UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

DETERMINATION OF MOISTURE AND TEMPERATURE VARIATION IN WET GRAINS OVER TIME AND SPACE TO EFFECT DESICCANT DRYING

By

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(B.Sc. Env. and Biosystems Eng. 2010)

A thesis submitted to the Department of Environmental and Biosystems Engineering, University of Nairobi, in partial fulfilment of the requirements for the Degree in Masters of Science in Environmental and Biosystems Engineering

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

I dedicate this research work to my loving Dad and Mum Mr & Mrs Kimani, my dear wife Wanjiku and daughter Wambui. Many thanks for the support you have given me, God bless you all.

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ABSTRACT

The aim of this study was to establish the best position to place super absorbent polymer (SAP)in an experimental granary for effective and economical drying. To achieve the aim of the study moisture migration and temperature distribution in stored wet grain was determined over time. Also determined was the best position for placing SAP in the silo for use in a direct solar drying grain silo. Results from experiments conducted were used to evaluate performance of the SAP in grain drying. The study was carried out in the University of Nairobi, Department of Environmental and Biosystems Engineering, Upper Kabete Campus.

An experimental silo was designed. From the design, three experimental silos were fabricated. The initial experiment was conducted to determine moisture migration within the silos without use of Super Absorbent Polymer (SAP). In a second experiment drying was conducted using sun and super absorbent polymer placed inside the silo. The silo was evaluated in fifteen different sections. The sections were: East (top, central and bottom), West (top, central and bottom), North (top, central and bottom) South (top, central and bottom) and Center (top, central and bottom). Thermometers were placed in each section and readings taken in the morning, midday and evening. Modeling was done using regression analysis (MS Excel 2010) based on the minimization of sum of squares by adjusting the model constants. The coefficient of determination (R^2), were used to evaluate the goodness of fit of the mathematical model to the actual data. The model considered for this study was: second degree polynomial regression model.

The results exhibited that drying occurred faster at the top compared to the center and bottom sections. This was due to the fact that the top section was open hence moisture easily escaped to the atmosphere aided by the high vapor pressure gradient between the grains at the top surface of the silo and the atmospheric air. Second degree polynomial regression model produced the highest values of R^2 for experiment with SAP and the that without.

Generally, it was established from the research that there is a significant difference in the moisture content with depth in the three layers investigated during the entire drying period. There was a high moisture depletion in the top layer while there was a high moisture concentration at the center and bottom section with the central section having the highest. This was a clear indication that the SAP ought to be placed in the center section and partly bottom section as these were the areas with high moisture concentration. From the two sets of experiments conducted it was revealed that the silo with SAP had a steeper and smoother negative gradient as compared to that without; whose curves showed a series of negative and positive gradients. This indicated that SAP was able to take up extra moisture that emigrated into the center and bottom section and those that were brought about by moisture diffusion.

The research work indicated that SAP can be used in drying maize grains. Future research work should consider passing preheated air in the grain to optimise moisture absorption by SAP and improve air circulation in the silo.

Keywords

Absorption, desiccant, drying, grain, migration, moisture, Super Absorbent Polymer, temperature.

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LIST OF ABREVIATION AND ACRONYMS

ASAE:	American Society of Agricultural Engineers
Al^{3+}:	Aluminium ion
BASF:	Baden Aniline and Soda Factory
BET:	Brunauer-Emmett-Teller model
Ca^{2+}:	Calcium ion
EMC:	Equilibrium Moisture Content
ERH:	Equilibrium Relative Humidity
FAO:	Food and Agriculture Organisation of United Nations
GAB:	Guggenheim-Anderson-Deboer Model
MR:	Moisture Ratio
RMSE:	Root Mean Square Error
SAP:	Super Absorbent Polymer
SPH:	Super Porous Hydrogels
WB:	Wet Bulb

1.0 INTRODUCTION

1.1 Background

Worldwide there is increasing demand for high-quality and safe food, free of chemical and physical contaminants and pathogens. Grain growers and users must maintain and protect their harvested grain from insect and microbial damage *(Sinha, 1995)*. Under dry conditions, grains (rice, maize, etc.), can be stored for extended periods provided that there is no insect infestation or microbial activity. Under humid storage conditions, however, the grains may deteriorate rapidly, resulting in qualitative and quantitative losses, and this deterioration is accelerated at higher temperatures. Preservation of grains at intermediate moisture levels under hermetic storage conditions could be feasible and economical in warm and moist climates *(Weinberg et al., 2008)*.

