DESIGN AND CONSTRUCTION OF A MAIZE ON COB SOLAR DRIER

BY

JEPKOSGEI JOAN

A THESIS SUBMITTED TO SCHOOL OF ENGINEERING, DEPARTMENT OF MANUFACTURING, INDUSTRIAL AND TEXTILE ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE OF MASTER IN SCIENCE IN INDUSTRIAL ENGINEERING

MOI UNIVERSITY

2021

DECLARATION

Declaration by Candidate

I declare that this thesis is my original work and has not been presented for a degree in any other University or educational institution. No part of this thesis may be reproduced in any form without the prior written permission of the author and/or Moi University.

Signature: ___________________________ Date:_________________________

JEPKOSGEI JOAN

TEC/PGMT/02/16

Declaration by the Supervisors

We declare that this has been submitted for examination with our approval as University Supervisors.

Signature: ___________________________ Date: _________________________

Dr. Owino George Omollo

Egerton University Department of Industrial & Energy Engineering

Signature: ___________________________ Date: _________________________

Prof. David Tuigong

Moi University Department of Manufacturing, Industrial & Textile Engineering

Signature: ___________________________ Date: _________________________

Dr Isaiah Muchilwa

Moi University Department of Electrical Engineering

Signature: ___________________________ Date: _________________________

Dr. Jerry Ochola

Moi University Department of Manufacturing, Industrial & Textile Engineering

DEDICATION

This research work is dedicated to my parents, siblings and friends for their unceasing prayers, encouragement and patience during the research and thesis writing and above all the Almighty God to whom all glory belongs to now and forever more.

ACKNOWLEDGEMENT

My grateful thanks go to my lecturers and fellow students from the department of Manufacturing Industrial and Textile Engineering for their full support and encouragement. I am greatly indebted to my supervisors for their scholastic guidance and counsel which steered me to undertake this research study. Their positive criticism and scholarly advice contributed immensely to the final realization of this thesis writing.

Am grateful to my parents for the full support financially, without which this research could have been impossible to accomplish and much further to the Head of Department, Head of Postgraduate studies, the staff, and my classmate at Moi University for their assistance in terms of moral and material support, their positive response and immediate help whenever the need arose.

My sincere thanks go to Rivatex Company Limited including its engineering section who contributed so much in the fabrication of my prototype and provided an environment for research. I am also indebted to my supervisors Dr. Owino George Omollo, Prof. David Tuigong, Dr. Jerry Ochola and Dr. Isaiah Muchilwa for their support throughout the writing of this thesis. My appreciation goes to Dr. Muchilwa for providing me with the testing material.

ABSTRACT

Drying is one of the traditional methods of maize preservation. Drying as a process has been practiced over years. It is performed in various ways which include sun drying or forced convection. Sun drying technique such as natural sun and forced convectional technique, which solemnly vary due to the source of heat supply. The sources can be diesel heaters or solar evacuated tubes. In Africa most of the farmers harvest maize while on cobs and move it into granaries. During rainy season, the harvest is delayed and the maize absorbs more water, increasing the risk of spoilage when piled. Storing wet grains for weeks in granaries predisposes the crop to fungal contaminants such as mycotoxins. This may be avoided by artificially drying the maize after harvest. This research work proposes a more efficient and optimal design to dry grains on the cob using solar energy. A dryer was designed, fabricated and then tested. The design involved simulation of the shape and size of the drying chamber, along with its airflow distribution using SolidWorks^{TM}. The amount of heat required, the arrangement of the solar evacuated tubes housing and the quantity of air to dry were determined. The dryer was fabricated to handle approximately one bag of maize on cob and consisted of a drying chamber, a solar heat collector comprising solar evacuated tubes and a blower. The solar heat collector was able to heat the air from a temperature of 27.1 ^{0}C to 56.7 ^{0}C and 7 kg of maize on cob was dried from an initial moisture content of 25.7%wb to 13.4%wb in two days, with six hours of operation per day. A moisture content of 13.5%wb and below is recommended for safe storage. The fabricated dryer reduced time of drying, producing clean dried maize and could therefore be used to enable farmers to have a good investment return during post-harvest handling of maize on cob in rainy seasons. It could also be used in empirical research to determine the air velocity and temperature for optimal drying of maize on the cob.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CFC	Chlorofluorocarbon
FAO	Food Agricultural Organization of the United Nation
IFPRI	International Food Policy Research Institute
KEBS	Kenya Bureau of Standards
KMDP	Kenya Maize Development Program
PUF	Polyurethane Foam
TSGC	Tri-State Grain Condition
USA	United State of America
USAID	United States Agency for International Development

CHAPTER ONE: INTRODUCTION

1.0 Introduction

Maize is a plant from the *Zea Mays* family. Maize is commonly known as the queen of cereals due to its potential genetic yield. It is a source of energy and proteins to human diet all over the world. In order to ensure availability of food at all seasons, constant supply of food is mandatory. This therefore calls for proper and timely grain drying so as to increase the shelf life of the maize. This will encourage the farmers to sell their products at best prices and hence improve the farmers' income.

When drying is not properly achieved, maize grain might lose its nutritional value due to the several changes being experienced in the maize grain during storage. Some of the factors that affect drying include temperature and humidity, since factors that affect storage include moisture, temperature, carbon dioxide, microorganism, insects, rodents, mites, oxygen, and geographical location and storage facilities structures. The moisture content of the grain should therefore be lowered to the required standard so as to inhibit growth of fungi.

Most Africans countries, have maintained the traditional way of maize drying (sun drying) due to inadequate information, resistance to change and also the costs incurred in implementation of change (Adebayo, et al., 2014). Although sun drying is the cheapest method of drying it can be time consuming and requires a lot of labour, advanced technology is therefore needed to minimize the disadvantages of sun drying and to maximize on its advantages.

1.1 Background of the Study

Maize is commonly grown in Kenya as a staple food and acts as a source of income and food. According to Kenya Maize Development Program (KMDP); maize consumption is at the rate of 98 kilograms annually per capita which contributes to about 35% daily dietary energy consumption. About 90% of the villagers grow and harvest maize and most of them are small scale farmers whose production contribution is 75% from the total production of maize each year, the other 25% is contributed by the large-scale farmers (Erastus, 2011).

Sun drying is one of the oldest methods of preserving food in Africa and all over the world in general, it uses the sun as a source of energy which is abundant and environmentally friendly. Around the world there is an encouragement of using renewable energy due to the depletion of fossil energy. Employing the use of the renewable energy by farmers with the advanced technology, will result in an increase in the farm productivity (Weawsak, 2006). Since the sun energy is abundant, environmentally friendly and is present everyday; it has been embraced as an alternative source of energy by farmers because it saves energy when it comes to the agricultural application (Akinola, 2006). Drying is used in order to remove moisture or water from a product so as to reduce microbial activity and fungi growth/multiplication, and to increase the shelf life of the product. Basically, there are two types of water available in an agriculture product: the physically held water and the chemically bounded water. The drying process usually aims at the removal of the physically held water.

The main hazard on the Kenyans agriculture products is the growth of mycotoxins, which when consumed lead to deaths (Korir, 2012). The Government of Kenya has invested programs to improve the irrigation scheme and also to establish storage facilities so as to reduce post-harvest losses and aflatoxin contamination.

There has also been a report that an advanced storage and drying system will reduce post-harvest losses leading to improvement of crop handlings and management practices, ensuring ease in storage of agriculture products due to efficient drying practice using the cheapest source of energy such as solar radiation. The drying process of the maize crop includes the reduction of moisture content from 18 % to 13.5% of its weight, by use of mass transfer and simultaneous heat (AflaStop, 2015). During harvesting of the maize crop, it is not fully dried hence it cannot be shelled or stored safely. For fear of losses most farmers prefer selling immediately after harvesting hence farmers receive small incomes.

In Africa, especially in Kenya, the most common drying methods are sun drying and the mechanized dryer, with minimal application of solar dryers. After harvesting, most farmers store the unshelled maize in the granary. After some months the maize is shelled then dried using sun drying for small scale farmers and the mechanized dryer for large-scale farmers. During the period of storage after harvesting the maize is not properly dried this makes the maize prone to growth of the mycotoxin.

The mechanized drying method is advantageous in the sense that, it speeds time of drying, less labour is required and a better quality of the product is produced. Its major challenges are the higher operation cost due to the use of electricity and substantive amount of fuel (Ajay, 2009). This therefore has called for the need to come up with a dryer that can outshine the disadvantage of sun drying (attack by insects, birds, rodents, occasional rain shower, and wild animals) while utilizing the beneficial aspects of the mechanized dryer.

My design will improve the linkage between farmers and the market, finance, input, equipment and information. It will also help the small holder farmers to increase their efficiency on farm business by improving the production and post-harvest handling practice.

1.2 Statement of the Problem

In Kenya, the common practice is that maize is harvested with a moisture content ranging from about 25% to 40%, of its weight. It is then put in the granary for it to dry during the rainy season to 13.5% of its weight and below depending on the length of storage (FAO, 2011). However, the rains are unpredictable or will have hot humid air, creating moisture stress during growth of maize seedlings especially during the flowering and grain filling phase, predisposing the crop to contamination by fungal pathogen, harmful to humans and animals. (IFPRI, 2010) or dry maize on the ground during sunny days. Drying on the ground exposes the grain to insects, dirt, birds, and this affects the quality of the grains. Insects feed on the crop and leave droplets of their poop on the grain hence affecting the physical structure of the grains.

To ensure the quality of the maize harvested is maintained, there is need to come up with a simple, cheap, portable maize cob dryer to enable the farmer to have good investment return during post-harvest handling of maize in the rainy season. There are few mechanized dryers which are rarely used by small scale farmers, since they are generally expensive to use, including cost of transportation, cost of fuel or electricity to be used.

1.3 Justification

Currently in Kenya, there is a continuous population growth and need to supply food. Late 2017 there were maize supply shortages in the entire country since the total average production was 3.2 million metric tons which is less than 4.1 million metric tons achieved in 2016 (Knoema, 2020) and Kenya was planning to import low quality maize from Mexico (Andae, 2017) or the products may have aflatoxins which are dangerous for consumption (NTV, 2019) due to the shortage of maize

There is also a need to use modern technology. The Government of Kenya is encouraging farmers to use modern drying methods, to curb such post-harvest losses on farms, which is estimated at 12-20% of the total production (Tegemeo, 2020), and are caused by the growth of fungi on the already harvested maize. This has been proven by the government setting apart funds to buy fixed and portable mechanical dryers (AflaStop, 2015). Despite the effort, it may be a challenge to farmers due to cost and availability as the project is still in its pilot stage.

The designed dryer will provide the solution to the post-harvest loss since the grains will be dried at an early stage, its quality will be maintained, and the drying time will be reduced. This will help the farmers to store their product at the appropriate moisture content ensuring the good price of the market, therefore earning them a good profit and hence improving their living standard.

In this research maize will be dried while still on the cobs, this is because when maize is harvested some grains may not be hard enough and if shelled at this point they may break and it allows immediate start process of drying; hence it is advantageous to dry the maize while still on the cob (KALRO, 2020).

1.4 Significance of the Study

This project will help in reducing post-harvest losses due to the contamination of maize with mycotoxin using advanced technology. In addition to this, the study will assist in;

- ✓ Reducing the time of drying maize hence minimizing the process of contamination of the maize grain.

- ✓ Providing Kenyan farmers with cleaner dried maize grains.
- ✓ Promoting research on advanced drying of maize technology hence minimizing post-harvest losses.
- ✓ Contributing to the body of knowledge and may lead to better grain handling procedures.

1.5 Research Objectives

1.5.1 General Objective

To design and test an affordable maize dryer for subsistent use.

1.5.2 Specific Objective

- ✓ To determine an appropriate shaped dryer for optimal airflow using solid works.
- ✓ To fabricate and test a maize-on-cob dryer using solar evacuated tubes.

1.6 Scope of the Study

The research will focus on the designing and construction of a maize on cob dryer. The maize dryer will be designed, fabricated and tested.

- ❖ Maize on cob (not shelled maize) was used.
- ❖ The study area was in Uasin Gishu County, Kenya.
- ❖ Research was quantitative analysis since the result was obtained from the data obtained.
- ❖ Temperature, relative humidity and days of drying were the parameters that were investigated.
- ❖ SolidWorks software was used to obtain an appropriate shape for the maize-on-cob dryer.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Maize drying is a process of removing moisture from the grain to a definite value of operation. The method of drying will therefore allow ease in processing, storage of the product and reduce the growth of microorganisms. The drying process includes transfer of heat and mass with varying rate processes that includes physical or chemical transformation (Cengel, 2000). Drying is basically an adiabatic process. It is widely applied in farm produce such as coffee, corn, vegetables, milk products and commercial fruits (Wang, 2005).

Drying techniques vary among farmers and they range from sun drying which is a natural method to the artificial methods using forced hot air through the material. The various ways of selecting the method of drying depend on the cost and the production scale. Sun drying is the common method that is practiced by most farmers since it is less costly, simple, and it depends on the direct sunlight which is abundant and renewable.

When the grains are harvested, they have a high moisture content of 25%- 40%. Drying is important in that it is used to reduce moisture content using simultaneous heat and mass transfer (Radhika, 2011). To ensure high production capacity, an appropriate temperature should be used, if a high temperature is used for drying it will affect the quality of the grains, and hence affect consumers such as the wet milling industries. (Thirugnanasambandham, 2016).

Table 2.1 Reasons for drying (Radhika, 2011)

Reasons of drying	Effects
Increase in price of storage	Storing the maize without drying makes the farmer purchase pesticides which keep maize free from bacterial infections but the total cost incurred on farmers using pesticides increases.
Rejection of grains	Rejection of maize from millers because of poor quality of the grains.
Prevention of the growth and multiplication of microorganisms	These are microorganisms which occur naturally due to enzymes, chemical reactions and structural change that occur during storage. This ensures the grain does not rot and increases the shelf life.
Diminishes spoilage during storage of the crop	The grain can be harvested with moisture as high as 35% of its weight, this moisture can promote growth and multiplication of moulds leading to making the grain toxic.
Diminishes field losses	Mostly when harvesting it is raining, and if taking an option of leaving the crop for a while before harvest the crop may be eaten by birds or may not dry due to dampness of the farm. So early harvest prevents the crop loss.
Encourages early harvesting	This is achieved where the grains can be harvested and stored immediately maintaining the quality, grade or germination. It also helps the farmer to harvest the crop with high dry moisture content which leads to highest weight grain sale. Early harvest allows early farm preparation for the next planting season, controlling weeds at an early stage by applying chemical early and tillage practice.
Increasing the harvest season	This is whereby the farmer can harvest in the morning and evening, this could ease capitalizing on machinery. The farmer can harvest and dry at the same time remaining with just storing the grains.

Table 2.1, shows the summary of some of the advantages of drying such as; reducing dependency on weather conditions for harvest. It also increases quality of harvested

grain by reducing crop exposure to weather. Drying also reduces size and/or number of combines and other harvest-related equipment as well as labour required due to extending harvest time. Drying is also advantageous in the sense that it allows more time for post-harvest field work. Drying the maize also employs the use of straight combining for small grains. Finally, it advances quality of harvested grain by reducing crop exposure to weather.

Some of the disadvantages of drying are that extra grain handling required may result in further investment for equipment. The original investment for drying equipment and annual cost of ownership might be higher for small scale farmers. The operating costs for fuel, electricity and labour might also be a challenge for the farmers.

2.1.1 Drying Methods

The drying method is one of the oldest methods of preserving food (Janjai., 2013). It is a main process in post-harvesting but is expensive due to the increase in the prices of the fossil fuels. This therefore calls for the need to find use of alternative renewable energy sources (Mirzaee, 2009). The drying process includes convectional and conduction processes which are put together to achieve the drying process but sometimes they vary:

- Convection- transfer of heat from the air to surface of the grain
- Transfer of mass from the surface of the grain to the immediate air
- Conduction- transfer of heat from the surface of the grain to the internals of the grain
- Transfer of mass from the internals of the grain to the surface.

2.1.1.1 Heat Transfer

Heat transfer is the movement of heat from a hot air into a cool grain, as the heat increases in the grain the latent heat vaporizes the moisture on the surface of the grain which will then cool the hot air temperature. Because of the heating of the surface of the grain by the convection air, a temperature difference is created within the grain. This leads to flow of heat from the surface to the Centre area and is controlled by the grain's thermal resistance to the conductive heat transfer (Menon, 1987).

2.1.1.2 Mass Transfer

Air carries the vaporized moisture; this increases the humidity of air and decreases the grains' moisture content. This process is controlled by means of convection. On the ambient environment the material property pressure on the internal moisture is exerted by the solids. As evaporation occurs on the surface of the grain, concentration difference within the grain occurs which leads to an increase in vapor pressure within the grain (Çengel, 2006). The moisture transfer will proceed until the point where the vapor pressure within the grain is equal to water partial pressure in the air which is referred to as equilibrium moisture content and is specific for a particular ambient condition. The way the water is held within the grain leads to vapor pressure which is a solution within the grain, held in capillaries, within the cellular structure or by physical or chemical forces. For this reason, materials have been defined on the way they hold water as a non-hygroscopic, capillary-porous, hygroscopic-porous or colloidal media. (Menon, 1987).

2.1.1.3 Drying Psychometry

Psychometry is the study of moist air. It is an important process during drying since the moisture in a product is removed and carried away by air. For this to be achieved, a concentration gradient must exist which will be created by hot dry air in the process of hot air convective drying (Singh, 2009). This process is excluded from the drying process of heat sensitive products which use freeze and vacuum dryers since it is an expensive drying method and emerging technology of super-heated steam drying (Mujumbar, 2004).

2.1.2 Factors that Influence the Drying Process

(a) Air flow rate

This the speed of moving hot air during process of drying, it is directly proportional to the rate of drying. The purpose of air is to carry moisture away from the product, if the depth of the grains is increased then the air flow rate should be increased, (Chinenye, 2009)

(b) Air temperature

During the drying process heat is applied to the grains and if very hot air is used, it will burn the grain. Very low air temperatures will lower the drying rate of the grain but produce a better-quality grain (Jayas, 1988). Low temperature can be used to dry very moist grains to the maximum temperature that is recommended to dry the grain without damaging the grain. If the temperature of the drying air is high it increases the moisture carrying capacity of the air and decreases the relative humidity. For grain drying, the recommended temperature difference is between 30-60^{0}C (Vidya., 2013).

(c) Relative humidity

This is the moisture content in the air, air picks the moisture as it enters the grain, but its temperature is lowered, the relative humidity increases until it reaches equilibrium with the grain. If the air reaches equilibrium with the grain, it passes through the remaining grain without any additional drying. High relative humidity lowers the process of drying. If high relative humidity air enters dry grain, some moisture is removed from the air and enters the grain (Hellevang, 2013). When the moisture is being removed from the grain it reaches a point where there is no exchange between the moisture of the material and the surrounding air.

(d) Moisture level on cob

This the amount of water contained inside the cob. It is measured during the determination of moisture content of the cob, and moisture content is the quantity of water in mass unit of the cob and is expressed as a percentage. All maize grains on the cob contain moisture inside the grain and the cob. The moisture content on the grain can be determined by cracking the grain with one tooth, if it is hard then it is dry, but if the grain is soft then it shows there is amount of moisture which makes it soft. The amount of moisture in the maize on cob is dependent on the weather conditions under which the crop was harvested and sold. Crops harvested during the rainy season have more humidity, but with time the grain hardens due to loss of the moisture during the drying process (Sawant., 2014)

Some scientists say that grains are hygroscopic because they can lose and gain moisture from the environment, everything that contains humidity has pressure. As the grain is being dried, the vapor of the humidity changes from higher pressure in the moist grain to a lower pressure in the air. This happens until the grain and air reach a balanced vapor pressure.

