabrication of the machine prototype are presented in the table below;

Table 7: Cost of materials of the machine

No.	Items Description	Quantity	Unit Price	Total
1	Sheet metal 1.5mm thickness (mild steel)	2	80,000	160,000
2	Motor			800,000
3	Angle bars (40 × 40× 14 mm)	2	40,000	80,000
4	On line pulley (diameter 20 × 280mm, 20 × 100 mm)		30,000 20,000	50,000
5	Belt (V-belt A56, A36)		7500	15,000
6	Bolt and nut			20,000
7	Welding rods (diameter 2.5mm)			30,000
8	Sieve (diameter 14mm and 6mm slotted hole		15,000	30,000
9	Paint	2 litres		30,000
10	Transport			150,000
Total				1,365,000

From table 7, the cost of materials used to construct the machine prototype is 1,365,000 UGX

Overhead Costs

This include all other costs that may not be wholly accounted for, e.g. power used in machine operations, tax for production and marketing the grain cleaner, transportation, etc. Other costs, which include welding, risk allowance etc., were estimated at 154,750 UGX for the maize grain cleaner. There the maize grain cleaner costs 1,519,750U GX

Cost of the Machine

The selling price was determined by putting into consideration the production cost, tax and suitable profit margin. Assuming a profit of 30% of the total production cost and then the selling price will be;

$$\frac{\mathbf{130}}{\mathbf{100}} \times \mathbf{1,519,750} = \mathbf{1,975,675}\ \boldsymbol{UGX}$$

This is quite a favorable price compared to the expensive machines on market.

From the results obtained, 221Kg of cleaned maize grains can be produced in one hour, thus in one day taking 8 hours of working; 1,768 Kg can be cleaned per day.

Assuming that the cost of producing one kilogram of cleaned maize is 100 Shs, the cost of producing cleaned maize in a day is 1,768 * 100 = 176,800Shs as total revenue.

The net benefit is the revenues less cost in the day. (Assume costs as: transport, marketing, electricity, materials, and communication approximately equal to 136,500UGX per day, labour approximates to 7,000 UGX per day for the cleaning operation.

$$Net\ profit\ per\ day = total\ revenue - cost\ of\ production$$

$$Net\ profit\ per\ day\ = 176{,}800 - 143{,}500 = 33{,}300 UGX\ per\ day$$

Assuming that the machine works for 21 days in a month per year, then the net profit in a year is;

$$Net\ profit\ per\ year = 33{,}300 \times 21 \times 12 = 8{,}391{,}600\ UGX$$

$$\text{Pay Back Period} = \frac{\text{Initial Investiment}}{\text{Net profit}}$$

$$\text{Pay Back Period} = \frac{\mathbf{1,975,675}}{8{,}391{,}600} = 0.24 years = 3\ months$$

This implies that it will take three months for the person using the grain cleaner to recover the initial investment.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

All conclusions basing on the objectives of the study and the results obtained from the tests carried out on the prototype were made and all recommendations from these conclusions are drawn.

5.1 Conclusion

The results obtained from the design and performance evaluation showed that, the maize grain cleaning machine was designed, fabricated, tested and found to have a throughput capacity 221 kg/hr and efficiency of 75.5%, also a speed of 500 rpm with air velocity of 3.2m/s. From the results the following conclusions were made:

1. The machine efficiency was influenced by the sieve slope and the feed rate.
2. The screen unit was able to separate the admixture of maize grains and materials other than grains.

The prototype can be constructed from any workshop since the materials used are readily available and cost of the machine is affordable since the initial investment can be recovered in three months. The developed machine can improve the quality of maize grains, storability and reduced discount rate since it can remove most of the contaminants from maize grains which boosts farmer's income. It also saves time for the farmer to carry out other activities thus improving labour productivity.

5.2 Recommendations

Although the final prototype of the maize grain cleaner was considered successful there are still improvements that can be made. Due to the time and financial constraints the design was unable to incorporate all of the ideas into the final product and thus the following should be incorporated into the design to increase the performance of the prototype;

1. A continuous feeding component to improve on the feeding rate for effective cleaning.
2. Varying sieve slopes and crank speeds to achieve maximum cleaning are recommended to improve the performance of the grain cleaner.
3. The aspiration channel should be modified with a better collection point of the chaff to reduce recontamination.
4. A destoning unit should be incorporated in the design for stone separation from the maize grains.

REFERENCES

Adane Kefele, 2004. Investigation into Mechanics of Grain Cleaning and Improvement of Asella Thresher. Unpublished MSc.Thesis. Haramaya University, Dire Dawa, Ethiopia.

Agricultural Engineering 8. ELSEVIER, Amsterdam, Oxford,New York, Tokyo. 294–295.