There are a number of losses that happen to the grains in the field and out of field; referred to as post-harvest losses. Post-harvest loss is a degradation in both quality and quantity of a food production from harvest to consumption *(Kiaya, 2014)* another loss is quality loss which include those that affect the nutrient/caloric compositions, the acceptability and the edibility of a given product, these kind of losses is experienced in developed countries *(Kader, 2002)*. Quantity loss results in loss of the amount of products, this is mostly experienced in developing countries *(Kitinoja and Gorny, 2010)*. Qualitative losses also include: appearance changes, nutritional degradation, aflatoxin contamination, loss of germination capacity, presence of insect fragments and mould contamination *(Sinha andMuir, 1973)*. Some of these are difficult to detect visually *(Lacey et al., 1980)*.

Post-harvest loss brings about the loss of the grains. Some of the post-harvest problems include; attack by insects, rodents and birds, this once appear to be a major factor in food crop loss. Other factors are: spillage/shattering of grains (due to wind and during milling), fungi and mycotoxin contamination of grains causing rotting or spoilage due to contamination, sprouting of grains, roots and tubers, rotting of grains, roots and tubers due to high temperature and poor ventilation and also discolouring of grains. Weight loss is also one of the major cause of post-harvest loss, this is mainly due to reduction of moisture content during drying and storage.

Post-harvest losses can be managed both in indigenous and modern ways. In all African countries indigenous methods such as sun drying of grains and applying smoke fumigation and botanical protectants to grains in store is practised. Modern methods for post-harvest management include drying of grains with machinery applying pesticides (insecticides, fumigants and rodenticides), using hermetic bags, storing in metallic silos, cold storage and use of integrated pest management (IPM) techniques and adopting industrial processing (*Macharia J 2013)*.

Super absorbent polymers are lightly cross-linked networks of hydrophilic polymer chains. The most efficient water absorbers are polymer networks that carry dissociated, ionic functional groups. These are essentially hydrophilic non-toxic and partially cross-linked polymers that can absorb several hundreds their weight in water, but cannot dissolve of their three dimensional polymeric network structure. The network can swell in water and hold a large amount of water while maintaining the physical dimension structure. The product swells and forms a tight gel that holds water molecules, even under pressure. One kg of these materials can absorb over 300 liters of water *(Jagdev, 2007)*.

Drying of grains with desiccants has several potential advantages over conventional methods: including uniform drying, little chance of over drying and independence from non-renewable fuels *(Sturton et al., 1983)*. Using hydrogel as a Super Absorbent Polymer (SAP) can assist tremendously in reducing moisture content in grains since it absorbs large amount of water compared to its weight. The purpose of the study was to evaluate the performance of SAP in drying maize grains stored in silos.

1.2 Problem Statement

Grain drying is important as it removes moisture required for decay, premature germination of seeds or growth of microorganisms. A study done by Erastus Kang'ethe and Published by FAO in 2011 indicates that Kenya loses 30-40% of harvested maize. Cause of postharvest losses is mainly poor handling in harvesting, drying and storage of produce resulting into loss of quality and quantity through physical damage, spillage, pest infestations and fungal infestations (mycotoxins). Adverse Impacts of storage losses include; Poverty, Food insecurity, Nutritional loss, ill health attributed to aflatoxin contamination, Economic and financial losses.

In Kenya, the problem of grain losses is mainly associated with poor grain drying and storage and is mostly experienced in rural areas by small scale farmers. In this areas, the problem of drying is brought by lack of facilities, lack of access to electricity and poor weather conditions during harvesting period. Farmers in this areas have to transport their harvested grains for long distances to driers in urban areas. High cost of grain drying coupled with high transport cost make it very expensive for the farmers. It costs an average of four hundred Kenya shillings to dry a 90kg bag of maize at harvested moisture content (~30% wb) to the recommended safe storage moisture content (<13.5% wb).