Safe moisture content of the grain is important since it determines the state at which the grain can be stored. At lower moisture content any chemical or physical changes of the grain will occur slowly, and most fungi do not develop under 70% relative humidity, but when it comes to maize the amount of moisture that the grain can maintain depends on the condition at which the maize can be stored. Maize can be stored safely at 13.5% moisture content or below and the storage surrounding temperature should be 25^0 to 30^0C. (TSGC, 2018)

2.1.3 Post Harvest Processes

Post-harvest technology includes harvesting, assembling, drying, shelling, milling storage, packaging, transportation, and marketing (World Bank, 2011). The function of the post-harvest handling system is to ensure that the harvested grain reaches the customer at the right quantity and quality. This in turn will ensure food safety, proper nutrition and food security while at the same time meeting consumers need. Post-harvest losses are high in developing countries as compared to the developed countries, due to lack of efficient farming system and management, poor infrastructure, poor storage and processing facilities that minimize the quality and safety of the harvested food (World Bank, 2011).

In Tanzania, the estimated post-harvest losses of the grain were 22% excluding the losses on the field and for the Benin Republic it was 27%. Feed the Future program of the USAID estimated although from the harvest made in Tanzania 40% is lost due to poor storage, processing, and transport systems (Hodges, 2012). Post-harvest occurs between the harvesting and consumption of the crop and is measured in terms of quality and value. The main causes of post-harvest losses are; the crops are highly perishable, mechanical damages, exposing the crop to high temperature, relative humidity, rain, contamination by fungal and bacteria, attack from rodents, insects, pests, and birds, (FAO, 2011).

There should always be an affordable solution to small-scale farmers, with a few options to invest, so as to improve the post-harvest practices and technologies, with minimal financial implication, so as to improve the storage hygiene and good storage management (Kiaya, 2014).

A post-harvest loss is the measurable quantitative and qualitative food loss during the post-harvest systems. The quantity loss includes; Effects on the nutrition or caloric composition, edibility of the product, and the ability to accept the product. (FAO., 2010) Reported that food losses in Africa due to post-harvest losses are estimated at 20-30%, which if evaluated amount to about 4 billion US Dollar.

A comparison is also done between the harvest made on different climate conditions and it is estimated that during damp conditions the drying losses were high by 16.3% compared to during favourable conditions which gave 6-10% of the drying losses (Hodges, 2012).

Another study also showed the farmers that climate variability is the real cause of food insecurity hence high post-harvest losses and poor crop yield that affect the African small farmers (Parry, 2009). A suggestion was also made that there should be a further understanding and study on how the climate change may affect the post-harvest for small scale farmers and come up with a technology that can be used to reduce these problems (Stathers, 2013).

A research was also done and showed that climate variability affects small scale farmers by lowering their productivity and increasing the post-harvest losses. This is due to poor post-harvest activities, handling infrastructure, lack of adequate knowledge on the best post-harvest handling methods which affects food security (Adebayo, et al., 2014). It further stated that more loss came about due to manual processing and poor storage. The current manual process is commonly practiced by women and is a tedious, time consuming process which produces a lower yield. This in the end reduces the farmer's outcomes such as their incomes. There is an increase interest on intervention of post-harvest losses to be reduced, the investment required to reduce the post-harvest losses is relatively different and the return on the investment rises faster as the price of the commodity increases.

2.1.3.1 Mycotoxin

Mycotoxin is a low molecular weight (small molecule) natural product which is produced by filamentous fungi as a secondary metabolite under suitable temperature and humid conditions. Figure 2.1. shows maize infested with mycotoxin. It is a poisonous chemical compound which, when ingested by vertebrates causes sickness or even death (Hussein, 2001).

Figure 2.1 Mycotoxin maize (Ncube, 2017)

They grow on grains and seeds which are commonly infected by moulds (Bennett, 1987). All mycotoxins are originated from fungi and not from all toxic compounds produced by fungi. Antibiotics are the fungal products that are toxic to bacteria especially penicillin, the specific and concentration of the mycotoxin.

Some of the various ways of avoiding the consumption of mycotoxins includes:

- Creating of awareness to the public encouraging the producers to test their products and setting a limit of mycotoxin in food (Wagacha, 2008).
- Encouraging early harvest which will prevent the crop from fungal infection on the field before harvest. Africans do harvest at an appropriate time because of need of cash, theft from the farm, unpredictable weather and a lot of labour

required during harvest, (Amyot, 1983) (Rachaputi, 2002). The study also showed that the groundnuts that were harvested early had been less contamination by aflatoxin hence achieving a 27% rate of return more than the late harvest.

- Encouraging an appropriate drying where drying is done immediately after harvest to reduce moisture content hence reducing the favourable condition that could allow growth of fungi and attack by insects making the grain last longer (Lanyasunya, 2005).

2.1.3.2 Pests and Rodents

Pests that attack grains include; saw-toothed grain beetle (80%), maize weevil (67.3%) and flat grain beetle *Cryptolestes pusillus* (50%). Other pests that were rated as moderately severe included termites (by 67.7% of the respondents), Angoumois grain moth *Sitotroga cerealella* (54.8% of the respondents), lesser grain borer *Rhyzopertha Dominica* (53.3% of the respondents), and Indian meal moth *Plodia interpunctella*) (Charles., 2016).

Since these pests are hazardous to the grains, one of the ways of reducing their infections is by managing insects and this can be done by storing the maize with an insecticide. When the insects are in the grain they create pores that allow mycotoxin which are produced by the fungi to enter the grain hence affecting the grain and damaging its physical characteristics (Munkvold, 2003).

Other ways include; establishing planting dates, irrigation and fertilization management, a practice of crop rotation and managing the infected crops before it spreads (Champeil., 2004).

2.2 Design Principles of Drying

Design is a plan that has been formulated either by coming up with a new or developing an existing idea to solve particular problem or need. Figure 2.2 below is a concept of how to design a machine. (Ali, 2020)

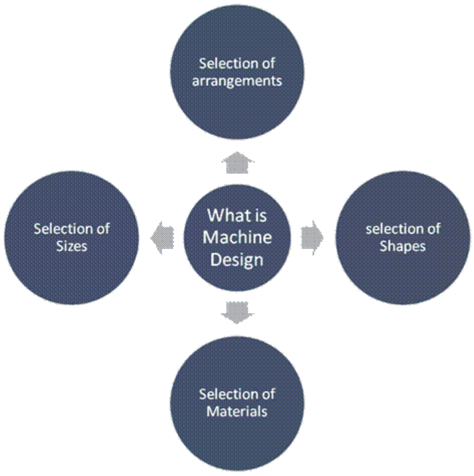


Figure 2.2 Concept of designing a machine

Where:

- Define a problem: where by providing all input constraints, output constraints
- Select material to be used: by selecting suitable material for each element: factors to consider includes: cost, availability, manufacturing considerations and mechanical properties,
- Select appropriate shape for the machine: to achieve appropriate flow of the process
- Select how they will be arranged: it should allow effective way of the process flow
- Assemble the element
- Test

At harvest, maize contains a lot of moisture about 25% -40% which is favourable for growth of fungi. Since the cover of the grains is still soft, the insects and rodents can damage them and therefore in order to avoid this, maize should be dried for safe storage.

Some of the crucial points to take note of while designing the dryer are;

- In calculating the vent dimension, the wind speed is considered.
- The solar radiation is studied in order to determine the energy received when drying during the day.
- Establishing the harvesting period in order to know how fast the product should be dried.
- Estimating the amount of moisture that has to be removed to ensure increase in the shelf life of the product.
- Finding the total drying time and also establishing the hour at which the sun shines daily.
- Establishing the volume of air needed to dry the product.

There are different designs principle of drying grains. These include natural drying and forced hot air drying.

2.2.1 Natural Drying

This method uses a natural source of energy for drying. This includes, use of natural air that has been heated by the sun and carried by the wind over the product to remove moisture from the grain hence making storage of the grain easier. It is a traditional method that is used by several farmers. It can be divided into:

2.2.1.1 Sun Drying

Sun drying utilizes the solar energy or UV radiation to dry the grain when the grains are spread on an open field. Sun drying can either be by drying small amounts of grain or by drying using plastic sheets (Vidya., 2013).

a) Drying small amount of grains

This the process where grains are placed on a thin layer on tray-shaped sieves that can easily be moved and stacked upon each other beneath roofed structures to protect the grain from dew and soil. The problem with this method is that the grains are exposed to attack by insects, birds, rodents, occasional rain shower, and wild animals hence lowering the quality of the grain (Sammy, 2018).

b) Drying using plastic sheets

In this method the plastic sheet made of polyethylene is used, the sheet is thick and a dark colour is preferred. When the sheet is being spread on the ground, there should be no stones, wood or other objects that can puncture the polyethylene below, posts are then used to tie the sheet down (Shepherd, 1999). The grains are then poured and continuously turned hence grain will be exposed to sun and wind as shown in Figure 2.3.

Figure 2.3: Drying using plastic sheets (Rwanda Rural Rehabilitation Initiative, 2018)

c) Drying using patio with a cement floor

The cemented ground can be used to dry the grain, where the grains are poured on the cemented ground, the grains should be turned over to allow it to dry, but the temperature of the ground should not rise above 40^0C.

The advantage of drying using sun is that it is a cheap method (solar energy is abundant and also environmentally friendly and can be easily managed). Also, it has some disadvantages such as: risk to spoilage due to climatic condition like rain, wind, moist, and dust; loss of grains through birds, insects, and rodents feeding on them; the process of drying is slow leading to growth of moulds. It also requires larger pieces of land for drying (Shepherd, 1999).

2.2.1.2 Drying Grain in a Crib

The crib is a ventilated structure, made of rounded bamboo, commonly used to dry the maize on cob in the open natural ventilation and can store the cob for 3 to 4 months. The crops are harvested then heaped on racks and topped by layers of stray or iron sheet to prevent the crop from being rained on. The drying process is dependent on the free movement of air through the crop using natural wind. (Unit., 1984).

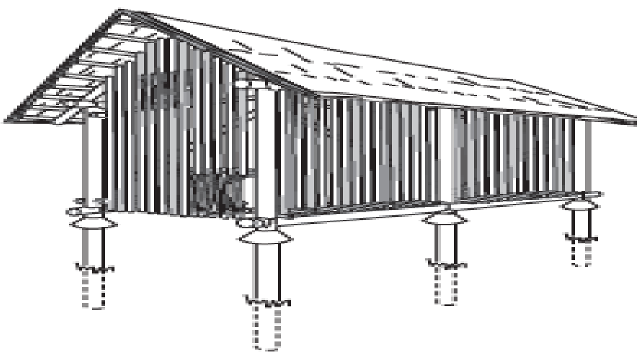


Figure 2.4: Rural structures (Unit., 1984)

2.2.2 Artificial Forced Hot Air Dryers

Artificial forced hot air dryers are commonly used to speed up the process of drying in that hot air is passed through the product in a conditioned chamber (Ahmet., 2013). Maize that is stored on a horizontal grid is dried by heat from the fire that has been set below from the kitchen fire. But the disadvantage of this method is that the grain changed colour and produced an odour due to the smoke effect from the fire. To overcome this problem a hot air chamber/ heat exchanger unit and a chimney were developed.

Other different artificial dryers where developed depending on the depth or thickness of the grains being dried, these include deep bed dryers, thin layers dryers and in sack dryers.

2.2.2.1 Shallow Layer Dryer

Bin dryers have a lower airflow rate hence the process of drying is slow and has low fuel consumption. They allow drying of large volumes of grain, and the drying amount of each day is the same.

a) Batch-in-bin process

It is cheap to construct these type of bin dryers, the grain depth is maintained in order to allow uniform and drying rate. In Figure 2.5, the grain near the inlet will dry faster and the dry front will then move through the grain. The best way of increasing the drying speed is by reducing the depth of the grain (John, 2017).

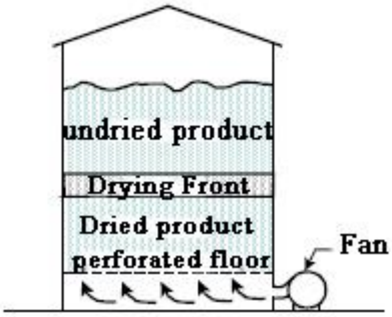


Figure 2.5: Bin Drying showing the drying front with about half the product dried (Wilhelm, 2005)

b) Batch dryers

These are shallow layer dryers and are perforated at the base. They are portable since they contain wheels which are used to move the dryers to the farm and back, and at the farm they are placed on a permanent position in a well-designed grain handling system hence achieve efficiency and conveniences (Kasiviswanathan., 2016). They are mostly used by farmers who have farms at different locations. Warm air is let into the plenum chamber then flows through the grains and goes out above the grain (John, 2017).

Types of portable batch dryers:

- Recirculating type
- Non-recirculating type
- Continuous flow type

i. Recirculating batch

This type of dryer is where the grain is loaded as a batch and is constantly mixed while drying. They are dryers that have one central air plenum surrounding the grain. In Figure 2.6, the wet grains are loaded into the dryer from the top until full then a hot air is pumped through the grain until it dries. Here the grain is constantly recirculated throughout the process of heating and cooling (Mujumbar, 2004). The dryer geometry is always circular with a vertical auger in the centre of the dryer. The auger picks the grain at the bottom and deposits to the top of the dryer. A complete recirculation of drying processes takes about 15 minutes which is similar to the unloading time. Due to continuous rotation of the grain this ensures a uniform drying and the grains are less damaged.

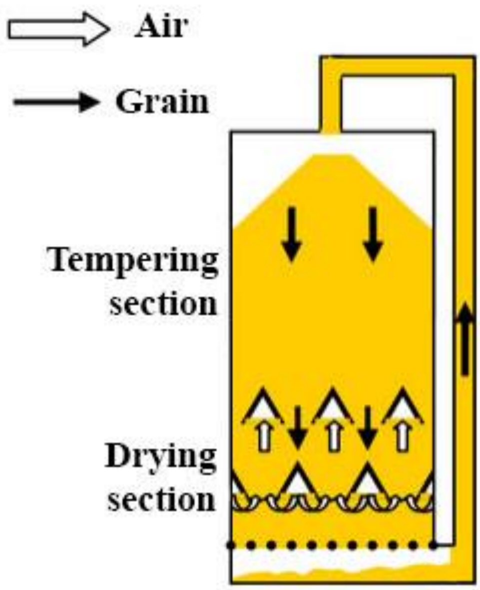


Figure 2.6: Recirculating type dryer (Mujumbar., 2015)

Its advantages include; Even drying, automatic operation and affordability. The main disadvantage is the mechanical wear of its components.

ii. Non recirculating type

Figure 2.7 shows a non-recirculating batch type, it is a drying type where the grain is loaded as a batch and remains stationary in the drying during the whole process of drying. They have two columns which are fully closed, when the wet grains are fed into the dryer from the top until it is full then hot air is forced through the wet grains until it dries, at this point the grains are not moving inside the dryer, so chances of grain getting over dried occur while the grains outside are not dried, after the heat circulation the grain is cooled inside by shutting off the heat or it is moved to the aeration bin for cooling. So, during unloading, the dried grains mix with the wet grains and if a safe temperature is applied then the grain will be appropriately dried and cooled and a suitable product result will be achieved. (Christian., 2012).

Their advantages include; availability of simple, cheap, local versions and the disadvantages include uneven drying and intensive labour.

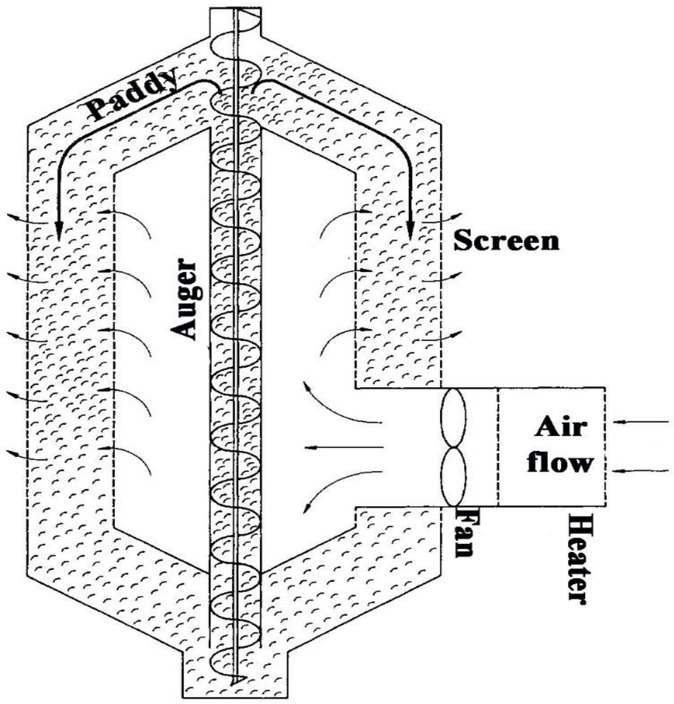


Figure 2.7: Non-Recirculating type dryer (FAO, 2018)

iii. Continuous-flow dryers

In a continuous-flow type dryer the grain is loaded and unloaded intermittently or continuously. A continuous flow dryer uses two or four vertical grain columns where air passes through the grain at a right angle to the flow of the grains. The grain is fed into the hopper on top of the dryer, flows down on both sides of the hot air plenum then through the cold air plenum. Finally, it moves out through the auger. The temperature of the hot air is very high and the flow of the inlet is controlled to allow hot air to penetrate the flowing grain. The time for drying depends on the moisture content of the grain. (Kasiviswanathan., 2016). The grains are not mixed as it flows downward hence the grain near the hot air plenum is overheated while the ones on the outside are under dried, as shown in Figure 2.8. This process is costly and is only used in a highly mechanized condition.

It has advantages of higher capacity and automatic operation even though it has a limitation on its intensive capital and its requirement of large volumes.

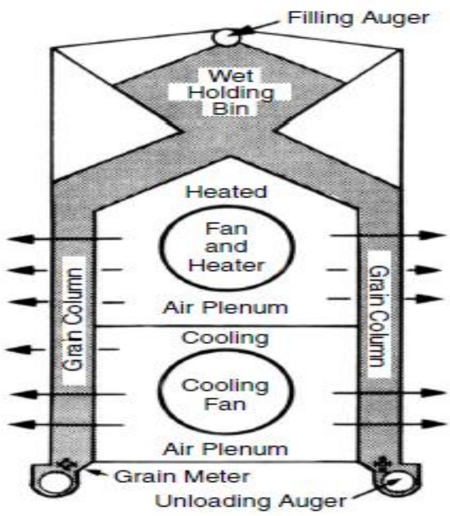


Figure 2.8: Section of a continuous type dryer (FAO, 2018)

2.2.2.2 Fluidized Bed Dryer

The fluidized bed is a packed bed through which fluid flows at a high velocity and the bed is loosened and the particle - fluid mixture behaves as though it is fluid. When a bed particle is fluidized, the whole bed can be transported as a fluid, both the gas and liquid flow can be used to fluidize a bed particle. Fluidizing bed is common since it gives a vigorous agitation of the solid in contact with the fluid, leading to an enhanced transport mechanism (diffusion, convection, and mass/energy transfer).

Fluidized bed drying is the most applied method of drying used in drying granular solid in industries that includes food, pharmaceutical, agriculture and food industries (Mujumdar., 2000).

The working principle of the fluidized bed dryer involves the hot air being fed through a bed at a high velocity which is sufficient to achieve optimal drying and to overcome gravitational effects on the product but still ensuring that the product is suspended in a fluidized manner. The wet product is fed in the main drying zone, from the bottom the hot air is pumped through the perforated plates allowing interaction between the hot air and the wet product. This interaction ensures that the product is fluidized, ensuring particle and gas contact to take place leading to drying of the product. And the dried products are removed from the drying chamber through the exit. The rate of drying and the depth of the drying chambers depend on the moisture content of the grain and hot air speed (Mujumbar., 2015). This is illustrated in Figures 2.9 and 2.10.