ASME, 1995. Design of Transmission Shafting. American Society of Mechanical Engineering, New York, USA

Amer, E.A.H., 2009. Aerodynamic and Solid Flow Properties for Flax grains for Pneumatic Separation by Using Air Stream. Journal of Agriculture & Biological Engineering, 2(4): 31-45

Dillon, B. M. &. B. C. B., 2013.. The impact of world oil price shocks on maize prices in East Africa.. *University of Melbourne, Melbourne.*.Eurasia Publishing House (Pvt.) Ltd. Ram Nagar, New Delhi-110 055

El–Sahrigi, A. F. 1997. Fundamental of food processing engineering. Acad. Library. Egypt.

Iranian Ministry of Petroleum, 1993. Engineering Standard for Process Design of Fans and Blowers. Original Edition, Tehran, Iran.

J.K. Gupta and R.S. Khurmi (2005). Design of Machine elements, first multi-color edition.

Kochhar, A. and C. K. Hira 1997. Nutritional and cooking evaluation of green gram cultivars . J. of Food Science and Technology. 34 (4): 328-330.

Mohsenin, 1986. Grain size and shape Analysis in Turkey using Digital photography.

Nyoro, J. K. L. a. J. T., 2004. Competitiveness of Kenyan and Ugandan maize production: Challenges for the future.. *International Development Collaborative Working Papers,* Issue Development Collaborative Working Papers KE-TEGEMEO-WP-10,.

Ray, B. a. A. B., 2007. Fundamental food microbiology.. *CRC press.*.

Rosegrant, M. M. E. V.-S. R. a. M. D., 2015. Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth.. *Working paper.CGIAR.*.

Shigley, J. E (1986). Mechanical Engineering Design S. I (metric) McGraw - Hill, New York, US A.

The World Bank, 2011. Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa. Report No. 60371-AFR, Washington, DC 20433.

World Bank. (2011). Agriculture for development. World development report, Washington DC.

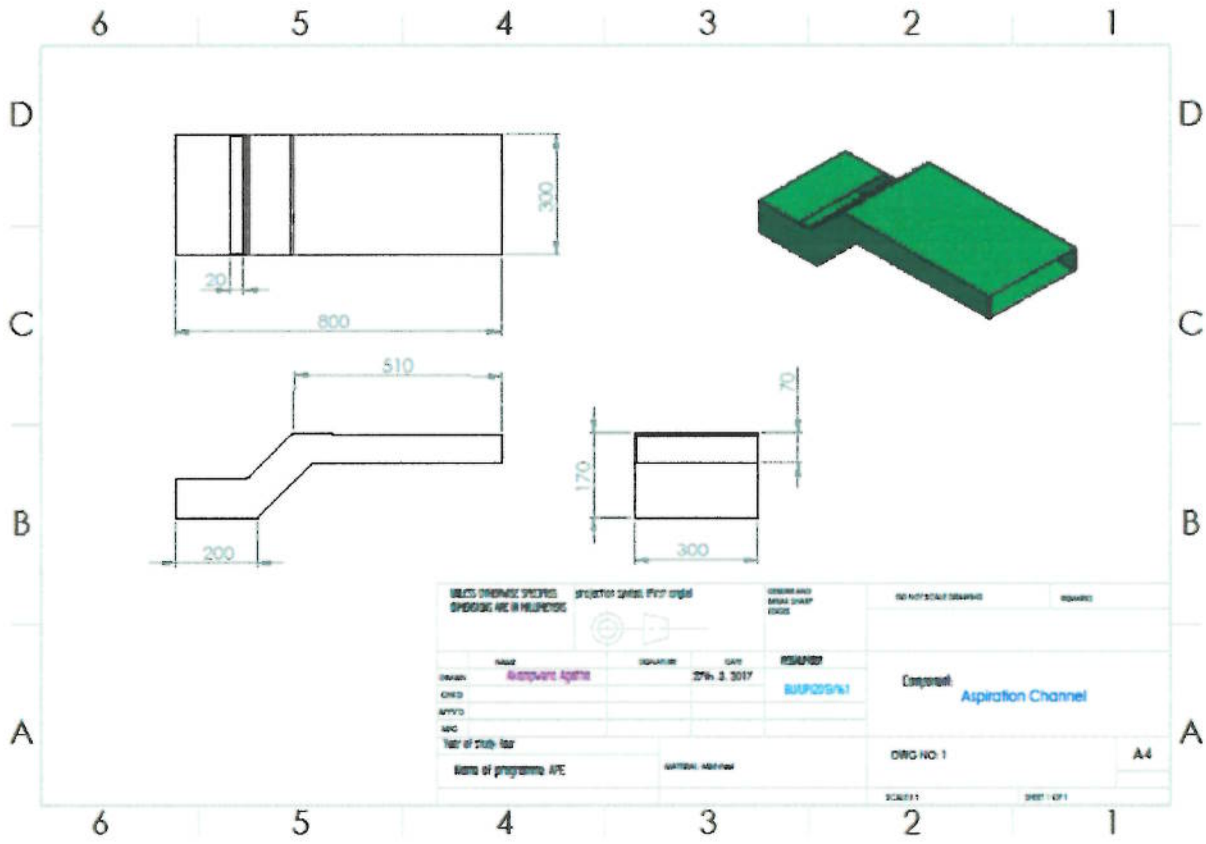
Wright, B.D., 2009. International grain reserves and other instruments to address volatility in grain markets. *World Bank Policy Research Working Paper Series, Vol.*