There are no effective small scale grain drying equipment in Kenya. The existing driers are expensive and intended for large scale farmers. Many rural farmers use open air solar drying due to lack of alternative methods, this mode of drying is highly affected by weather conditions. In this research, the use of super absorbent polymer (SAP) in metallic grain silos was studied for its effectiveness.

The presence of aflatoxin in significant quantities can cause illness to both humans and animals. Regulatory agencies lack information pertaining to industries' knowledge of the cause and effect of aflatoxin in common agriculture products and the strategies that industries employ to prevent aflatoxin contamination *(Godwin, 2011)*.

In Kenya, control of aflatoxin contamination of maize has relied mainly on testing maize at marketing outlets and withdrawing the contaminated lots *(Kang'ethe et al., 2011)*. In 2010 the Government tried to remove all the contaminated maize in market by purchasing the maize from farmers at reduced prizes, this was not very successful and came at a high cost *(Kang'ethe et al., 2011)*. In 2004, several hundred Kenyans became severely ill, and 125 died, of acute aflatoxicosis: a disease of liver failure associated with consuming extremely high levels of aflatoxin in food *(Lewis et al., 2005; Strosnider et al., 2006)*. Internationally recommended approach is based on contamination prevention, rather than letting it happen and then trying to remove the contaminated maize from the market. Better crop handling and management practices are critical to reducing aflatoxin contamination.

Better grain drying and proper storage at recommended grain moisture content are essential to ensuring high quality stored grains free of aflatoxin contamination. It will also help reduce postharvest losses and enable smallholders to increase nutritional value and volume available for consumption and sale. There is need to invest in effective storage facilities that ensure that maize is properly dried during storage. Such facilities should be affordable to poor farmers in the rural areas.

This research targeted to contribute knowledge on grain to benefit small scale farmers in Rural Kenya and in Africa who incur losses associated with poor grain drying.

1.3 Objectives

1.3.1 Overall Objective

The overall objective was to determine the best position to place SAP in the granary for effective and economical drying.

1.3.2 Specific Objectives

The specific objectives were:

1. Establish the moisture migration and temperature distribution in stored wet grain over time
2. Determine the best position for SAPs for use in a direct solar drying grain silo and evaluate performance of the SAP in grain drying

1.4 Scope

The study was done to establish the best position to place desiccant SAP in an experimental granary for effective and economical drying.

The study was carried out in the University of Nairobi, Department of Environmental and Biosystems Engineering, Upper Kabete Campus of latitude: 36^0 43’ 57. 03’’ E, longitude: 1^0 15’ 06. 72’’ s and Elevation of 1875 m.

The experiment was conducted using wetted maize grain at 30% moisture content (MC) in three silos each holding 200 kg of wet maize grain. The Super Absorbent Polymer used was sodium Poly-acrylate placed in a tea bag in respective silo and in different position (top, center and bottom). The experiment was done outdoor. Modelling was done using regression analysis (MS Excel 2010) based on the minimization of sum of squares by adjusting the model constants.

2.0LITERATURE REVIEW

2.1. Desiccants used for Drying Maize and other Grains

Desiccants are mostly used for drying seed rather than grain. They are used to increase seed longevity where there is moisture accumulation and high temperatures associated with hot air drying. Different desiccants have been used. *Daniel et al., 2009* studied the use of silica gel for drying seed maize and concluded that using a seed: silica gel ratio of between 1:1 and 2.5:1 in sealed containers with the maize and gel in contact maximised the storage life extension of seed longevity.

Aluminium silicates also called drying beads or "zeolites" were reported by *(Hay et al., 2012)* to have a higher affinity for moisture than silica gel and were found to swell by 20-25% of its original weight. They worked with seed: desiccant ratios between 4:1 and 2:3. They showed that drying beads may be dried and reused.