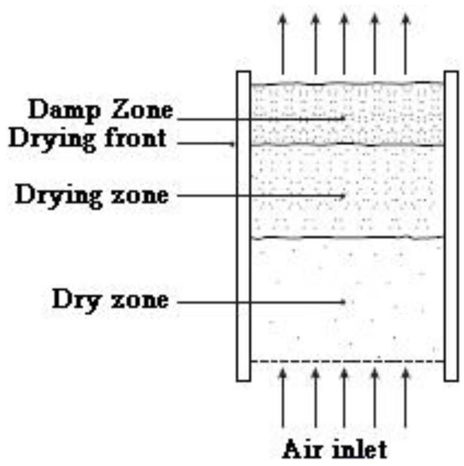


Figure 2.9: Cross Section of a fluidize bed flow (Yashwant., 2015)

Fluidized bed uses a low temperature which minimizes the grain damages that may be caused by high temperatures. Here, uniform drying is achieved, and improvement in drying movement, leading to reduction in period of drying.

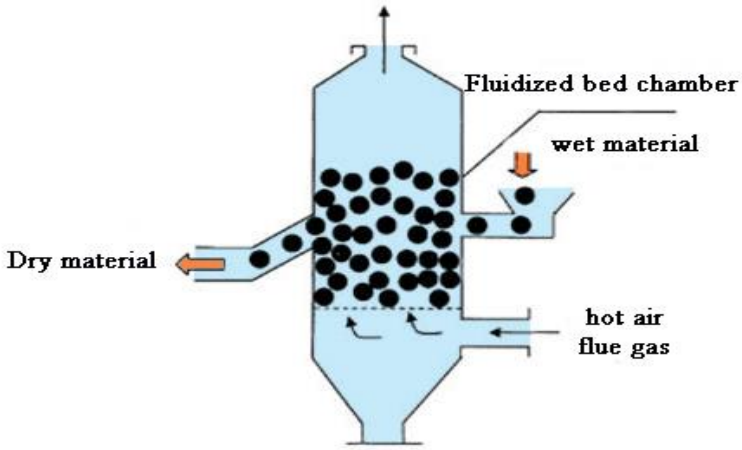


Figure 2.10: Section of the fluidized bed dryer (Ozioko, 2016)

The advantages of the Fluidized dryer are (Ozioko, 2016);

- It has minimal maintenance and capital cost.
- It is easy to control.
- It has less drying time.
- It has high rates of moisture removal due to excellent gas-particle constant which results in high heat and mass transfer rates

The demerits of the dryer are (Ozioko, 2016);

- Non uniform product quality for certain types of fluidized bed dryer.
- Poor fluidization and low flexibility especially if the feed is too wet.
- Requires increased gas handling due to extensive recirculation of exhausts gas for high thermal efficiency operation.
- High potential of attrition and sometimes agglomeration of fine particles.
- High pressure drops results as a result of the need to suspend the entire bed in gas which equally leads to high energy consumption.
- Can't be used in removing of organic solvents during drying process.

In regard to fluid flow, the drying model involves packed fixed and fluidized bed. There are designs where the large surface area for contact between a liquid and gas adsorption on solid and gas or liquid adsorption is obtained for achieving rapid mass and heat transfer and particularly in the case of fluidized bed reaction.

For a typically packed bed, it is a cylindrical column that is filled with a suitable packing material. The liquid is uniformly distributed at the top of the column and flows downwards wetting the packing material, a gas is admitted at the bottom and flows upwards, contacting the liquid in the counter current fashion. Pressure drop is an important fluid mechanic perspective when considering gas to flow through a column at a specific flow rate. To calculate pressure-drop of the bed, the equations in **APPENDIX A** can be used.

2.2.3 Solar Dryers

Solar dryers are specialized devices that control the process of drying and prevent the products from damages caused by insects, rain, and dust (Bala., 2002) (Senadeera., 2007). Solar dryers absorb solar energy hence converting it into heat energy which then heats the air hence drying the product. Solar dryers have been beneficial in the sense that, they generate high temperatures, lower relative humidity, lower product moisture content, reduce spoilage of product during drying processes, use less space, less time and are relatively inexpensive compared to another artificial drying (Mohanraj, 2008)

2.2.3.1 Types of Solar Dryers

Solar drying includes indirect, direct and mixed mode drying.

In indirect drying, the solar energy is absorbed by the solar collector that is separate to the drying chamber. The fan blows the air into the solar collector, which is heated then flows into the drying chamber hence drying the product. Its advantage is that the product is protected from the direct ultraviolet rays, and there is minimal damage to the product due to regulation temperatures but its limitation is its initial installation cost which is expensive (Chua., 2003).

In direct drying the product is placed in a transparent cover, then as the sun is shining its ray's pass through the cover creating a greenhouse effect hence drying the product. Its benefits include its simplicity and less expensive method of drying since it uses direct sunshine.

The mixed mode drying is the combination of both the direct and indirect effects. It is beneficial in ensuring less damage of the product due to controlled temperature, but it is expensive and complex to install, operate and maintain.

2.2.4 Components of the Solar Dryer

a) *Drying chamber*: The drying chamber is the section where the drying process will take place, it is the section where the product to be dried is placed. (Folaranmi, 2008)

b) *Air flow system*: For the flow of air into the drying system can be either be natural or forced (convection). For natural system, the air is being blown into the system by wind or hot air moves up and cold air moves down into the drying chamber. For the forced convection, the air is blown in with the help of a fan. The fan can be powered by the generator or the utility electricity. When using the fan, the drying time is reduced and the product quality is maintained hence optimizing the drying process (Mathew, 2001). The fan works either to create a negative pressure in the system which will prevent hot air leakage during drying to positive pressure which prevents cold air and dust into the system.

c) *Solar collector*: The solar collector is used to absorb the solar energy converting it into heat hence it is used for thermal application. It is used to absorb shorter wavelengths of the sunlight of 0.3-2mm and prevent heat wavelength of 2-10mm from loss into the atmosphere using a greenhouse effect. Some of the types of solar collector includes; flat plate, heated pipes and solar evacuated tubes (Norton, 2006), (Kalogirou., 2004).

The flat plate collector has commonly been used for several solar experiments. Its operation parameters are mass flow rate of the fluid, inlet, outlet and ambient temperature, solar radiation, air speed, glass cover and environment condition (Akpinar, 2010). Its performance depends on the design parameters which include, type and thickness of the glazing, number of the cover, space between the collector and the inner glass, type of coating on the collectors plate, evacuated space between the collector and the inner glass, insulation type, convection movement of the air in the system (Alghoul, 2005).

Solar evacuated tubes have been used for many years in Germany, Canada, China and UK. There are various types of evacuated tubes but the most commonly used is the one with a double glass tube, because of its reliability, excellent performance and ease to manufacture (Zulovich, 2013). An evacuated tube has two glass tubes, i.e. the outer tube and the inner tube. The outer tube is made of very strong transparent borosilicate glass that can resist impact from hail and is 38 mm in diameter. The inner tube is made of borosilicate glass but is coated with special selective coating which is excellent in absorbing solar energy and has minimal reflection property (Kalogirou, 2004). The air is evacuated from the space between the two glasses to form a vacuum that will eliminate loss of heat through conduction and convection.at the bottom it has a layer of barium that is used to absorb CO, CO_2, N_2, O_2, H_2O and H_2 during operation and storage which ensures that the vacuum is maintained, also the barium shows the status of the vacuum in that when the vacuum is over the silver coloured barium layer will turn white. As shown in Figure 2.11.

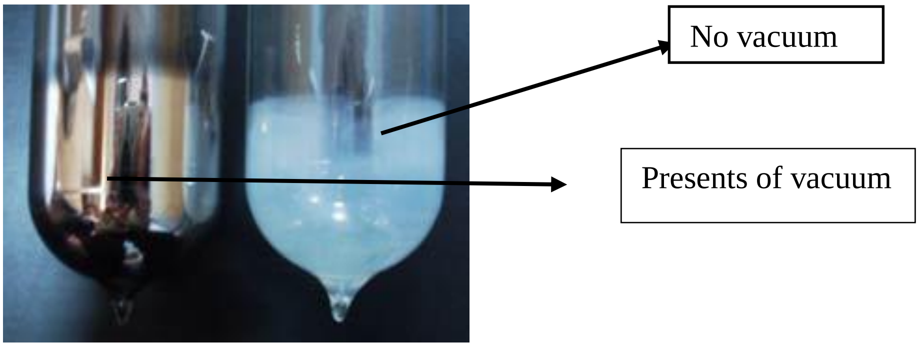


Figure 2.11: Solar evacuated tube, with vacuum and with no vacuum (Green Spec, 2018)

The desirable features of a solar collector include the following:

(a) *Transparent cover:* Transparent cover traps heat from the thermal radiation, this ensures less radiation and convection losses into the atmosphere. It protects the absorber from damage during hostile weather conditions. Covers are commonly made of low iron glasses such as fibre glasses, flexi glass, thin plastic films, and reinforced polyester and ultraviolet resistant plastics sheeting. The low iron glasses have a high transmission and low reflection of the sunshine, and are small increasing thus their efficiency (Joshua, 2008).

(b) *Insulation:* The insulation property prevents the thermal energy loss which minimizes the overall heat loss of the system when placed below the absorber plates. The insulator must withstand the stagnating temperature, not damaged by moisture or insects and must be fire resistant (Joshua, 2008). Insulators are made from mineral wool, Styrofoam, fibre glass, urethanes and selective grade of CFC free polyurethane foam (PUF). The insulators must be kept dry or it may lose all its insulating qualities. Since the air that is flowing into the system contains moisture, the insulator should have a desiccant to absorb the moisture (Alghoul., 2005).

The advantages of these solar dryers include;

i. Dried grains are tasty, nutritious, the nutritional value and flavour in food is only minimally affected by drying.
ii. Dry grains have high carbohydrates and low fat making them source of energy when consumed.
iii. Easy to store, and use of minimal space for storage.
iv. Easy to prepare; Solar grain drying is a very simple skill.
v. Protection from rain and pollution by dust particles.
vi. Longer storage of dried grain (because of more complete drying).

Some of its limitations solar dryer are;

i. Inadequate infrastructure in Kenya.
ii. Growing market difficulties by intensifying competition in the worldwide agricultural market.
iii. Improve population income and supply situation.
iv. For the automated Solar powered dryer, the limitation is the fan. The fan should be inexpensive, durable and produce high flow rates at a high pressure while having a low Power consumption in order to keep the price of the solar crop dryer down and at the same time ensure an efficient drying process.
v. Insufficient processing capacities.

2.2.5 Simulated Models drying system

Simulation is an isothermal air flow which is used to create the relationship between the model and a prototype. Mathematical models can be created if there is no prototype. In order to come up with an appropriate simulation it must fulfil the kinematic, geometric, dynamic simulation and the boundary condition required for the process. Simulation is done to reduce time, cost and the space for fabrication. It is used to predict the behaviour of the prototype before creating (Yui., 2006). Simulation modelling is the process of creating and analysing a digital prototype of physical model to predict its performance in the real world. It helps the designers and engineer understand whether, under whatever conditions and in which ways a part could fail/perform and what loads it can withstand or can help in predicting fluid flow and heat transfer patterns (wikipidia, 2010). To improve a drying system, the mathematical model of a thin layer should be created (Alibas, 2012).

Defining an accurate mathematical model is important to simulate the drying kinetic of biological materials. Simulation model of drying process are commonly used for designing new drying systems or improving the existing systems, predicting the air flow over the product and controlling the process (Aghbashlo, 2011). Drying of agriculture products varies from use of thin layer drying of the agriculture product. There are two modes, that is, diffuse models (Darvishi, 2013) (Da Silva, 2004) and empirical models (Diamante, 2010) (Kaleta, 2010) (Silva, 2012).

Modelling of a drying kinetic as a process control should be created to prevent effects on the quality and physicochemical characteristic of the grains (Rayaguru, 2012). Empirical models are used to describe heat penetration and thin layer water removal using hot air. Diffusion equation is used to govern heating that balances the energy of the drying rate (Kumar, 2010) (Mariani, 2008). Empirical model is also used to study deep bed drying where during simulation, the deep bed design is divided into several thin layers hence an equation is created for each layer, the equations derived will be used to show the drying time as a function of moisture content and time (Aregba, 2006) (Dantas, 2011). Batch dryers are commonly used because of the simple requirements during the design. The use of batch dryers usually leads to an uneven distribution of air and this usually leads to low drying efficiencies and lack of homogeneity on the dried products (Mirade, 2003) (Misha, 2013).

The drying medium and geometry are crucial since they determine the uniformity of the drying process and also the quality to be achieved at the end of drying process (Tzempelikos, 2012). The other important drying parameter includes configuration of drying which defines the uniformity of air flow of the product, and this comes after selecting the drying process and medium, since non uniformity commonly occurs in drying chambers especially fix drying (Janjai, 2012) , (Roman, 2012). Due to non-uniformity of drying, (Syahrul, 2002) suggested that for an industrial batch dryer, air distributions should be optimized to reduce energy consumption and still achieve a good quality of drying. The creation of effective thermal analysis should then be performed. For this reason, an energy analysis should be done which will provide a better understanding of the influence of thermodynamics phenomena on the whole process. Its contrast on different thermodynamics factors and the determination of the best ways of improving the process will be considered (Sogut, 2010).

Muller did a study on a newly designed batch type dryer to achieve a uniform drying with uniformly distributed air flow in the drying chamber (Müller, 2006). For a fixed-bed batch dryer air flows from one side of the drying chamber to the other end. Because of the air movement moisture from the product gets into the air thus creating the drying effect on the product from the beginning. By the time the air reaches at the end there is reduction in time of the flow. Hence a diagonal shape is created at the inlet the design in order to maintain the velocity pressure and to avoid the use of baffle plates. Air flow is always connected to how the temperature will be distributed and therefore to obtain a uniform air distribution, it is dependent on the drying rate and the energy consumed to achieve the drying process. Some research has been done on ways to reduce energy consumption during drying and still achieve the quality of drying (Strahl-scheafer, 2012), (Tippayawong, 2009) (Darabi, 2013), (Ehiem, 2009).

2.3 Existing Fabricated Dryers

In the process of drying maize, the main reason is to remove moisture from the grains at a temperature that cannot damage the quality of the grain in the context of texture, colour and flavour. If the temperature is too low at the start of drying it will encourage growth of fungi on the maize grain before it is completely dried. And if the temperature is too high and the humidity ratio is low, it will harden the grain cover, or discolour the grain. For an appropriate drying the dry air should absorb the moisture that is released. There should be adequate circulation of air to carry away the moisture from the surface of the grain and adequate heat should be applied to remove the moisture from the grain without cooking it (Adu., 2012).

2.3.1 Simple Maize Grain Dryer

It is an example of a distributed passive solar energy dryer which is made up of a drying chamber and air heating solar energy collector which consists of a cover plate, an absorber plate and an insulator. This design is made in such a way that the solar radiation is not directly incidental on the maize, but the preheated air flows into the drying chamber through a low pressure. It has a thermos phonic solar energy air collector which is made of insulating material (polystyrene). It also has an absorber plate made of aluminium sheet and is painted black and is covered by a glass of 5mm thickness.

The test result of Figure 2:12, gave a temperature above 45^0C in the drying chamber, Maize grain 50 kg of moisture content 20% reduced to 12.5% wet basis in 27 hours drying time (9 hours each day for 3 days) (Folaranmi, 2008).

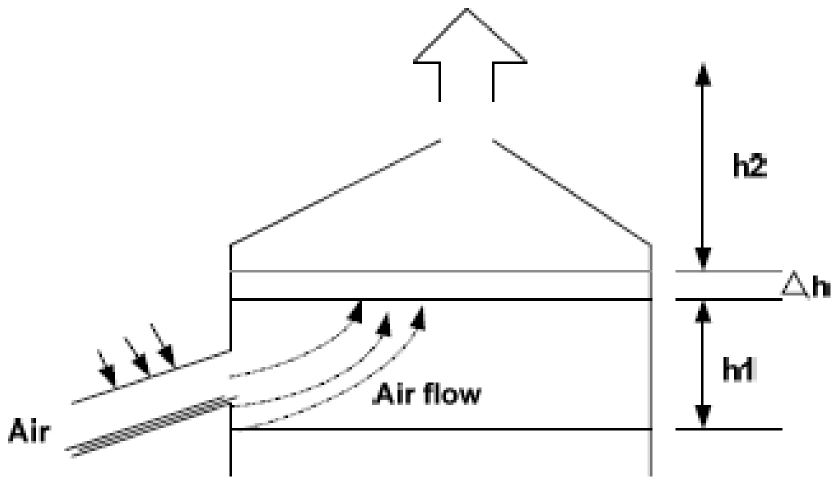


Figure 2.12: Representation of a simple maize dryer (Folaranmi, 2008)

2.3.2 Mixed Mode Dryer

Tonui (2014) developed a mix mode dryer. The solar dyer was combined with the simple biomass burner and then was constructed using available material to dry the maize. The dryer consisted of a drying chamber, back up heater, solar collector and an airflow system all integrated together (Tonui, 2014). The dryer, was used to dry 100kg of maize grain for 6 hours under natural convection from an initial moisture content of 21% to 13% wet basis.

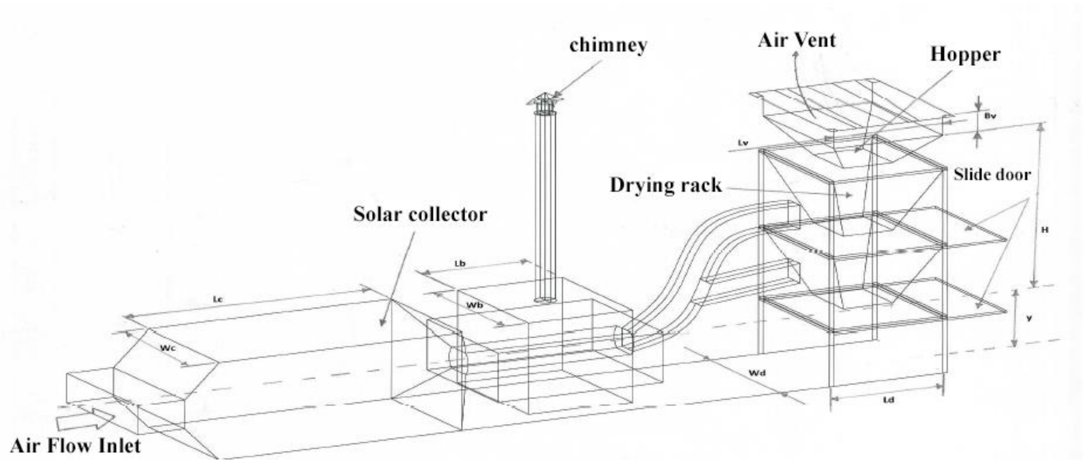


Figure 2.13: Schematic view of a solar assisted maize dryer (Tonui, 2014)

Using solar drying in Figure 2.13, the maize moisture content was reduced from 19.3% to 13.25% wet basis, at a temperature difference of 27.3^{0}C and 32.0^{0}C. Using the biomass heater, the maize mass of 4.1 kg with moisture content of 19.3% was reduced to 13.3% wet basis in 4hours and 40 minutes with the temperature range of 40^{0}C - 45.9^{0}C.

2.3.3 Simple Solar Dryer

The dryer was constructed using wood, glass, galvanized steel, wire mesh and copper tubes. The design in Figure 2.14, uses the greenhouse effect and the thermo siphon principle. The air enters in the solar collector and is heated up by the greenhouse effect (air in a control room is heated from the surrounding and is maintained). The hot air rises through the drying chamber passing through the trays and around the product hence removing the moisture which is let out through the outlet. It was used to dry 20kg fresh vegetable from moisture content of 89.6% to 13% wet basis in 2 days, with the temperature ranging from 42^{0}C to 47^{0}C (Vidya., 2013).