Werby, R.A., 2010. Performance Cleaning Unit for Clover Grains Affecting Some Physical and Mechanical Properties. Misr J. Ag. Eng., 27(1):266- 283

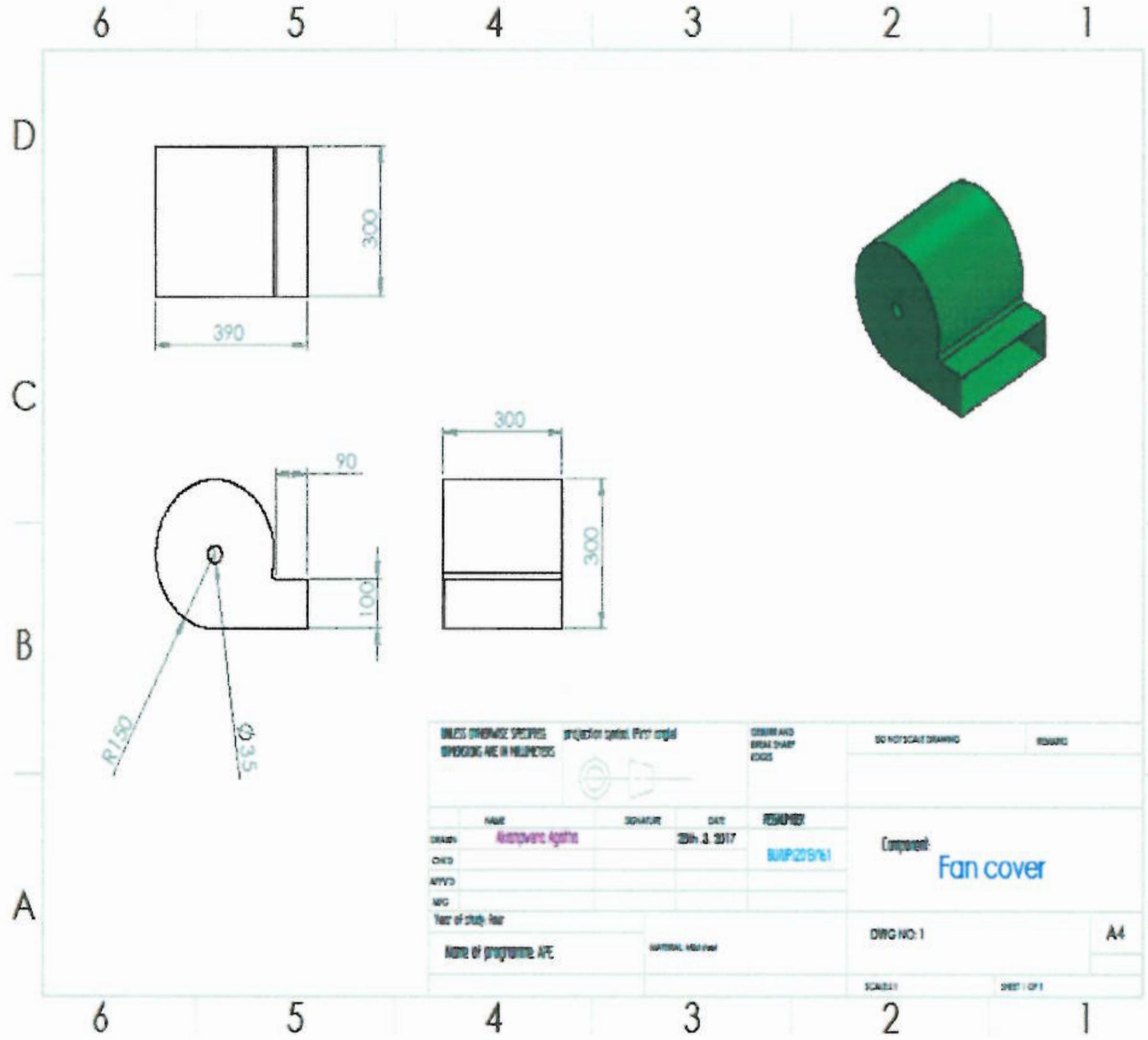
Sitkei ,G. 1987.Mechanics of Agricultural Materials. Developments in Agricultural Engineering 8. ELSEVIER, Amsterdam, Oxford, New York, Tokyo. 294–295.

Appendix B: Machine Parts

Appendix B (1): Aspiration channel of the machine



Appendix B (2): Fan cover



Appendix B (3): Machine during fabrication after fabrication