A study on research-scale drying of rough rice using silica gel, whereby during the experiment, drying incorporated a combination of 1- and 5-g moisture-permeable packets of silica gel, mixed with rough rice samples in plastic bags. The average adsorptive capacity of the packets in closed rough rice samples was established as 25% to 27% (i.e., 0.25- to 0.27-g water / 1-g silica gel). A desired final MC (12.5%) was achieved for silica-gel-dried rice samples within four to five days, and the milling quality of samples dried to 12.5% MC, expressed as head rice yield, was not significantly different from that of control-dried samples *(Odier et al., 2011).*

Sturton et al., 1983 conducted a study to determine moisture exchange between maize grains and the desiccant bentonite in an intimate mixture. They used a 1:1 corn to bentonite ratio, and achieved drying to about 18% mc in less than 24 hours. They reported that bentonite swelled up to 20 times its original volume in water, developed drying equations for the swelling of the desiccant and showed that the bentonite could be blown off the grain, leaving an ash content of 1.7%. The developed equations to describe the loss of moisture in corn and swelling of bentonite are presented in equations 2.1 and 2.2 respectively.

$$m = m_0 - a_c(1 - e^{-b_c t}) \quad (2.1)$$

$$m = m_0 + a_b(1 - e^{-b_b t}) \quad (2.2)$$

Where:

m = moisture content (% WB) of the component (maize or bentonite) at a given time t(h)

m_o = initial moisture content (% WB) of the component

a_{bc} = constant which equals the difference between the initial and final moisture content of the component at equilibrium ($t = \infty$)

b = bentonite

c = corn

b_{bc} = constant related to the rate at which the curve approaches equilibrium.

In 2014 V Sutcliffe, J Adams showed the possibility of using charcoal and maize meal and previously dried seed to dry wet seed. *Thoruwa et al., 2007* used a combination of desiccants bentonite and calcium chloride in addition to solar drying and managed to dry 90kg of maize from 38% to 15% moisture content in 24 hours.

The findings of different researchers show that the use of desiccant for drying both seed and grain is highly promising and needs to be studied further and perfected. Compared with the other desiccants, Superabsorbent polymers (SAPs) have a higher absorption capacity, rate and other properties that make them suitable for use as desiccants for drying maize. It is for this reason that super absorbent polymers were studied in this research.

Using desiccant in drying of seed maize has several advantages such as energy conservation and seed quality preservation *(Probert, 2003)*. This is because during desiccant seed drying under hermetic conditions there is little or no temperature rise as the heat of hydration is negligible. More also desiccant such as hydrogel are regenerated at relatively low temperature *(Tahat, 2001)* and can therefore be dried under the sun to store the energy for rainy seasons. When dry maize is exposed to humid environments, it gains moisture content and equilibrates to a value of equilibrium moisture content, which may be different than the equilibrium moisture content obtained during the moisture desorption *(Correa et al., 2011)*.

In the research to determine moisture sorption in seed maize during hermetic drying using SAP, the seed maize rapidly gave up its moisture to the hydrogel. *(Gatwiri, 2013)*. The experiment was conducted in an air tight glass container with lid, wire mesh basket and a stand. The container was cylindrical with lid hence formed a hermetic system. As the seed maize reached equilibrium with the hydrogel the rate of drying slowed down. Final moisture content of the seed maize reduces with increase in temperature from $25^{\circ}C$, $30^{\circ}C$, $35^{\circ}C$ and $40^{\circ}C$ *(Gatwiri, 2013)*. The drying curves show significant moisture reduction within the first 50 hours due to low relative humidity created by the SAP. The drying rate reduced as the hydrogel approached saturation. The least final moisture content for each set of treatment was observed for samples that were dried at $40^{O}C$ compared to those dried at 25, 30 and $35^{O}C$. It was found that lower moisture content was achieved with a higher drying temperature and ratios as revealed in the study *(Gatwiri, 2013)*.