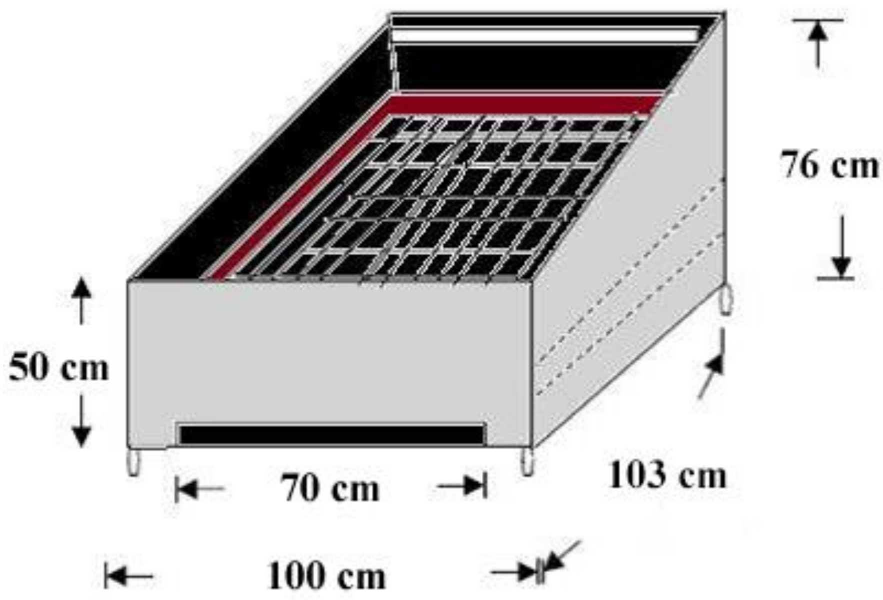


Figure 2.24: Representation of a simple solar dryer (Vidya., 2013)

2.3.4 Simple Hybrid Maize Dryer

Adekanye designed a dryer that consisted of the drying chamber, fan, and a chimney at the top of the drying chamber. It contained 5 trays, the maize on cob was placed on each tray and warm air was forced through the trays, as shown in Figure 2.15. The source of heat was from burned waste corn. The moisture content of the 2kg maize on cob per tray was reduced from 75.10% to 13.29% in 7 hours (Adekanye., 2016).

Figure 2.15: A Simple hybrid maize dryer (Adekanye., 2016)

2.4 Tests Performed

In every design constructed above, test should be performed in order to establish the fail at an early stage and also to gather more accurate requirements so as to enable the designer to understand the problems that can be encountered during its operation. This information would be useful in enabling the designer to come up with an appropriate solution to the design failures.

From the designs reviewed in section 2.2, the common tested performances are shown in Table 2.2.

Table 2.1 Tests that should be done on the Fabricated Design and the Maize

Measurement	**Purposes**
1.Mass of the product	It is the total weight of the product; it determines the size of the drying chamber
2.Mass of water evaporated	It determines the property
3.Drying period	Is the time taken to dry product to the required moisture content and below
4.Sizing of the chamber	Is the capacity of the dryer
5.Moisture content	Is the amount of water removed from the maize grain
6.Temperature	Is the amount of heat required to dry the maize
7.Relative humidity	Is the amount of moisture in the heated air

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

The maize on cob from a family of *Zea mays* was used for the study, it was obtained from Nandi County, in the month of July 2018. The maize was grown on an irrigation scheme. The maize on cob was harvested and prepared by hand for the experiment.

The study area was Oasis which is located in Uasin Gishu County, Kenya at a latitude of +0.52^0 and longitude of +35.2^0, with an average ambient temperature of 23.7 ^{0}C, and solar irradiation ranging between 16-21 MJm/day in a year. This data was obtained from the office of Kenya meteorological service in Eldoret. As shown in Figure 3.1.

Figure 3.1 Image from google map

3.1 Maize on Cob Design Consideration

The intention of the design was to achieve the appropriate shape of the drying chamber for optimal air flow, the drying area and the weight of the maize. For the purpose of this study the drying area was considered for each 20 kilograms (due to scarcity of maize on cob during the month of May-July and filled half normal maize sack) of the maize on cob to be dried. The minimum and maximum limit temperature of drying a maize grain was used to establish the drying temperature which was 40-60^{0}C. From the month of July 2018, the mean average temperature each day was 23.7^{0}C. And its relative humidity was 56.3% from the psychometric chart of humidity ration is 0.012Kg/Kg dry air.

In order to obtain the appropriate size of the dryer and its design calculations some information was considered, such as crop characteristic, loading densities acceptable, quantity of the batch and type of crop to be dried. These were required due to the location of the dryer and maize on cob climatic conditions during the harvest.

3.1.1 Product Characterization

Maize on cob is the long-rounded part of the maize or it is a corn plant on which small white or yellow seeds grow and is consumed by animals.

Product characterization includes identification of the plant, bulk density, initial and final moisture content, maize on cob porosity, mass of the maize, and loading bed void fraction.

Figure 3.1 Image of the maize on cob

i. **Bulk Density of the Maize**

Bulk density is the weight of maize on cob at a given volume, it increases with compaction and increases with depth.

Finding volume for each maize on cob**:** Using the displacement method, the maize on cob was placed in the polythene bag, ensuring no air in the bag, it was immersed in a full bucket of water, as it was being released it displaced the water which was then measured using a measuring cylinder to obtain the volume in millilitres, this was repeated for 150 samples (pieces of maize on cob that filled the normal size [radius of 0.35m height of 1m] sack of maize), and an average was obtained.

The mass of all the 150 samples was measured and an average obtained.

Different packaging bags of different areas and mass were used, the maize on cob was placed to full, and its mass was established, total sum of the maize on cob volume placed in each package whether scattered or arranged was also established.

To find the porosity of each package

$$porosity = \frac{A-B}{A}$$ **Equation 1**

A= the volume of each package

B= the total volume of the maize on cob in each package

When maize is harvested it is always in different shapes and sizes hence the expected volume for the dryer at each time is 20 kg (150 samples) of maize on cob, and its total volume is $0.117m^3$.

$$Bulk\ density = \frac{mass}{volume}$$ **Equation 2**

Assumption that was considered during calculation of bulk density:

- Moisture content of maize on cob is constant
- The maize cobs were stacked irregularly

- The maize on cob have same shape

WeiHeng portable electronic scale weighing machines (Figure 3.3), was used to measure the mass of the maize on cob, it can weigh 10 grams to 40 kilograms.

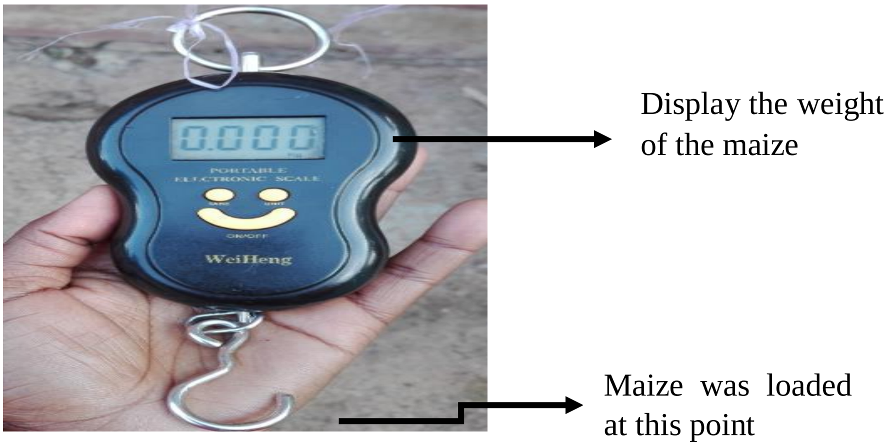


Figure 3:3 Weighing Machine

ii. Void Fraction

Void fraction is equal to porosity.

$$\varepsilon = \frac{empty\ volume}{total\ volume(empty\ volume + solids\ volumes)}$$ **Equation 3**

iii. Moisture Content

Moisture content is the amount of water that the maize on cob contains, it influences the taste, texture, weight, microbial stability, predicts the behaviour of the grains during processing appearance and the shelf life of the maize. Moisture content can be calculated in two different ways, which is: dry basic moisture content which is the percentage ratio of water weight to dry matter weight (mostly used in microwave drying) and wet basis moisture content which is the percentage ration water weight to the total weight of the material (mostly used in food industries) (Dissa, 2009).

$$MC\% = \frac{Ma - Mb}{Ma} * 100$$ **Wet basis** **Equation 4**

m_a initial mass, m_b final mass after drying (bone dry mass)

Super pro moisture meter (Figure 3.4) was used to measure the moisture content of the maize grains after drying.

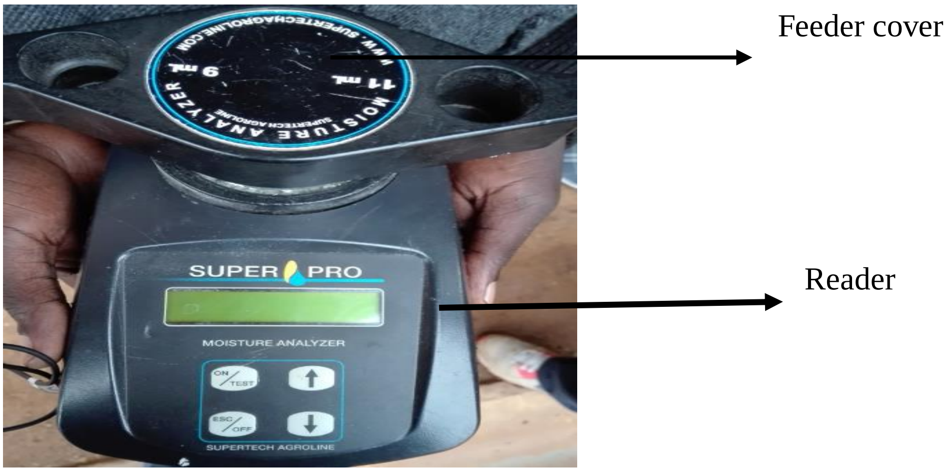


Figure 3.4: Moisture meter

How it works: the feeder cover is opened, 3 to 4 shelled grains are fed into it, as it is closed the grain is grinded and the machine could measure the moisture content.

It is important to obtain the moisture content of the maize since there are legal minimum and maximum amounts of water that must be available in the maize grain which are obtained from the standards board's such as Kenya Bureau of Standards (KEBS), where moisture content should be below 13.5%.

iv. Mass of Water Evaporated

Mass of water evaporated is the mass of water that was lost into the atmosphere during drying. This is achieved when water at the surface of the maize on cob is evaporated & water on the inner parts of maize migrates to evaporate porous. Determination of the movement of this water (High temperature, high wind speed & low relative humidity may lead to dying) is achieved by Equation 5:

The amount of moisture removed can be computed using the equation below:

$$MW = \frac{M1 - M2}{100 - M2} * M \qquad \textbf{Equation 5}$$

Where *M* is the mass of the maize to be dried, *M1* is the initial moisture content 25.7%, *M2* is the final moisture content 13.4% according to the result obtained. The amount of moisture removed is 2.84Kg.

3.1.2 Simulation of Air Flow with Solid Work

Process of simulation (Colangelo, 2016)

a) Draw a model hollow (circular or cornered shape i.e. rectangular shaped) geometric model. A rectangular shaped design of dimensions of 1 by 1 by 5 metres and A circular dryer of 1-metre diameter, 1-metre height, was drawn

b) Select the boundary conditions by defining the inlet and outlets for the flow, the face we choose for the boundary in the interior face of the lid that we have sealed hence the software assign those lead surface which is in contact with the fluid. Select the volumetric flow rate such as 2.8m^3.

   Define the outlet by putting a pressure boundary condition at the outlet of the dryer chamber at the inner face of the lid, where the outlet pressure is defined by the external pressure (101kPa)

c) Bring the model to flow environment, by activating the SOLIDWORKS flow simulation on the menu ribbon

d) Select the wizard option from the menu bring up dialog box

e) On the wizard unit system used to perform flow of thermal simulation select the default IPS units

f) The next dialog is the analysis type: here the internal flow is bounded by the solid at the outer boundaries which is the shape of the dryer

g) Add the fluid by selecting real gases such as air then add to the project fluid section

h) Mesh the fluid volume into a grid for the process of simulation to achieve a finite element

i) From there go to tools, flow simulation, solve, run the program

3.2 Fabrication of the Maize on Cob System

The maize on cob dryer system includes:

- ✓ Drying chamber
- ✓ Solar evacuated tube
- ✓ Blower

The following considerations were carefully followed in the design of the maize on cob dryer for reliability and effectiveness of the various components of the drying system:

- Used locally available materials to reduce the overall cost hence making the dryer affordable to the local farmers.
- Selection of the material that is; resistance to corrosion, water proof, non-toxic, resistance to heat, and durable.
- The outer and the inner walls of the dryer were painted and fully lagged to prevent loss of heat by conduction, convection, and radiation.
- A blower was used to blow in air into the solar chambers and also ensured even distribution of the hot air in the drying chamber which was to maintain evenness in drying the product during the drying period.
- The outlet and drying unit were based on the air flow requirement. The estimated airflow was $20m^3$/hr and estimated airflow velocity for drying was 3m/min and the direction of flow was upward.

A flow chat was created, showing the procedures which were taken during the design, construction and testing of the maize on cob. As shown in Figure 3.5:

`

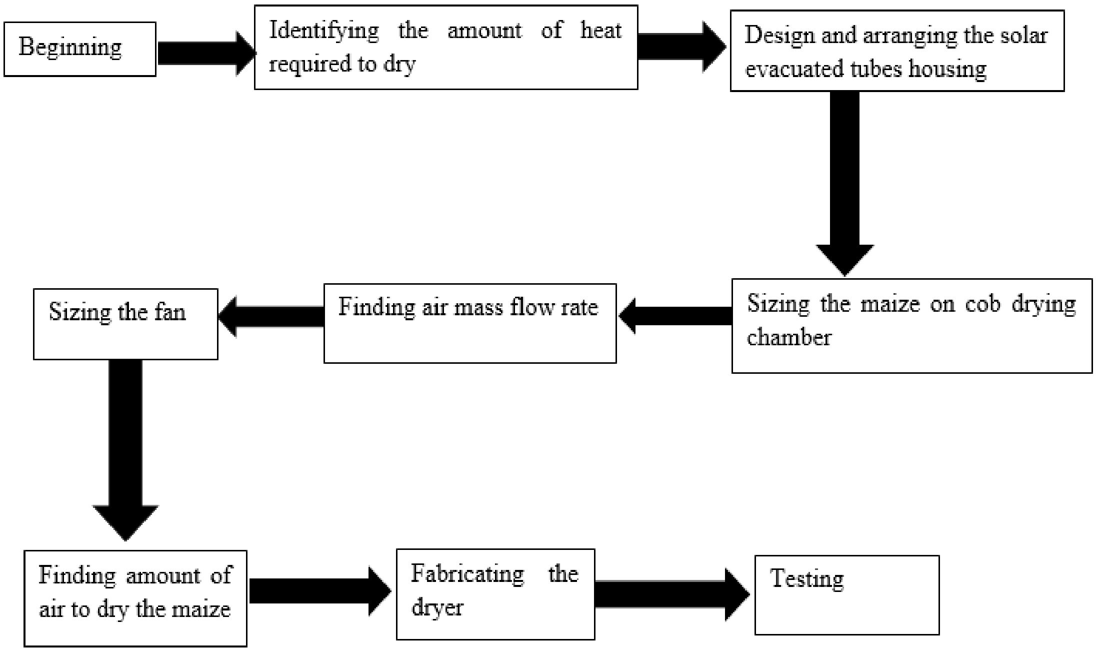


Figure 3.5 Flow chart of the design system

3.2.1 Dryer Chamber

To achieve an appropriate drying chamber the quantity of heat required to dry and the volume of the maize on cob to be dried were considered.

3.2.1.1 Quantity of Heat Required to Dry the Maize on Cob

The quantity of heat required to achieve drying of maize on cob is obtained from Equation 6.

$q = (MaCp\Delta T) + (MbHl)$ **Equation 6**

Where *Ma* is the mass of the maize to be dried, *Cp* is the specific heat capacity of the maize cob (which is assumed to be equal to shelled corn) 1.8 kJ/kg^{0}C, ΔT is the change in temperature (final temperature-initial; temperature), *Mb* is the mass of water to be removed, *Hl* is the latent heat vaporization of water = 2,260 kJ/kg (Fashina, 2013)

3.2.1.2 Sizing of the Maize on Cob Dryer Drying Chamber

The design of the dryer (see Figure 3.6) is built based on the amount of maize on cob to be dried, amount of moisture to be removed and the quantity of heat required. The design was established based on drying approximately a half full sack of maize on cob. The minimum and maximum limit temperatures of drying a maize grain were used to establish the drying temperature which is 40-60^{0}C, for the months of April and May. The mean average temperature each day was 21.3^{0}C and its relative humidity was 71.4% therefore from the psychometric chart the humidity ratio is 0.0013Kg/Kg dry air.

The dryer configuration was determined using solid works software simulation of cylindrical and cornered shapes such as rectangular shapes. A cylindrical configuration gave a uniform airflow distribution with less pocket for moisture during drying, the dryer was sized on the assumption of a normal half full maize sack and concluded to a diameter of 0.5 m and a height of 0.6 m, its total volume was computed using Equation 7 below.

$$V=\pi r^2 h \qquad \textbf{Equation 7}$$

Where *V*= volume occupied by the grain *(m3)*, *r*= radius of the chamber (m), *H*= the height of the chamber (m)

Figure 3.6 Drying chamber

And the total volume was 0.118 m^3

3.2.1.3 Volume or Quantity of Air Required to Dry the Maize

The quantity of air required depends on the drying time which in turn is related to the rate at which moisture migrates from the inside to the surface, as well as the heat and mass transfer kinetics. Finding the volume of air required to dry the 20kg of maize on cob can be achieved by using Equation 8 below:

$$Va = \frac{Qa}{\rho a}$$ **Adopted from (Ajisegiri., 2006)** **Equation 8**

Where *Va* is volume of air required to dry the maize, *Qa* is the quantity of air used to dry, ρa is the density of air =1.225kg/m^3

Quantity of air (Qa) is the amount of air required to carry the heat through the maize and the moisture from the maize on cob to the surroundings. It can be computed using Equation 9 below:

$$Qa = \frac{Mw}{H1 - H2}$$ **Adopted from (Adamade., 2014)** **Equation 9**

Where: *Mw*= amount of moisture to be removed (kg), *H1*= initial humidity ratio (kg/kg dry air, *H2*= final humidity ratio (kg/kg dry air)

Hence the quantity of air used to dry the maize was 208.82, and the total volume of air required was 170.47m^3.

3.2.2 Designing and Arrangement of the Solar Evacuated Tube Housing

The experiment system consists of 7 open ended evacuate glass tubes which are connected to a manifold chamber of length 0.74 m and consist of a circular pipe at the centre. The blower is used to blow in air into the solar evacuated tubes.

The design and arrangement of the solar evacuated tube consist of the following parts:

- Solar evacuated tubes
- Manifold chamber

3.2.2.1 Solar Evacuated Tubes

The solar evacuated tube that is used in this system is as shown in Figure 3.7, each evacuated tube consists of two concentric glass tubes made of extremely strong borosilicate glass. It consists of two glass tubes, in between the glass tube it contains a vacuum. The outer tube is transparent which allows rays of light to pass through with minimal reflection. The inner tube is coated with special selective coating (Al-N/Al) which absorbs the solar radiation superbly with negligible reflection properties. The length of the evacuated tube is 1.8m and the outer and inner tube diameter is 0.057m and 0.047m.