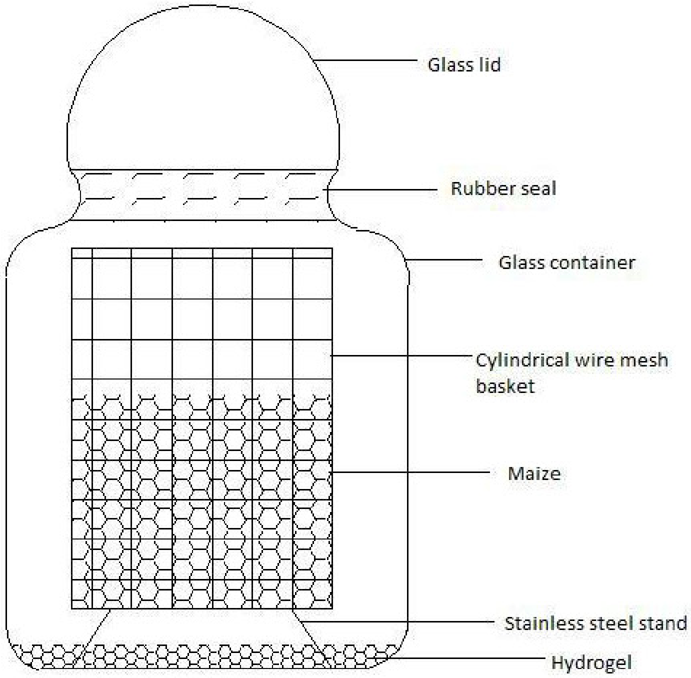


Figure 2-1: Schematic of the hermetic drying and storage system *(Gatwiri, 2013).*

A study to find the effect of super absorbent polymers on aflatoxin contamination in maize. Where survey of study was conducted using an open and closed questionnaires in eastern part of Kenya. From each farmer, a sample was bought for the purpose of testing for aflatoxin *(Nyakundi, 2014)*

It was found that drying by SAP reduced the aflatoxin contamination and that the more SAP is used the less the incidence of aflatoxin contamination. To be absolutely sure that there was no aflatoxin contamination, a ratio of 1:5 (SAP: Maize) or less was recommended. Higher ratios (such as 1:10 and 1:20) may prevent aflatoxin contamination below 20˚C and with changes of SAP every 24 hours *(Nyakundi, 2014)*

2.2. Super Absorbent Polymers (SAPs) and Selection for Grain Drying

Super absorbent polymers (SAPs), also called hydrogels and Super Porous Hydrogels (SPH). They are known for their ability to absorb large amounts of water. According to *(Kuruwita-*

Mudiyanselage, 2008) one gram of hydrogel may absorb more than 4000g of water in 200 minutes, with half of this water being absorbed within the first 12 minutes. SAPs were first used in agriculture for drainage but have now found use in health products such as baby diapers and sanitary pads (Delgado et al., 2009). Because of their moisture absorbing capability, they may serve as a possible solution to aflatoxin contamination, operating as moisture sponges for maize during the post-harvest (storage and drying) stage. The important parameters in hydrogels with regard to water absorption, which would apply in storage facilities, are: the rate of moisture absorption (swelling rate) and the amount of moisture absorbed per unit volume (swelling capacity). A material that is more superior than others in the two properties would be selected.

When the swelling rate is high the polymer absorbs moisture efficiently and prevents aflatoxin contamination. A high swelling capacity defines the effectiveness of the polymer since it maximizes on water absorption in the long run. The swelling capacity is a function of the equilibrium moisture content of the polymer with a given environment and its determination involves the recording of sorption isotherms. There are different models of sorption isotherms such as the Langmuir, BET (Brunauer-Emmett-Teller) and GAB (Guggenheim-Andersson-DeBoer) models *(Delgado et al., 2009)*.

The swelling rate of a SAP may be modelled as *(Delgado et al., 2009):*

$$\frac{Q}{Q_{eq}} = \frac{kt}{1+kt} \tag{2.3}$$

Where Q is the initial swelling, Q_{eq} is the swelling at equilibrium, t is the elapsed time and k is the swelling rate constant.

2.2.1. Analysis of super absorbents polymers

Desired features of SAPs are: high water absorbency (they should absorb and retain huge amounts of water even under load or in contact with other materials), high absorption rates (a large amount of fluid must be absorbed per unit of time) and good gel strength (the material should not become 'slimy' and flow away after swelling). These requirements are dependent on the final use of material. For some applications, fluid absorption should be reversible (the polymer must be able to absorb and desorb the fluid several times without degradation). Moreover, they must be non-toxic and should not contain traces of unreacted monomers and finally the cost of the raw material and the production process should be low. In practice it is difficult for a polymer structure to meet all of these requirements simultaneously. How these properties are measured is optional and generally is as follows:

I. Absorption capacity

Absorption capacity is measured by putting a dry polymer sample in excess water for a time sufficient to saturate it and then after removing the excess of water, *e.g.* with a sponge, weighing the gel obtained.

Water absorbing capacity or swelling of the polymer can be controlled by two methods - type and degree of cross linking between polymeric chains and morphology of the SAP. A research by *(Xie et al., 2016)* discusses that the water absorbing property of the SAPs can be greatly affected by type of cross-linking agent used. Also the cross linking agent varies the polymeric chain length –longer polymer chains have more network space and thus increases water absorbing capacity *(Buchholz et al., 1997)*. Besides, the length of polymeric chain also affects its water absorption capacity – smaller polymer chains have more polymer ends which do not contribute to water absorption *(Liu et al., 2007)*.

II. Absorption rate

The absorption rate can be expressed in two ways: either through the amount of fluid absorbed by a weighed amount of the polymer in a fixed short time (a rate factor) or through the time required by the polymer sample to absorb a given amount of fluid.

III. Gel strength

Gel strength measurement methods are even more exotic and in many cases a qualitative observation is preferred. Typical methods used include, the maximum diameter of a steel ball required to settle through the gel, the amount of gel free-flowing through a screen, or the pressure to be applied to the gel in order to force it to flow through a certain screen

The SAP selected for grain drying would have to comply with food safety requirements if it is to be allowed for use with substances for human consumption. The most commonly available SAP was identified as sodium poly-acrylate. It is used in the manufacture of SAPs which are listed as food grade such as the BASF products Luquafleece and Luquasorb that are applied in fish and meat packaging containers.

SAPs are fairly easy to manufacture from local materials and may also be made from natural products even in developed countries. For instance, *(Ekebafel et al., 2011)* prepared a superabsorbent hydrogel from native cassava starch-Poly [sodium acrylate-co-acrylamide], by alkaline hydrolysis of starch/PAN physical mixture. They contend that graft copolymerization of vinyl monomers onto natural polymers is an efficient approach to achieve biopolymer-based super absorbing hydrogels. Because of their exceptional properties such as biocompatibility, biodegradability, renewability, and non-toxicity. All these are desirable properties for maize drying.

2.2.2. Uses of Super Absorbent Polymers

I. Hygienic and Bio-related Areas

The most volume of SAP produced all over the world is used in disposable diapers. Use of SAP has revolutionized the baby diaper and adult incontinence industries over the last 30 years, globally millions of people use SAPs daily *(Elliott, 1997)*.

SAPs are one of the members of the family of smart hydrogels; hence they can be potentially employed in separation science and technology, particularly bio-separation. Due to large changes in the swelling ratio, the hydrogels have been used widely in the separation of various molecules including proteins *(Kim et al., 1998)*. In medicine, SAPs may be used for elimination of body water during surgery, e.g., treatment of edema *(Sannino et al., 2003)*.

II. Uses of Super Absorbent Polymers in Agriculture

In agriculture superabsorbent polymers are used as a soil additive, as reservoir of nutrients, and as water superabsorbent in the soil. As a soil additive SAP have been developed to improve the physical properties of soil in view of: increasing their water-holding capacity, increasing water use efficiency, enhancing soil permeability and infiltration rates, reducing irrigation frequency, reducing compaction tendency, stopping erosion and water run-off and Increasing plant performance, especially in structure -less soils in areas subject to drought *(Abd EI-Rehirn et al., 2004)*.

In arid areas, the use of SAP in the sandy soil, to increase its water-holding capacity seems to be one of the most significant means to improve the quality of plants. The SAP particles may be taken as "miniature water reservoirs" in soil. Water will be removed from these reservoirs upon the root demand through osmotic pressure difference.