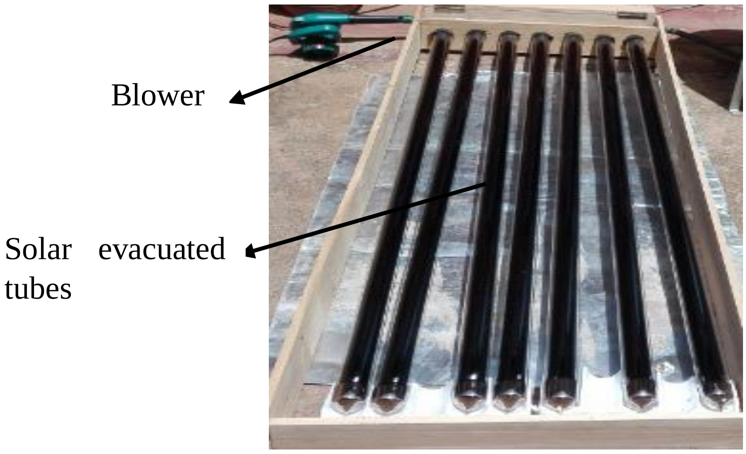


Figure 3.7: Arrangement of the solar evacuated tubes

a. Manifold Chamber

The manifold chamber consists of a square chamber made of wood which is a poor conductor of heat, and its measurements are 0.74 by 0.10 by 0.14 m, and a circular pipe of diameter 0.196 m made of aluminium pipe. The circular pipe is centrally passed through the square chamber and is closed at one end. Its surface contains seven holes in which chromium pipes are attached which direct air into the solar evacuated tubes and the seven holes are also made on the square chamber where the solar evacuated tubes are attached and the closed ends are supported by a frame. As shown in Figure 3.8.

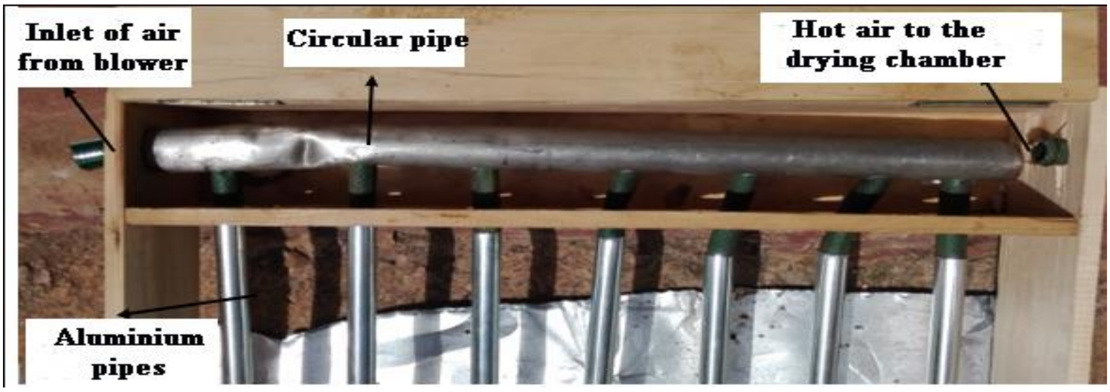


Figure 3.8: Manifold with the aluminium pipes

3.2.3 Fabrication of the Dryer

The dryer component parts include: solar collector, heat exchanger, air blower, drying chamber, and electric circuit. The drying chamber was fabricated using 18-inch thickness mild steel as shown in Figure 3.9.

The system operation: The maize on cob was fed at the top of the drying chamber, hot air was then forced up through the product. A blower was placed at the front of the solar tube system to create a positive pressure to force hot air up the drying chamber. As the hot air penetrated the product it warmed it thus creating pressure difference between the environment air and the crop hence releasing moisture from the product into the surrounding air. The released moisture then flowed out through the outlet. At the end of the day the moisture content of the grains was tested. This process continued until equilibrium moisture content was achieved. This is the point where the maize on cob balanced its own moisture content and the moisture vapor in the surrounding air. At this point the drying process stopped. The drying process started from the bottom of the drying chamber to the top.

Figure 3.9 Drying system

3.2.4 The Blower

The blower in Figure 3.10, was used to blow in air into the system, it is an installed equipment that provides the transfer of air in the emitted environment at high or low pressure and rotates the fan with a force that is received from its motor. Its specifications include: voltage 240V, frequency 50Hz, rate input power 1800W, weight 1.2 Kg, rated no load speed 2.8 m^3.

Figure 3.10: Image of the blower

MS6252A digital anemometer (Figure 3.11) was used to measure the speed of air at different intervals at the outlet of the drying chamber.

Figure 3.11: Anemometer

3.3 Test Procedure Experiments

Based on the conditions placed during drying, the measurement system was placed surrounding the dryer therefore a flow diagram was created in Figure 3.12 to simplify the testing procedure.

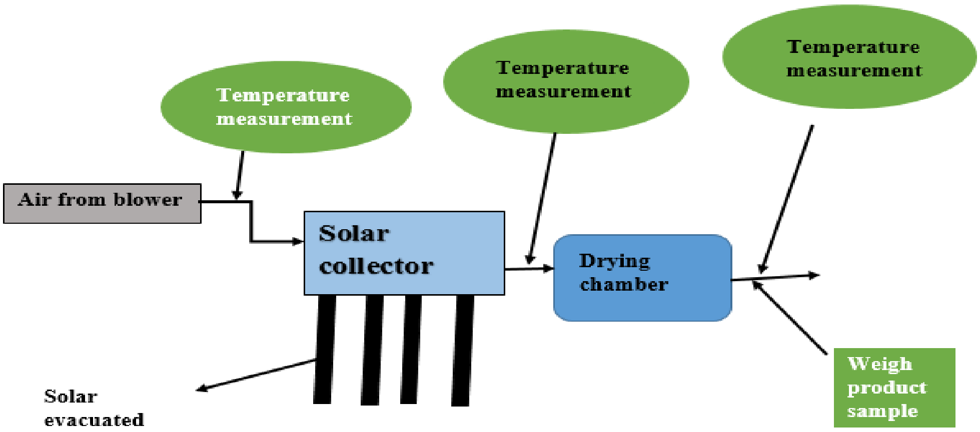


Figure 3.12: Point to measure temperature

Figure 3.12 showed the points at which the testometer was placed to measure both the air and relative humidity of the air:

- Before starting the process of drying: the maize on cob was weighed.

- During the drying process: the temperature was recorded at the inlet of the solar collector, inlet and outlet of the drying chamber.
- After 4 PM the dryer was emptied, the maize on cob was weighed.
- Determination of the moisture loss was done.

Testo 174H machine (Figure 3.13) was used to measure the relative humidity and temperature, its limits are 0-100% RH and 0-70 ^{0}C.

Figure 3.13: Testometer

3.3.1 Testing run for the Fabricated Dryer

The maize on cob was fed at the top of the drying chamber, hot air was then forced up through the product. A blower was placed to pump in air into the solar system, with the positive pressure the heated air was forced into the drying chamber hence penetrating through the product. As the product was being heated moisture moved from the surface of the maize creating pressure difference between the environment air and the crop hence releasing moisture from the product into the surrounding air, the released moisture then flowed out through the outlet. This process continued until equilibrium moisture content was achieved. This is the point where the maize on cob balanced its own characteristic between the moisture content it contained and the moisture vapor in the surrounding air around the grain, at this point the drying process stopped. The moisture removed from the surface of the grain was released into the environment through the chimney at the top of the drying chamber. The drying process started from the bottom of the drying chamber to the top, and when it reached the top of the level of maize on cob then the maize was dry.

Different tests were done from the fabricated dryer including temperature, moisture content and relative humidity.

3.3.2 Drying Parameters Calculation

To achieve appropriate drying some calculations should be done and they include:

Equilibrium relative humidity (ERH %)

ERH % of the moist air at the exit of the drying process was evaluated using sorption isotherms in Equation 13:

$$a = 1 - exp[-exp(0.914 + 0.5639 InM)]$$ **Equation 10**

$$M = \frac{Mf}{(100-Mf)}$$ **Equation 11**

$$ERH = 100a$$ **Equation 12**

Where *a* is the water activity: M (Kg/Kg) dry basis, *Mf* final moisture

Volume flow rate of air is calculated by

$$Va = Wa/Td$$ **Equation 13**

Where: Wa is the quantity of air required to dry, Td is the total drying time

Mass flow rate of air

$$Ma = \rho * Va$$ **Equation 14**

Where: ρ is the density of drying air in Kg/m^3

Average drying rate

Average drying rate is the amount of water removed during drying at a given time.

$$Dr = \frac{mass\ of\ evaporated\ water}{time\ taken\ per\ day}$$ **Equation 15**

Total energy balance equation for drying process

Total energy required for drying given maize on cob is equal to energy for the evaporation of water

$MwLv = MaCp(T1 - T2)$ **Adopted from (Fashina, 2013)** **Equation 16**

Where: *Mw* is the mass of water evaporated from the product Kg, *Lv* latent heat of vaporization. *Ma* is the mass of the drying air Kg, *Cp* is the specific heat capacity of air at constant pressure = 1.005 kJ/kg°C

CHAPTER FOUR: DATA COLLECTION AND ANALYSIS

4.0 Maize Characterization

Maize is Zae mays, a member of the grass family Poaceae. It is a cereal grain and is grown commonly in Kenya especially in Rift Valley, it is a staple food for Kenyans. Maize is a leafy stalk whose kernels have seeds inside. In order to perform drying some conditions had to be undertaken regarding the design calculation and sizing of the dryer. The Table 4.1 gives the summary of the geographical location of the drier, the quantity of maize on cob to be dried per batch, type of crop to be dried, characteristics of the maize on cob to be dried etc.

Table 4.1*: Maize Specification*

Item	**Assumption and Condition**
Location of drying	Oasis, Uasin Gishu county
Location obtain the maize on cob	Nandi county
Crop	Maize on cob
Crop porosity,	0.60
Drying batch, (kg/batch)	7
Initial moisture content, (mi (%) w.b)	25.7
Final moisture content, (m_f (%) w.b)	13.4
Average ambient air temperature, t_{am}(^{0}C)	23.7
Minimum and Maximum allowable temperature	0-60^{0}C
Average wind speed, w_s(m/s)	0.5
Collector tilt angle, (^{0}) (Tonui, 2014)	15
Drying time each day, t_d(hrs.)	6

From Table 4.1, a 7 kg of maize on cob was obtained from Nandi County. The dryer was designed, fabricated and used to dry the maize grain in Uasin Gishu County whose average ambient temperature was 23.7^{0}C and relative humidity of 56.3%, drying was done 6 hours for 2 days. The void fraction of the bed porosity is 0.6 which was less than one to mean (fraction of the volume of void over total volume of the maize on cob) there was more space in the drying chamber to allow smooth flow of the hot air. The initial moisture content of the maize on cob was 25.7% w.b which was within the range of 25-40% of moisture content for matured maize (Owolade, 2005), and the final moisture content was 13.4% which was below 13.5% as required by KEBS. The safe drying temperature of drying maize on cob should be 60 ^{0}C and below.

4.1 Design of the Maize on Cob Dryer

Designing of the maize on cob dryer is an important factor, it involved determination of the shape and sizing of the dryer.

4.1.1 Choices of Shape and Size

The shape of the dryer determined the flow of hot air through maize on cob without creating dead pockets which may allow condensation of the moist air, falling down into the dried grain causing wetness.

4.1.1.1 Designing and Simulation of Air Flow through Rectangle or any Angled Walls

Turbulent air flow Rectangle shaped, trapezoids shaped or any design with angles at the walls of the design were studied using solid work software. Using the solid work software, a rectangular shaped design of dimensions of 1 by 1 by 5 meters, was drawn. These measurements were considered due to cost implications during fabrications and conservation of computer simulation memory, if the dimensions were large then the simulation would take long to run, then a simulation of air flow was performed for both the rectangular and circular shaped. Figure 4.1 and 4.2 shows the turbulent flow of air, through a rectangular drawn design, it showed formation of dead pocket regions at the angle corners which would lead to uneven drying and deposition of moisture or vapours, hence failing on the maize at those points causing them to rot. Also, it is observed that the path line of air velocity increased from the inlet to the outlet because the diameter of the outlet was smaller. Hence the appropriate blow velocity for the air was between 1.7 - 2.4 m/s.

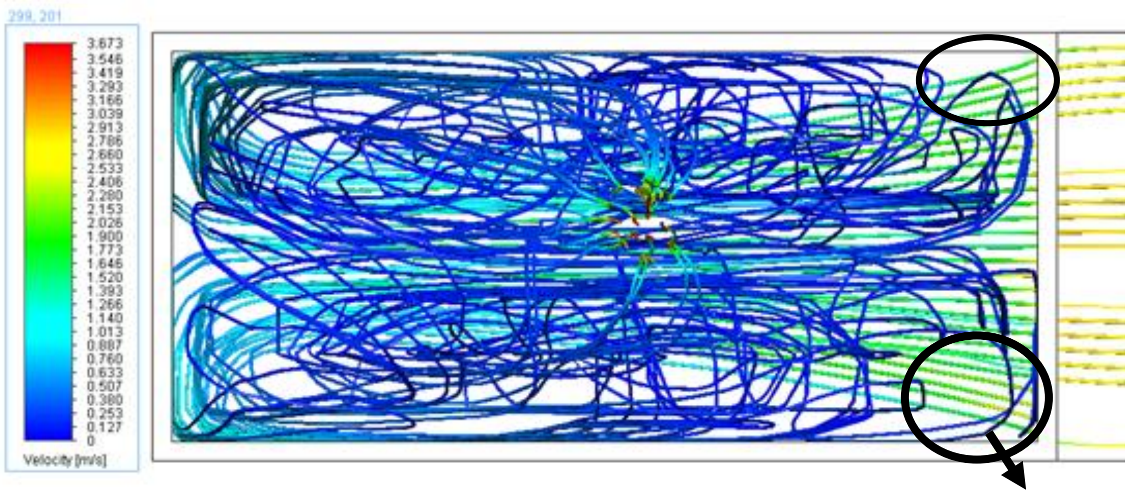


Figure 4.1*: Turbulent flow from the view near the inlet*

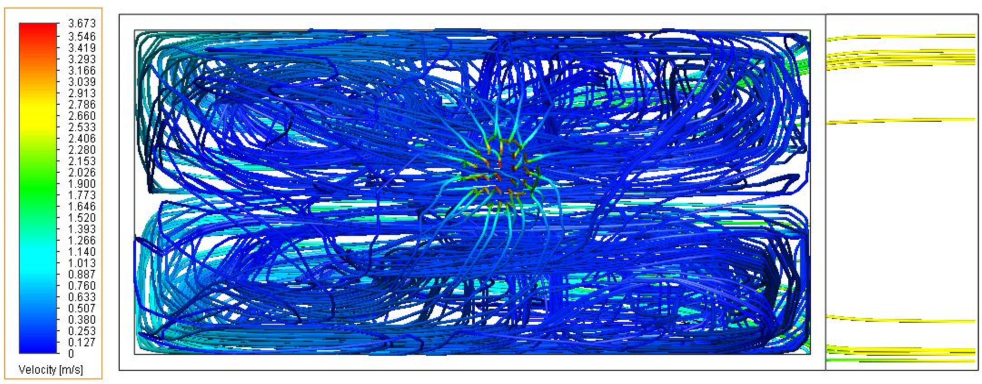


Figure 4.2*: Turbulent flow from the outlet view of the whole system*

4.1.1.2 Designing and Simulation of Air Flow through Circular Shapes

A circular dryer of 1 meter diameter, 1.5 meter height and from fluid dynamics of design principle, to achieve a streamline flow of the system the length of the inlet duct should be 4 times the diameter inlet to allow the air to flow streamline as shown in figure 4.3, was drawn using solid work software, an air flow simulation of the drawn dryer was performed.

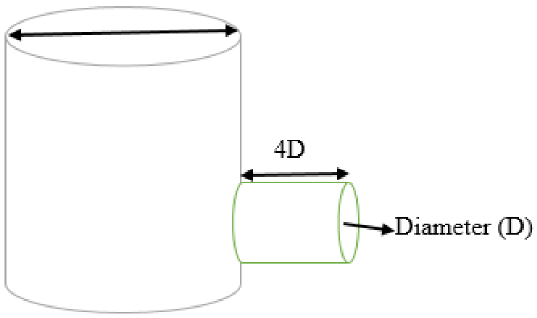


Figure 4.3*: Drawing of proposed circular dryer*

Figure 4.4, and 4.5, shows the path lines of air velocity, as the air enters the inlet it flows in and distributes all through the circular design to the outlet with an even flow of air. Hence the appropriate blow velocity for the air was between 2.1 - 2.4 m/s.

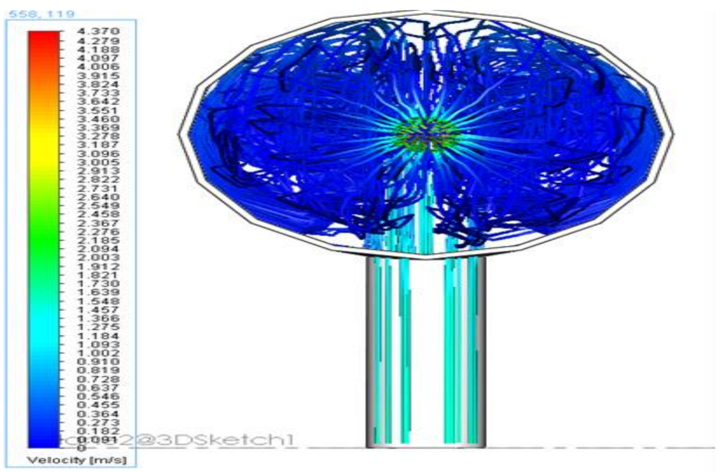


Figure 4.4*: Turbulent flow from the out face of the whole system*

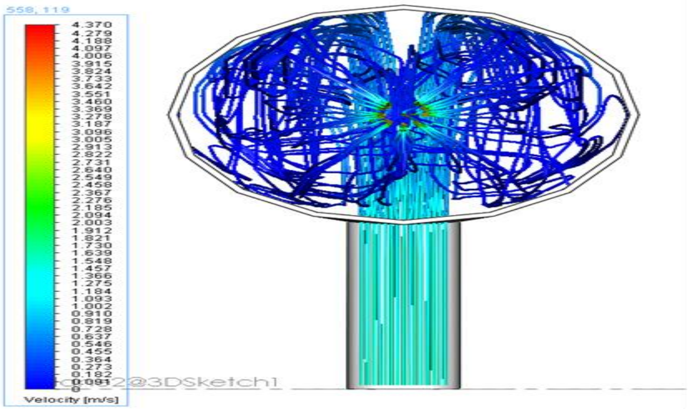


Figure 4.5*: Turbulent flow of the outlet on half of the system*

Figures 4.4 and 4.5 above showed streamline flow of airflow, with less pockets of dead region, hence considered a circular shape design for the drying process.

4.1.2 The Proposed Design of the Circular Dryer

A proposed circular dryer was drawn as shown in Figure 4.6.

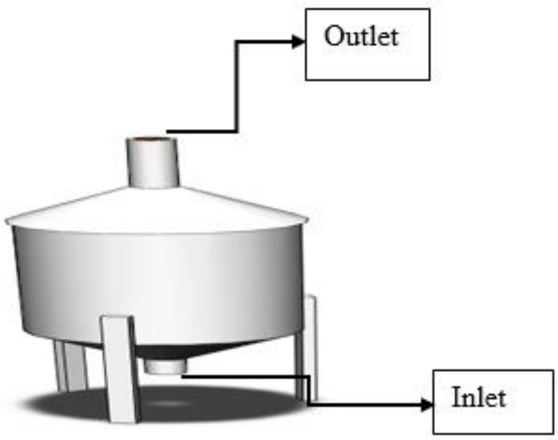


Figure 4.6*: Diagram of the circular shaped proposed design*

Figure 4.6 has an inlet which was connected to the solar system, it has a drying chamber which is circular in shape due to the results obtained from Figure 4.4 which showed a streamline flow of air ensuring evenness of maize on cob drying. At the base of the drying chamber, wire mesh was placed above the perforated plate. This wire mesh prevented grains that had fallen from the cobs from entering the inlet, which were likely to cause blockage of hot air from the solar system into the drying chamber, and the perforated plate would allow the hot air into the drying chamber as shown in Figure 4.7.