The hydrogels also act as a controlled release system by favouring the uptake of some nutrient elements, holding them tightly, and delaying their dissolution. Consequently, the plant can still access some of the fertilizers, resulting in improved growth and performance rates *(Liang et al., 2007).*

SAPs can also be used as retaining materials in the form of seed additives (to aid in germination and seedling establishment), seed coatings, root dips, and for immobilizing plant growth regulator or protecting agents for controlled release *(Abd EI-Rehirn et al., 2004).*

2.2.3 Limitations of Super Absorbent Polymers in Agriculture

SAPs are quite fragile and tend to break apart easily thereby losing their water retention property. Further SAPs can also dehydrate rapidly in a matter of hours thus losing their absorbed water *(Nadarajah et al., 2010).* The water absorption of SAPs greatly reduces in the soils as SAPs are under pressure and unable to swell and take in water (Bhardwaj *et al.*, 2009). The water absorption of SAPs in soils further decreases due to formation of additional crosslinks with certain ions like Ca^{2+} and Al^{3+} present in the soil *(Rigas and Chatzoudis ., 1999).* The water absorption of the SAP also decreases with increase in salinity of irrigation water *(Sojka et al. 2009; Naeini and Taban, 2006)*. The SAPs in soils releases water with increase in temperature and this water could be potentially lost to deep percolation *(Andry et al., 2009).*

Furthermore from *(Schmidhalter and* Geesing *., 2004)* work, it could be inferred that the effectiveness of SAP decreased on rewetting and can affect the hydraulic properties of soil only if applied in higher application rates. Also the efficacy of the SAP decreases over a period of time and to compensate for these loses, higher application rates are required *(Al-Harbi et al., 1999).* This factor affects the economic value of crops grown on fields amended with SAP

2.3 Moisture Migration in Stored Grain

A situation may arise where the total amount of water held in a storage structure in a given space may be the same at the end of a given storage time as it was in the beginning which is moisture migration, but as a result of this, the moisture contents of various parts of the silo change considerably (gains or losses being found). It is more usual, however, for part of the moisture that migrates to be lost to the external atmosphere as a result of ventilation, or to be drained off according to *(Navarro et al., 2002)* there are six mechanisms for moisture migration:

a) Diffusion of moisture through inter particle contact conduction.
b) Leakage of water through openings in the structure.
c) Exchange of water vapour with the atmospheric air at the grain surface.
d) Diffusion of moisture to vapour gradients in the bulk.
e) Translocation of moisture due to convection currents.
f) Condensate that forms on the inside surfaces and downspout of the silo that falls onto the grain.

Energy produced as a result of oxygen respiration bring about an increase in the grain temperature and moisture content. For satisfactory drying and storage of grains, preventing grain moisture migration and controlling moisture exchange is an important management process of farm-stored grain because grain adsorbs or desorbs moisture under changing environmental conditions.

Grain is a good insulator; heat loss from grain is relatively slow in comparison to other materials. For this reason, when grain is placed in a bin in the fall, the grain near the center tends to maintain the temperature at which it came from the dryer or field *(Talbot, 2002)*.

The grain near the bin wall tends to cool near the average outside temperature. As the outside temperature decreases, the difference in temperature between the grain at the center of the bin and that near the bin wall produces air currents inside the grain mass. The cool air near the bin wall falls since it is denser, forcing the warmer air up through the center of the bin *(Talbot, 2002).*

Based on their model's prediction, (*Montross et al., 2002*) showed that moisture accumulation is primarily due to equilibration with the headspace and plenum air due to natural convection, diffusion, or both. Based on these model analyses, moisture should accumulate near the top center region when outdoor temperatures are lower than the grain temperature and accumulate near the bottom center when outdoor temperatures are higher than grain temperature (*Jayas, 1995*).

Improper control of temperature causes moisture to move or migrate from one part of the grain mass to another, where the moisture can accumulate and cause grain spoilage problems. Although moisture migration problems can occur any time grain temperatures vary considerably in different parts of the bin, the most critical time occurs when warm grain is stored into cold temperatures (*Mckenzie et al., 2009*).