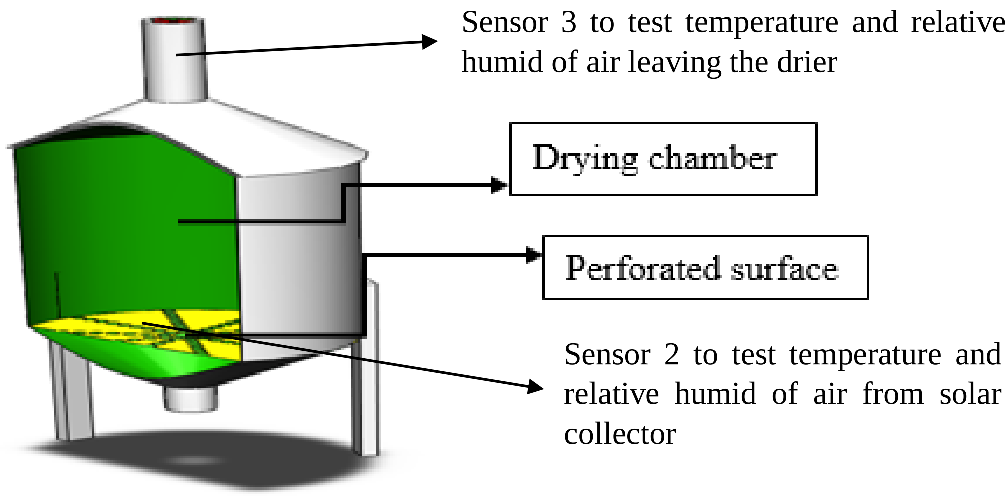


Figure 4.7*:* Section of the proposed design

During loading, the maize on cob was fed into the drying chamber, and the inlet was closed. The blower connected to the solar system power to blow in hot air. From the solar system it entered the drying chamber, as shown in Figure 4.6. Sensors were placed at strategic positions as in Figure 3:1, sensor 1 was near the bower to measure the surrounding temperature and relative humidity, sensor 2 and 3 was places as shown in figure 4.7, after drying the outlet gate was opened and the maize was unloaded.

In the process of drying, constant and falling rate period occurred. Where, at the entry of hot air into the chamber to the maize on cob, constant rate period occurred, this is because water was evaporated from the surcease of the maize grain into outer side and the temperature of the product was constant. At the final stage, falling rate period occurred, this is because the maize cob temperature was increasing, water moisture was moving from interior of the maize to the surface for evaporation

4.2 Fabricated Dryer

Table 4.2 represents the calculated result of the relevant design parameter of the fabricated solar dryer

Table 4.1: Evaluation of the Design Parameters

Parameters	**Results**	**Equations**
Bulk density	148.5466 Kg/m^3	Equation 2
Moisture content removed	47.86 %	Equation 4
Mass of water evaporated	2.84 Kg	Equation 5
Equilibrium relative humidity	63.54 %	Equation 12
Quantity of air needed to drying	170.47 m^3	Equation 8
Volume flow rate of air	17.40 m^3/hr	Equation 13
Mass flow rate of air	21.31 kg/hr	Equation 14
Quantity of heat required to dry	67.48 MJ	Equation 6
Average drying rate	0.47 Kg/hr	Equation 15
Initial humidity ratio	0.012 Kg/Kg	Psychometric chart
Final humidity ratio	0.0256 Kg/Kg	Psychometric chart
Initial enthalpy	55 KJ/Kg	Psychometric chart
Final enthalpy	88.5 KJ/Kg	Psychometric chart

When designing the dryer, it was built depending on the quantity of air required for drying, the amount of moisture to be removed, the volume of air to achieve drying, the actual amount of heat used in drying, rate of drying and thermal efficiency. The dryer operated on the average ambient temperature t1 of 23.7 ^{0}C. The initial humidity ratio was determined to be 0.012 Kg/Kg dry air which was obtained from the psychometric chart under normal temperature. The mass of moisture to be removed was 2.87Kg. For effective drying, 170.47 m^3 volume of air was needed, which was obtained from Equation 10, h1 was obtained using the ambient temperature t1, which was 0.012 Kg/Kg and h2 was obtained using final temperature t2, which was 0.0256 Kg/Kg from the psychometric chart under normal temperature. The quantity of heat required to dry the maize on cob was 67.48 MJ. The actual amount of heat used was 84.799KJ.

4.2.1 Temperature and Humidity against Time

Below graph show the drying trends:

a) Before Loading

Figure 4.8, shows the relationship between temperature and relative humidity against time when the drying chamber is empty. From Figure 4.8, t1 and h1 is the temperature and relative humidity of the ambient air, the ambient temperature t1 is lower with an average of 23.8 ^{0}C, and relative humidity has a high average of 55.3%, as the air passes through the solar system the temperature of air t2 is increased to an average temperature of 46.7 ^{0}C, and relative humidity h2 decreases to 45.3%. This is because as the temperature increases, moisture in the air is converted to vapor gas hence it decreases in the amount of water in the air. As the air from the solar system is passed through the drying chamber, the temperature is lowered further to an average temperature of 45.5 ^{0}C. This is because the heat is lost into the air, some of it is absorbed by the walls of the chamber, and the humidity is lowered to an average of 42.1%.

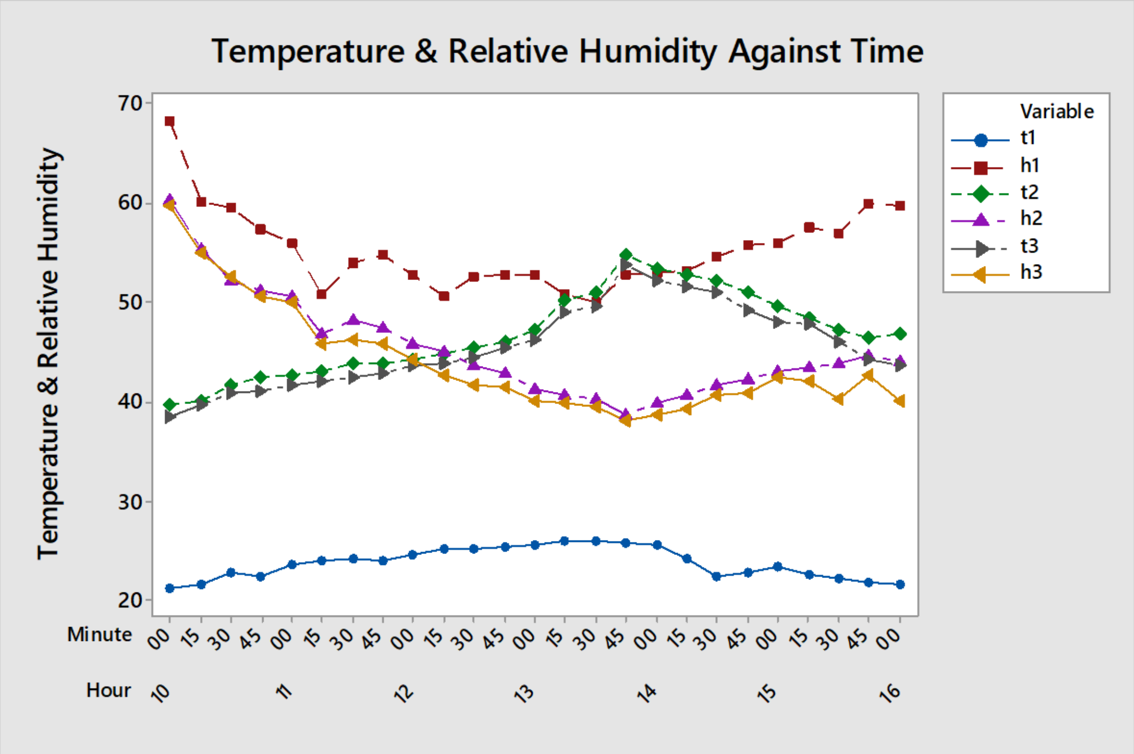


Figure 4.1*:* Temperature, relative humidity against time before loading

b) After Loading

Figure 4.9 shows the relationship between temperature and humidity against time when the drying chamber is loaded. The ambient temperature t1 is low with an average of 23.3 ^{0}C, and h1 is 55.9%.

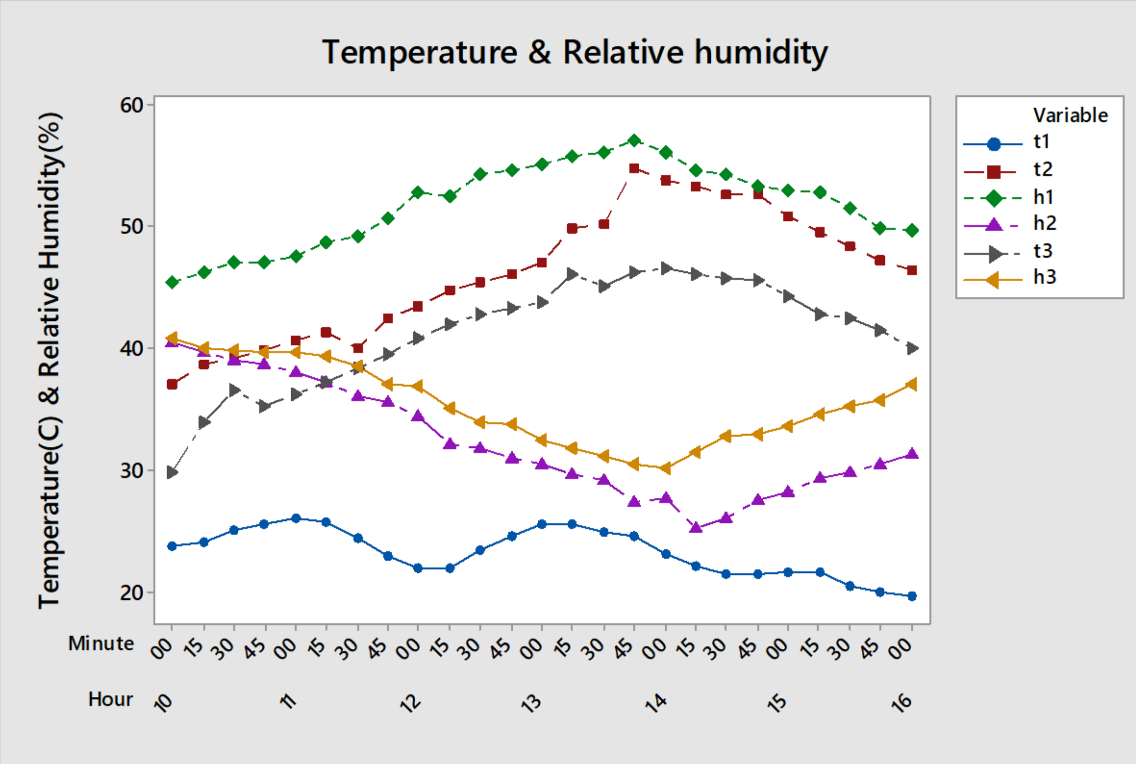


Figure 4.2*: Temperature, relative humidity against time before loading*

As the air is being heated up in the solar system, t2 increases to an average of 44.8 ^{0}C and h2 to an average of 30.7%, this may vary due to factors such as solar intensity variations and since the dryer is loaded, the air passes through the maize on cob, after which t3 decreases to an average of 41.3^{0}C. This is because the hot air was adsorbed by the maize and it experienced friction as it passed through the product hence loss of heat, and h3 increased by an average of 32.7%, this is because the air was able to carry the moisture that was both released by the maize on cob and some moisture in the drying chamber.

4.2.2 Temperature Variation

a. Before Loading

The temperature of the drying system was measured at different points, at the inlet of the solar system, inlet of the drying chamber and outlet of the drying chamber.

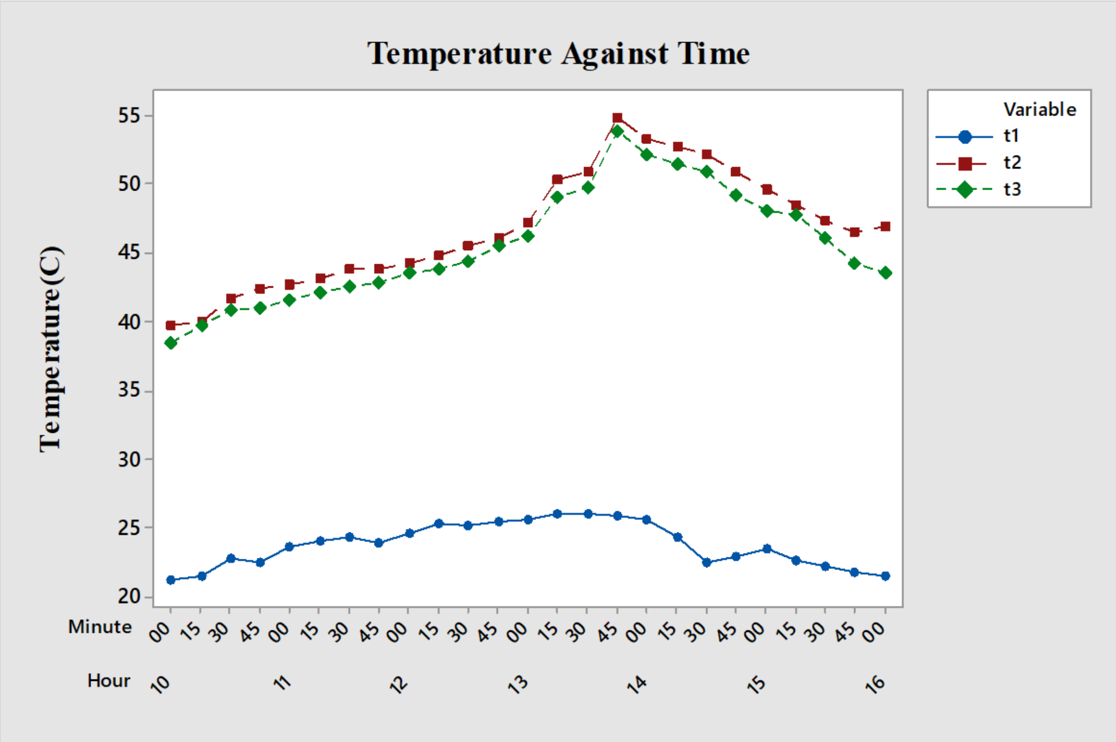


Figure 4.3: Variation of temperature before loading

Figure 4.10, shows the variation of temperature during drying before loading of maize on the cob, and is represented by t1, t2 and t3 (where t1 is the ambient temperature, t2 is the temperature at inlet of the dryer, t3 is temperature at the outlet of the dryer). The temperature increases with time up to 1300 hours, after which it starts decreasing. The temperature of the ambient air is increased from 26.1 ^{0}C to 50.9 ^{0}C, at 1300 hours, this because the sun is at its peak. The heated air as it flows through the empty chamber, temperature decreases due to loss of heat (friction of air and absorption of moisture in the drying chamber) with an average difference of 1.19 ^{0}C.

b) On Loading

Figure 4.11 shows the temperature variation when the dryer is loaded with maize on cob, 7 kg during sunshine, from the 1000hrs to 1600hrs, in the month of July. The ambient temperature of the air is generally low with an average of 23.6 ^{0}C. As the air passes through the solar system there is an average increase in temperature with an average difference of 21.02 ^{0}C, and the moisture content was reduced from 25.7% to 13.4% in the two days each six hours per day.

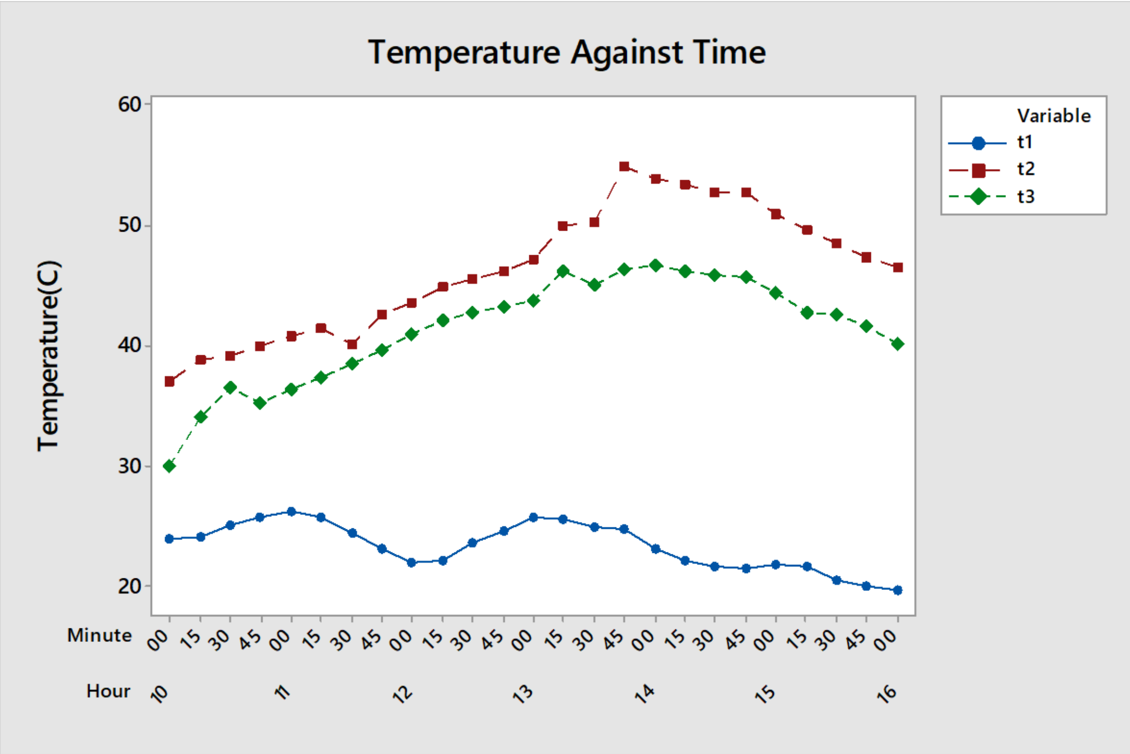


Figure 4.4: Temperature against time after loading

The difference of the inlet and outlet temperature of the dryer chamber was 2.56 ^{0}C and the highest temperature at the inlet of the dryer was 56.7 ^{0}C, and the outlet was 51.2 ^{0}C at midday.

If compared the difference of the inlet and outlet temperature before and after loading at the drying chamber, after loading of 2.56 ^{0}C the difference is higher than before loading of 1.19 ^{0}C, this is because moisture released by the maize on cob is carried away by the air. And the outlet temperatures are still high with an average of 41.3 ^{0}C meaning that more heat was lost in the atmosphere, which could have been used to dry more maize on cob, this maybe because the dryer was less packaged.

4.2.3 Relative Humidity Variation

a) Before Loading

Relative humidity of the dying system was measured when the solar system was operating and the drying chamber was empty giving results of h1, h2, h3 (where h1 is the ambient relative humidity, h2 is the inlet relative humidity of air entering the drying chamber, h3 is the relative humidity of the outlet air from the drying chamber) as shown in Figure 4.12.

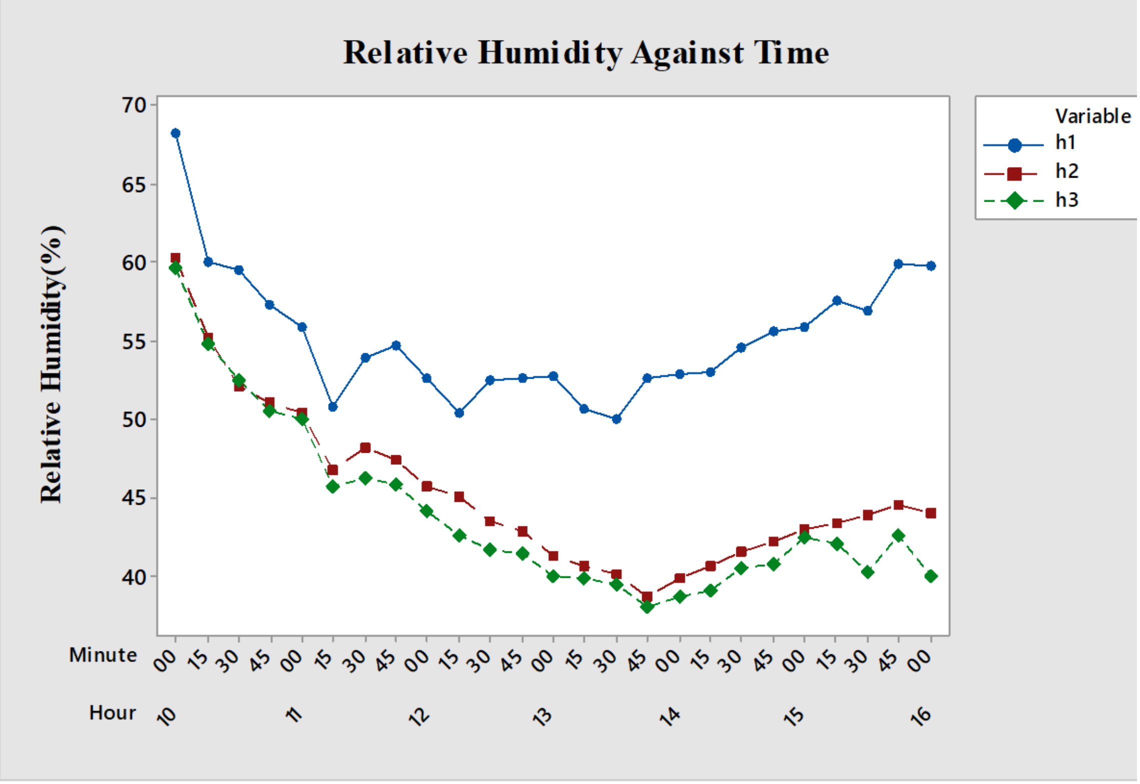


Figure 4.5: Relative humidity variation before loading

Relative humidity increases with time, h1 was high, representing the general moisture from the environment and after the air is heated the amount of moisture in the air is decreased. As the air rose up the chamber it increased. This is because the air carried away the moisture in the drying chamber.

b) After Loading

Figure 4.13 shows the variation of humidity after loading. After loading the drying chamber with the maize on cob, the humidity of inlet air at the solar system increased with time, from 1345 hours it started decreasing. This was due to the change in ambient temperature. The humidity of the outlet air from the drying chamber was higher than of the inlet air in the dryer chamber. This is because as the air passed through the wet maize it carried away some moisture, leading to drying of the maize on cob.

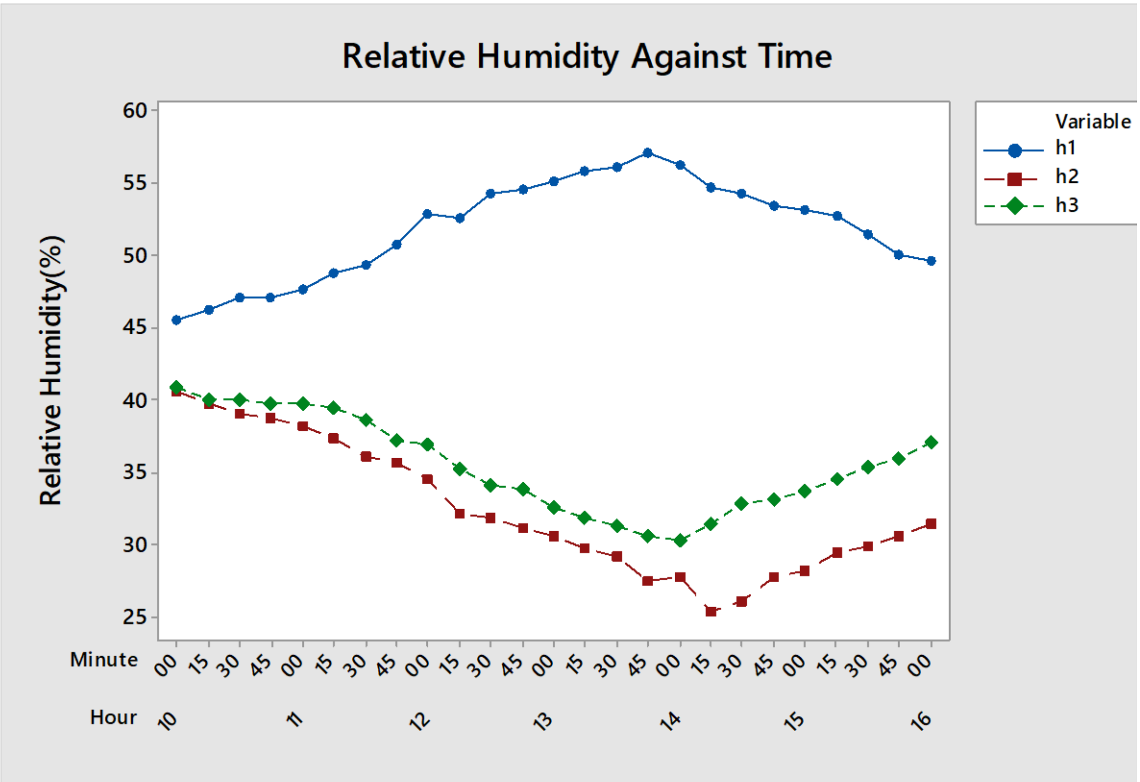


Figure 4.6 Humidity against time after loading

4.2.4 Temperature and Relative Humidity Variation

a. Before Loading

Figure 4.14 showed the relationship between temperature (^{0}C) and humidity (%). Temperature was inversely proportional to humidity, as temperature increased the relative humidity of air increased, as also observed by (Ahmad., 2011).

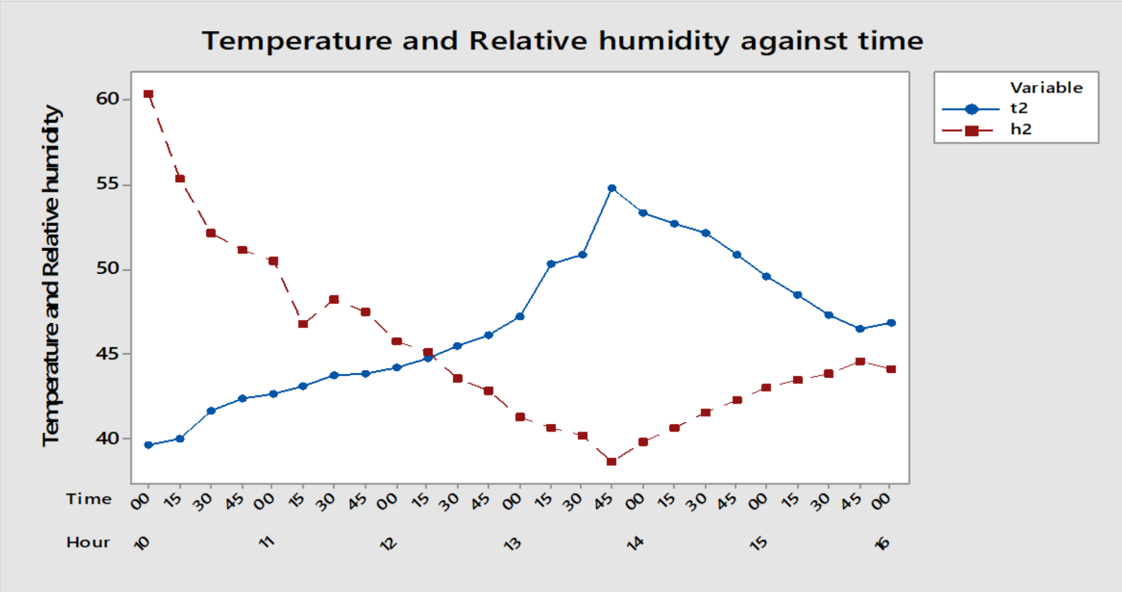


Figure 4.7: Relationship between temperature and humidity before loading

b. After Loading

Figure 4.15 shows the relationship between temperature and humidity after loading. As temperature increased, from 37.5 ^{0}C to 56.5 ^{0}C, humidity decreased from 50.8% to 42.1%, this is because the air was being heated up at the solar system. From mid-day the temperature decreased from 56.5 ^{0}C to 43.6 ^{0}C and humidity increased from 42.1% to 45.5 %, this is because the air contained the moisture that was lost into the atmosphere by the maize on cob.

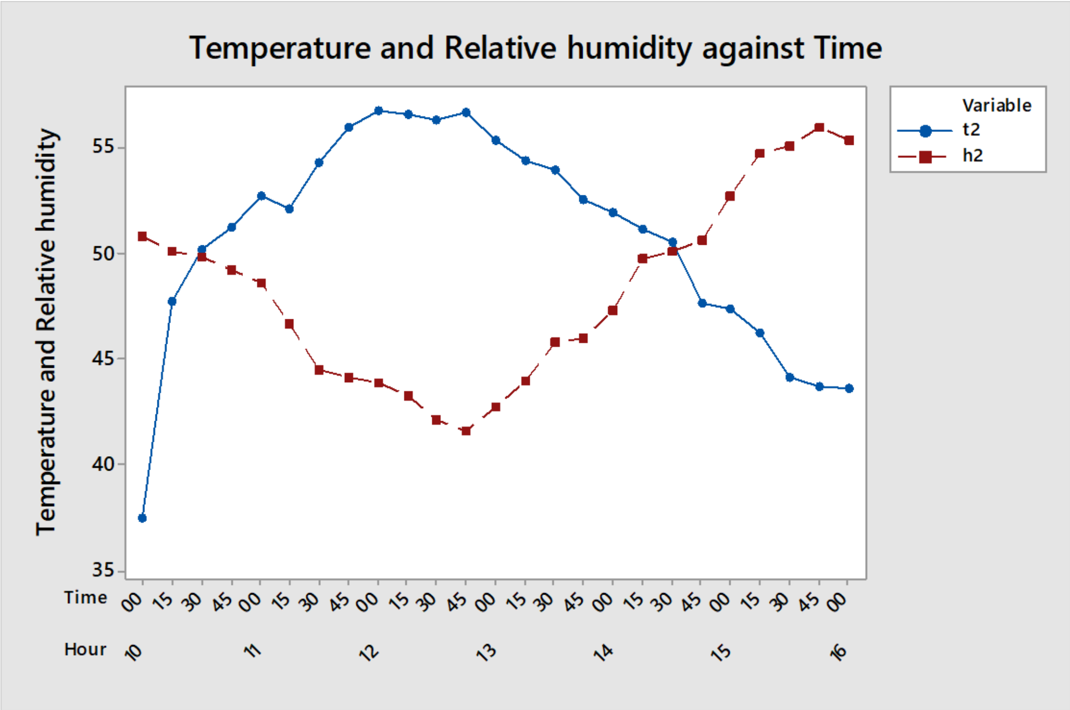


Figure 4.8: Relationship between temperature and humidity after loading

4.2.5 Moisture Content Variation

The purpose of drying the maize on cob was to reduce the moisture content to increase the shelf life of the product. Table 4.3 shows the amount of moisture that reduced each day.

Table 4.2: Moisture Content Lost

Day	Time (Hrs)	Mass (kg)	Moisture content %
Day 1	1000	7.0	25.7
	1600	5.3	18.5
Day 2	1000	5.5	19.1
	1600	3.6	13.4

The maize on cob had an initial moisture content of 25.7% wet basis and reduced to 13.4% using solar system. Its mass was reduced from 7.0 kg to 3.6 kg in two days for six hours each day in the month of July, the ambient temperature of the environment was of an average of 23.7 ^{0}C and average relative humidity of 55.6% since it was the sunny season.

Continuous drying of the grain for the two consecutive days reduced the moisture content by 47.8%, and both the grain and the cob where dried, it was shown that at the second day the moisture content loss was at a difference of 5.7%; this is because it required a lot of energy to remove bound water from the grain. The average drying rate was 0.805 Kg/hr (Equation 16) to remove a mass of 2.84 Kg of water (Equation 5).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

A circular shaped dryer was considered due to fact that there were fewer void pockets, as it was achieved by use of SolidWorks Software. The maize on cob was characterized. A solar dryer was then fabricated using readily available material. It consisted of a solar collector (solar evacuated tube whose absorbing area of 2.21m^2 per tube), a dryer chamber made of readily available and cheap material (mild steel plate) and a blower of an average speed of 2.4 m/s. The dryer was used to dry 7 kg of maize on cob from a moisture content of 25.7 % to 13.4% in 2 days each six hours per day. From the fabricated dryer through testing, it has shown that maize can be dried using solar evacuated tubes (solar collector) which is faster than the traditional ways of drying such as sun drying, maintaining the quality of the grain after harvest by reducing the damage caused by insects, rodents and birds. This will encourage early harvest of maize and reduction of growth of fungi such as mycotoxin which are harmful when consumed by man and animals.

5.2 Recommendations

The inference of this research project has culminated in recommending the following for future research: -

i. Improvement of the dryer performance can be done by performing some modification on the solar collector (use of both opened ends of the solar evacuated tubes).
ii. More performance test should be done on the dryer system in the rainy season in Eldoret or on other agro-ecological zones
iii. Consider the heat loss through the drier and the size of the maize grain for accuracy.

REFERENCES

Adamade., C. O. (2014). Development And Performance Evaluation Of A Dryer For Locust Bean Condiments. *Condiments. Proceedings Of The 15th International Confrence*. Nigeria: 35th Annual General Meeting Of The Nigerian Institution Of Agricultural Engineers.

Adebayo, B. A., Ndunguru, G., Mamiro, P., Alenkhe, B., Mlingi, N., & Bekunda, M. (2014). Post-Harvest Food Losses In A Maize-Based Farming System Of Semi-Arid Savannah Area Of Tanzania. *Journal Of Stored Products Research 57*, 49-57.

Adekanye., T. A. (2016). Development Of A Maize-On-Cob Dryer For Small Scale Farmers. *Scientia Agriculturae*, 172-178.

Adu., E. A. (2012). Design, Construction And Performance Evaluation Of A Solar Agricultural Drying Tent. *International Journal Of Engineering Research & Technology (IJERT) Vol. 1*.

Aflastop. (2015). Retrieved From Storage And Drying For Aflatoxin Prevention: Http://Www.Merid.Org/Content/Projects/Aflastop_Storage_And_Drying_For _Aflatoxin_Prevention.Aspx

Aghbashlo, M. K. (2011). Modelling The Carrot Thin-Layer Drying In A Semin-Industrial Continuous Band Dryer. *Czech Journal Of Food Science*, 528-538.

Ahmad., F. M. (2011). The Effects Of Drying Air Temperature And Humidity On The Drying Kinetics Of Seaweed. *Research Gate*, 129-133.

Ahmet., D. U. (2013). Modeling Of A Hot Air Drying Process By Using Artificial Neutral Network Method . *Termothehnica*, 51-57.

Ajay, C. S. (2009). Design Of Solar Dryer With Turboventilatir And Fireplace. Deopur, India: Suman Foundation.

Ajisegiri., E. A. (2006). Development Of Artificial Dryer For Yam Chips. *Proceedings Of The 7th International Conference* (P. 348). ABU,Zaria: 28th Annual General Meeting Of The Nigerian Institution Of Agricul-Tural Engineers.

Akinola, A. A. (2006). Exergetic Nalysis Of A Mixed-Mode Solar Dryer. *J. Engin. Appl. Sci 1*, 205-210.

Akpinar, E. K. (2010). Energy And Exergy Analysis Of A New Flat-Plate Solar Air Heater Having Different Obstacles On Absorber Plates. *Applied Energy*, 3438-3450.

Alghoul, M. S. (2005). Review Of Material For Solar Thermal Collectors. *Physics Department*, *University Putra* , 199-206.

Alghoul., M. S. (2005). Review Of Material For Solar Thermal Collectors. *Research Gate*, 199-206.

Alibas, I. (2012). Selection Of The Best Suitable Thin-Layer Drying Mathematical Model For Vacuum Dried Red Chili Pepper. Journal Of Biological And Environmental Science. *Journal Of Biologicl And Environmental Science*, 161-170.

Amyot, J. (1983). Social And Economic Aspects Of Dryer Use For Paddy And Other Agricultural Produce In Thailand. *Chulalongkorn University Social Research Institute And International Development Research Center*.

Aregba, A. S. (2006). Stationary Deep Bed Drying: A Comparative Study Between A Logarithmic Mode; And A Non-Equation Model. *Journal Of Food Enginnering 77 (1)*, 27-40.

Bala., B. (2002). Solar Drying Of Pineapples Using Solar Tunnel Drier.

Bennett, J. (1987). Mycotoxins, Mycotoxicoses, Mycotoxicology And Mycopathology. *Mycopathlogia 100*, 3-5.

Blunden, G. R. (1982). Mycotoxins In Food. *Med. Lab. Sci. 48*, 271–282 .

Bulato Jayme, E. A. (1982). A Case- Control Study Of Primary Liver Cancer Risk From Aflatoxin Exposure. *Int. J. Epidem*, 111-112.

Cengel, Y. (2000). *Heat And Mass Tranfer An Engneering Approach.* Mcgraw-Hill.

Cengel, Y. (2006). *Heat And Mass Transfer: A Practical Approach.* Mcgraw-Hill: 3rd Ed.

Champeil., A. F. (2004). Influence Of Crop System On Fusaruim Head Blight And Mycotoxin Levels In Winter Wheat, *Crop Protect. 23*, 531-537

Charles., A. M. (2016). Managing Storage Pest Of Maize: Farmers Knowledge Perception And Practice In Western Kenya. *Crop Protection 90*, 142-149.

Chinenye, N. (2009). Effect Of Drying Temperature And Drying Air Velocity On The Drying Rate And Drying Constant Of Cocoa Bean. *Agriculture Engineering International: The CIGR Ejournal. Vol.XI*, 1091.

Christian., V. A. (2012). Ensuring Technical Product Quality In Energy Efficient Hot Air Drying Of Extruded Fish Feed: Definition Of An Industrial Research Project. *18th International Drying Symposium (IDS 2012) Xiamen, China*, 11-15.

Chua., K. A. (2003). Low-Cost Drying Methods Fr Developing Countries. *Trends In Food Science & Technology 14*, 519-528.

Da Silva, W. S. (2004). LAB Fit Curve Fitting: A Software In Portuguese For Treatment Of Experimental Data. *Revista Brasileira De Ensino De Fi'sica 26*, 419-427.

Dantas, L. M. (2011). Dynamic Software For Simulation Drying Of Seeds And Grains Corn. *Revista Btasileira De Produtos Agroidustriais 13 (3)*, 309-318.

Darabi, H. Z. (2013). Design Of Cbinet Dryer With Two Geometric Configurations Using CDF. *J. Food Sci. Technol. 52 (1)*, 359-366.

Darvishi, H. A. (2013). Drying Characteristics Oof Sardine Fish Dried With Microwave Heating. *Journal Of The Saudi Society Of Agriculture Science 12*, 121-127.

Diamante, L. I. (2010). A New Mathemtical Model For Thin Layer Drying Of Fruit. *International Journal Of Food Science And Technology 45 (9)*, 1956-1962.

Dissa, A. J. (2009). Modelling And Experimental Validation Of Thin Layer Indirect Solar Drying Of Mango Slices. *Renewable Energy 34*, 1000-1008.

Ehiem, J. I. (2009). Design And Development Of An Industrial Fruit And Vegetable Dryer. *Research J. Appl. Sci. Eng Technol. ISSN: 2010-7467 1 (2)*, 44-53.

Fandohan, P. G. (2005). Natural Occurrence Of Fusarium And Subsequent Fumonisin Contamination In Preharvest And Stored Maize In Benin, West Africa. *Int. J. Food Microbiol. 99*, 173–183.

FAO. (2011). Global Food Losses And Food Wastage- Extent Causes And Prevention*.: FAO* Rome, Italy.

FAO. (2018). Retrieved February 13, 2018, From FAO: Http://Www.Fao.Org/Docrep/T1838e/T1838E0W.HTM

FAO., F. A. (2010). Reducing Post-Harvest Losses In Grain Supply Chains In Africa: Lessons Learned And Practical Guidelines. *FAO/ World Bank Bank*, 18-19.

Fashina, A. B. (2013). Design Parameters For A Small- Scale Batch In-Bin Maize Dryer. *Agricultural Sciences*, 90-95.

Folaranmi, J. (2008). Design, Construction And Testing Of A Siple Maize Dryer. *Leornado Electronic Journal Of Practices And Technology*, 122-130.

Green Spec. (2018). Retrieved March 20, 2018, From Green Spec: Http://Www.Greenspec.Co.Uk/Building-Design/Solar-Collectors/

Gulah, C. C. (2009). Design Of A New Solar Dryer System With Swirling Flow For Drying Seeded Grpe. *Int. Commun Heat Mass Transfer 36 (9)*, 984-990.

Hamiton, D. (2000). *Toxic Fungus Threatens Health Of Consumers*. Retrieved From Www.Agnic.Org/Pmp/2000/Ama0826.Htm

Hellevang, D. K. (2013). *Grain Drying*. North Dakota State University, North Dakota: NDSU EXTENSION SERVICE.

Hendrickse., R. G. (1982). Aflatoxins And Kwashiirkor: A Study In Sudanese Choldren. *Br. Med. J*, 843-846.

Hodges, R. J. (2012, July 31). *Post-Harvest Weight Losses Of Cereal Grains In Sub-Saharan Africa*. Retrieved From Http://Www.Erails.Net/FARA/Aphlis/Aphlis/Weightlosses-

Hussein, H. B. (2001). Toxicity, Metabolism, And Impact Of Mycotoxins On Humans And Animals. *Toxicology 167*, 101–134.

IFPRI. (2010, July 1). *Aflatoxins In Kenya: An Overview*. Retrieved From Afla Control Project Note: Http://Programs.Ifpri.Org/Afla/Afla.Asp

Itodo, I. (2007). Agriculture Energy Technology. *Aboki Publishers*, 12-24.

Jacek, S. A. (2010). Improved 3-D Temperature Uniformity In A Laboratory Drying Oven Based On Experimentally Validated CFD Computations. *J. Food Eng, 97*, 373-383.

James, B. (2005.). Public Awareness Of Aflatoxin And Food Quality Control In Benin. *International Institute Of Tropical Agriculture*.

Janjai, S. I. (2012). *Improvement Of The Air Flow And Temperature Distribution In A Convectional Longan Dryer*. Thailand, Roman: Internatiinal Symposium Towards Sustainable Livelihoods & Eosystem In Mountaneous Regions.

Janjai., B. B. (2013). Solar Drying Of Argricultural Products. *An International Journal For Reviews In Postharvest Biology And Technology*, 1945.

Jayas, D. (1988). Thin Layer Drying Of Barley At Low Temperatures. *Canadian Agricultural Engineering*, 21-23.

John, J. (2017, June 14). *University Of Georgia Extension*. Retrieved From UGA. Http://Extension.Uga.Edu/Publications/Detail.Html?Number=B873&Title=Grain%20and%20Soybean%20Drying%20on%20Georgia%20Farms

Joshua, F. (2008). Design, Construction And Testing Of Simple Maize Dryer. *Federal University Of Technology, Leonardo Electronic Journal Of Practices*, 122-130.

Kaleta, A. G. (2010). Evaluation Od Drying Model Apple (Var. Mcintoch) Dried In A Convective Dryer. *International Journal Of Food Science And Technology 45 (5)*, 891-898.

Kalogirou, S. (2004). Solar Thermal Collectors And Applications. *Progress In Energy And Combustion Science.*, 231-295.

Kalogirou., S. A. (2004). Solar Thermal Collectors And Applications. *Progress In Energy And Combustion Science*, 231-295.

Kasiviswanathan., M. S. (2016). Grain Drying Systems. *Research Gate*.

Kiaya, V. (2014). Post Harvest Losses And Strategies To Reduce Them. *ACF International*.

KMDP, (2010). *Agriculture Development & Value Chain Enhancement Project: Tranforming The Agriculture Sector Through Increased Competitiveness.* Kenya: Boost Household Incomes, Raising Productivity.

Korir, K. B. (2012). Mycological Quality Of Maize Flour From Aflatoxin "Hot" Zone Eastern Province-Kenta. *African Journal Of Healt Science*, 143-146.

Kumar, R. J. (2010). Drying Behaviour Of Rapeseed Under Thin Layer Conditions. *Journal Od Food Science And Technology 47 (3)*, 335- 338.

Lanyasunya, T. W. (2005). The Risk Of Mycotoxins Contamination Of Dairy Feed And Milk On Smallholder Dairy Farms In Kenya. *Pak. J. Nutr. 4*, 162–169.

Loewer, J. O. (1994). On- Farm Drying And Storage Systems. *American Societynof Engineers.Pam Devore- Hansen, Acquisitions Books And Journals*.

M Gummert, J. R. (2017, March 7). *Rice Knowledge*. Retrieved From Bank Website: Http://Www.Knowledgebank.Irri.Org

Margaris, D. G. (2006). Dried Product Quality Improvement By Air Flow Manipulation In Tray Dryers. *J.Food Eng. 75*, 542-550.

Mariani, V. L. (2008). Apparent Thermal Diffusivity Estimatio Of The Banana During Drying Using Universe Method. *Journal Of Food Engineering 85 (4)*, 569-579.

Menon, A. A. (1987). *Drying Of Solids: Principles, Classification And Selection Of Dryers.* New York: Marcel Dekker, Inc.

Mestres C, L. (1991). Dry-Milling Property Of Maize. *Cereal Chemistry 68*, 51-56.

Mirzaee, E. R. (2009). Determination Of Moisture Diffusivity And Activation Energy In Drying Of Apricots. *Res. Agr. Eng. 55(3)*, 114-120.

Mohanraj, M. (2008). Drying Of Copra In A Forced Convection Solar Drier.

Mujumbar, A. S. (2004). Research And Develo[Ment In Drying: Recent Trend And Future Prospects. *Drying Technology*, 1-26.

Mujumbar., A. S. (2015). *Handbook Of Industrial Drying.* New York.: CRC Press, Taylor And Francis Group.

Mujumdar., A. S. (2000). Fluidized Bed Drying. In &. S. S. Mujumdar, *Developments In Drying. Vol 1: Food Dehydration* (Pp. 59-111). Bankngkok: Kasetsart University Press.

Müller, J. H. (2006). Drying Of Medicinal Plants. In: Bogers, R.J., Craker,L.E., Lange, D.(Eds.). *Medicinal And Aromatic Plants: Agricultural, Commercial, Ecological, Legal, Pharmacological And Social Aspects. Pringer, Dordrecht*, 237-252.

Munkvold, G. (2003). Cultural And Genetic Approaches To Managing Mycotoxins In Maize. *Ann. Rev. Phytopathol. 41*, 99–116.

Ncube, E. (2017, December 14). *African Farming.* Retrieved July 23, 2018, From African Farming: Https://Www.Africanfarming.Com/Mycotoxins-In-Grains-In-Subsistence-Farming-Systems-A-Threat-To-Food-Safety-And-Food-Security/

Norton, B. (2006). Anatomy Of A Solar Collector: Developments In Materials, Components And Efficiency Improvements In Solar Thermal Collector Systems. *Refocus*, 32-5.

Owolade, E. A. (2005). Effects Of Drying Of Different Varieties Of Maize. *Journal Of Food Technology*, 159-182.

Ozioko, C. (2016). *Drying Equipment.* Drying Equipment.

Parry, M. E. (2009). Climate Change And Hunger:Responding To The Challenge.

Rachaputi, N. W. (2002). Management Practices To Minimise Pre-Harvest Aflatoxin Contamination In Australian Groundnuts. *Austr. J. Exp. Agric. 42*, 595–605.

Radhika, G. B. (2011). Mathematical Model On Thin Layer Of Drying Of Finger Millet (Eluesine Coracana). *Adnvance Journal Of Food Science Technology*, 127-131.

Rayaguru, K. A. (2012). Mathematical Modelling Of Thin Layer Drying Kinetics Of Stone Apple Slices. International Food Research Journal . *International Food Research Journal 19(4)*, 1503-1510.

Roman, F. S. (2012). Improvement Of Air Air Distribtion In A Fixed-Bed Dryer Using Computational Fluid Dynamics. *Bio Syst. Eng. 112*, 359-369.

Rwanda Rural Rehabilitation Initiative. (2018). Retrieved February 26, 2018, From RWARRI: Https://Rwarri.Com/Why-The-Landscaper-Is-The-Best-For-Business/

Sammy, S. (2018, June 05). *Division Of Agriculture*. Retrieved From Agriculture And Natural Resource: Https://Www.Uaex.Edu/Publications/PDF/FSA-1072.Pdf

Sawant., A. P. (2014). Effect Of Temperature, Relative Humidity And Moisture Content On Germination Percentage Of Wheat Stored In Different Storage Structures. *Dapoli Dist: Ratnagiri-*, 415-712.

Senadeera., W. I. (2007). Performance Evaluation Of An Affordable Solar Dryer For Drying Of Crops.

Shepherd, A. (1999). *A Guide To Maize Marketing For Extension Officer*. Rome,Italy: Food And Agriculture Organisation Of United Ntion.

Silva, W. S. (2012). Empirical And Diffusion Model To Describe Water Transport Into Chickpea (Cicer Arietinum L.). *International Journal Of Food Science And Technology*, Http://Dx.Doi.Org/10.1111/J.1365-2621.

Singh, R. P. (2009). Introduction To Food Engineering. *Elsevier*, *Academic Press*.

Smith, E. K. (1992). Toxicological Evaluation Of Aflatoxin And Cyclopiazonic Acid In Broiler Chickens. *Poult. Sci. 71*, 1136–1144 .

Sogut, Z. I. (2010). Energetic And Exergetic Performance Evluation Of The Quadruplet-Effect Evaporator Unit In Tomato Paste Production. *Energy 35 (9)*, 3821-3826.

Stathers, T. L. (2013). Post-Harvest Agriculture In Changingnclimates: Its Importance To African Smallholder Farmers. *Food Security 5*, 361-392.

Strahl-Scheafer, V. H. (2012). Improvement Of Air Distribution In A Fixed-Bed Drye Using Computational Fluid Dynamics. *Biosyst. Eng. 112*, 359-369.

Swamy Gabriela John, S. P. (2016). Moisture Dpendent Physical Properties Of Maize Kernels. *International Food Research Journal*, 109-115.

Syahrul, S. H. (2002). Thermal Analysis In Fluidized Bed Drying Of Moist Prticles. *Appl. Therm. Eng. 22 (15)*, 1763-1775.

Tefera T, K. F. (2011). The Metal Silo: An Effective Grain Storage Technology For Reducing Post-Harvest Insect And Pathogen Losses In Maize While Improving Smallholders Farmers Food Security In Developing Countries. *Crop Prot 30*, 240-245.

Tefera, T., Stephen, M., Yoseph, B., Haron, K., & Regina, T. (2011). Grain Yield, Stem Borer And Disease Resistance Of New Maize Hybrids In Kenya. *Afr. J. Biotechnol. 10*, 4777-4783.

Tefera., T. (2012). Post-Harvest Losses In African Maize In The Face Of Increasing Food Shortage. *Food Sec 4*, 267-277.

The World Bank, N. A. (2011). *Missing Food: The Case Study Of Post Harvest Grain Loss In Subsahara Africa.* World Bank, Washington, DC: Report No. 60371-AFR.

Thirugnanasambandham, K. S. (2016). Enhancement Of Shelf Life Of Coriandrum Sativum Leaves Using Vacuum Drying Process: Modeling And Optimization. *Journal Of The Saudi Society Of Agriculture Science*, 195-201.

Tippayawong, N. T. (2009). Energy Conservation In Drying Of Peeled Longan By Forced Convection And Hot Air Recirculation. *Biosyst. Eng. 104*, 199-204.

Tonui, K. S. (2014). *Design And Evaluation Of Solar Maie Grain Dryer With A Back Up Heater.* Nairobi: Univerity Of Naitobi.

TSGC. (2018, May 16). *Tri-State Grain Condition, Inc*. Retrieved From Is Grain Moisture Content Throwing A Wet Blanket On Our Profit?: Https://Www.Tsgcinc.Com/News/Grain-Moisture-Content-Affects-Profits

Turner, P. M. (2003). Modification Of Immune Function Through Exposure To Dietary Aflatoxin In Gambian Children. . *Environ. Health Perspect. 111*, 217–220.

Tzempelikos, D. V. (2012). Anlysis Of Air Velocity Distribution In A Laboratory Natch-Type Tral Air Dryer By Computational Fluid Dynamics. *Int, J. Math. Comput. Simulat. Issue 6 (5)*.

Unit., R. S. (1984). *The Improved Maize Crie: A Guide To Small Farm Grain Storage*. Nakuru: Ministry Of Agriculture.

Vidya., S. R. (2013). Design And Fabrication Of Efficient Solar Dryer. *Int.Journal Of Engineering Research And Application*, 1445-1458.

Wagacha, J. M. (2008). Mycotoxin Problem In Africa: Current Status, Implications To Food Safety And Health And Possible Management Strategies. *Int. J. Food Microbiol. 124,* , 1–12.

Wang, Y. X. (2005). Drying Characteristics And Drying Quality Of Carrot Using A Two-Stage Microwave Process. *Journal Of Food Engineering*, 505-511.

Wannapakhe., S. C. (2011). Hot Air Dryer With Closed-Loop Oscillating Heat Pipa With Check For Reducing Energy In Drying Process. *I-SEEC*, 77-82.

Watson, S. A. (1984). Toxicol. *Fundam Appl*.

Weawsak, J. C. (2006). A Mathematical Modeling Study Of Hot Air Drying For Some Agricultural Products. *Trmmasat International Journal Of Science And Techonology,11(1)*, 14-20.

Wikipidia. (2010, October 27). *Wikipidia*. Retrieved From Simulation Modelling: Http://En.Wikipedia.Org/Wiki/Simultation_Modelling

Wilhelm, L. R. (2005). *Drying And Dehydration*. Michigan: American Society Of Agriculture Engineers.

Wilhelm, L. R. (2016). *Drying Equipment*. Drying Equipments.

World Bank, F. N. (2011). *Missing Food: The Case Of Post Harvest Grain Losses In Sub- Sahara Africa*. Washington, DC: Economic Sector Work.

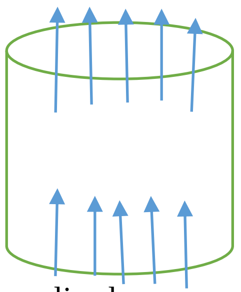
Yashwant., K. S. (2015, May 21). *Fluidized Bed Drying Of Fruits And Vegetables*. Semantics Scholar. Retrieved From Semantics Scholar: Https://Www.Semanticscholar.Org/

Yui., H. L. (2006). Simulitude Criteria For Two-Dimention Wall Jet In An Isothermal Mechanically Ventilated Enclosure. *Biosystems Engineering Journal 93 (4)*, 1-11.

Zulovich, J. (2013). *Active Solar Collectors For Farm*. Retrieved From Http://Muextension.Missouri.Edu/

APPENDIX

Appendix A: Fluidizes Bed Flow



Generalized energy equation

$$\frac{\Delta p}{\rho} + \Delta\left(\frac{u^2}{2}\right) + g\Delta z + f + w = 0$$

Analysing the system yield

$\Delta\left(\frac{u^2}{2}\right) = 0$; Entering fluid leaves the column at the same speed

$w = 0$; No work done by or on the fluid

$g\Delta z = gL$; Change in elevation (Z outlet - Z inlet) equals the total length of the column

Substituting yield

$$\frac{\Delta p}{\rho} + gL = -f$$

Flow in the pipe:

$$f = 2(fF)(uM)^2\frac{L}{D}$$

Assumption made:

1) For a horizontal bed or small L, gravity effect can be neglected
2) Particles pack uniformly in a sack resulting with continuous flow channels
3) bed can be modelled as a bundle of the pipes

4) flow is laminar (i.e., $fF = \frac{16}{Re}$

Combining both the assumption and above two equations to give

$$-\frac{\Delta p}{\rho} = 2\left(\frac{16}{Re}\right)\left(\frac{L}{D}\right)um^2 = 2\left(\frac{16\mu}{\rho fUmD}\right)\left(\frac{L}{D}\right)um^2 = \frac{32\mu Lum}{\rho fD^2}$$

Determination of actual velocity and actual diameter to be used

Velocity

$$um = \frac{Q}{Ae} = \frac{Q}{\varepsilon A} = \frac{volumetric\ flow\ rate\ through\ the\ bed}{cross\ sectional\ area\ of\ empty\ space}$$

Where ε is the void fraction defined as

$$\varepsilon = \frac{empty\ volume}{total\ voume(empty\ volume + solids\ volumes} = \frac{ve}{vt} = \frac{ve}{ve + vs}$$

And,

$$um = \frac{Q}{A} = superficial\ velocity$$

Substituting the yields:

$$um = \frac{u\infty}{\varepsilon}$$

and hydraulic radius is defined as:

$$Dh = \frac{4cross\ sectionsl\ area\ for\ flow}{wetted\ perimeter}$$

Multiply L/L, gives:

$$Dh = \frac{4fluid\ volume\ (vs)}{wetted\ surface\ area}$$

$$ve = \varepsilon vT = \varepsilon(ve + vs)$$

Solving yields

$$ve = \frac{\varepsilon}{1-\ \varepsilon} vs$$

Where v_s =$\# \ of \ particles * vp = Np * \frac{\pi}{6} Dp^3$

Wetted surface area= total solids surface area= $Np * \pi Dp^2$

Substituting above for D_h, gives;

$$\text{Dh} = \frac{4 * \frac{\varepsilon}{1-\varepsilon} Np * \frac{\pi}{6} Dp^3}{Np * \pi Dp^2}$$

$$Dh = \frac{4\varepsilon Dp}{6(1-\varepsilon)}$$

Finally substituting above for the pressure drop, yield:

$$\Delta p = \frac{72\mu Lu\infty(1-\varepsilon)\hat{}2}{Dp^2\varepsilon^3}$$

The real situation is that the flows in the tortuous path (not straight as was initially assumed), and bed length can really be ignored, therefore, experimental result has consistently resulted with data suggesting replacing the constant 72 by 150;

$$\Delta p = \frac{150\mu Lu\infty(1-\varepsilon)\hat{}2}{D^2\varepsilon^3}$$

This equation is known as Blaze-Kozeny equation. (Best use for ε< 0.5 and Rep = $\frac{\rho f u\infty Dp}{(1-\varepsilon)\mu}$ <10)

Now, in the above derivation we considered laminar flow i.e. $fF = \frac{16}{Re}$ for turbulent flow, the pressure drop is:

$$\Delta p = \frac{3\rho f f T L u\infty^2(1-\varepsilon)}{Dp\varepsilon^3}$$

For flows with Re> 1000, experimental data shows that the above equation is better presented as:

$$\frac{1.75pfLu\infty^2(1-\varepsilon)}{Dp\ \varepsilon^3}$$

This equation is known as Burke-Plummer equation

For the transition region, the Ergun equation is to be used:

$$\Delta p = \frac{150\mu\ L\ u\infty(1-\varepsilon)^2}{Dp^2\varepsilon^3} + \frac{1.75pfLu\infty^2(1-\varepsilon)}{Dp\ \varepsilon^3}$$

The Ergun equation is commonly expressed as follows in different references:

$$\frac{\Delta p}{\rho f u\infty^2}\frac{Dp}{L}\frac{\varepsilon^3}{(1-\varepsilon)} = \frac{150}{R\varepsilon p} + 1.75$$