As the cold air passes through the center of the grain mass, it warms and picks up more moisture. As this air nears the top center surface of grain, it cools to a point where it can no longer hold the moisture it has picked up. This moisture condenses on the surface of the grain, increasing the surface grain's moisture content and creating a local environment that enhances mold or insect growth. This surface moisture change can occur even though the average grain moisture content is at or below recommended levels. Crusting on the surface of stored grain is a common symptom of moisture migration. Moisture can also migrate to colder grain near the bin walls during cold winter weather *(Talbot, 2002).*

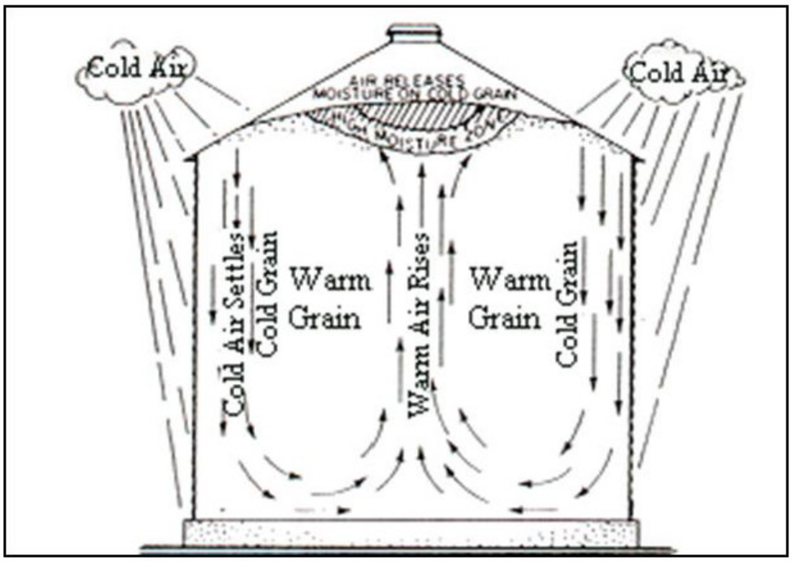


Figure 2-2: Cold Season Moisture Migration *(Talbot, 2002).*

The reverse situation occurs during the dry weather months and is illustrated in figure 2-4. In this case, the moisture condenses near the bottom center of the grain mass. This is usually not as serious as the moisture migration upward and outward during cold winter weather *(Harold et al., 2015)*

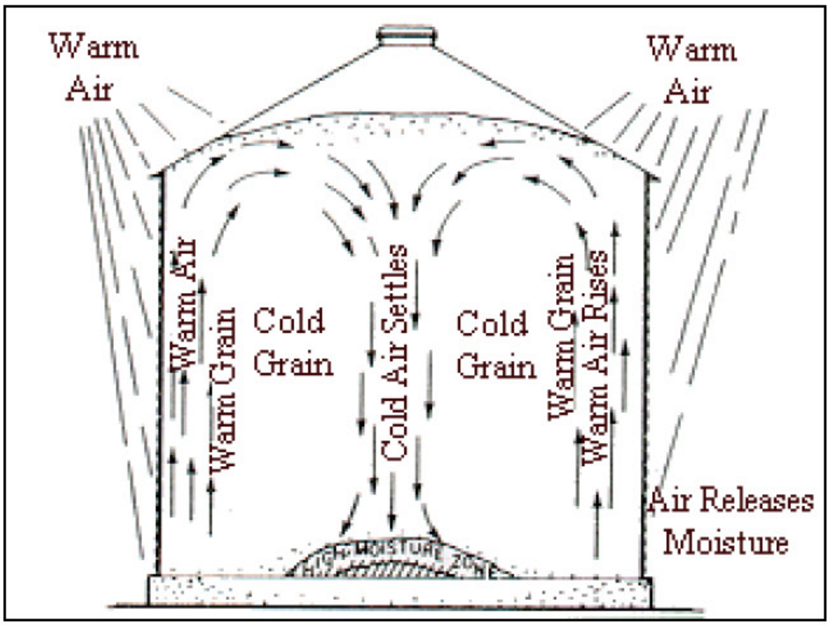


Figure 2-3: Dry Season Moisture Migration (*Harold, 2015)*

It is important to equalize and maintain uniform temperatures throughout the storage. Aeration is therefore very important in improving the "storability" of grain by maintaining a cool, uniform temperature throughout the storage to reduce mold development and insect activity and to prevent moisture migration. Aeration is not a grain drying system but a management tool. It involves moving low volumes of air through the grain to control and maintain uniform temperature through the grain mass *(Michael et al., 2013)*.

Practical farm storage conditions are summarized in Figure 2-5. The ideal condition would be a moisture content of 12% or less and a temperature of 3 °C or less.

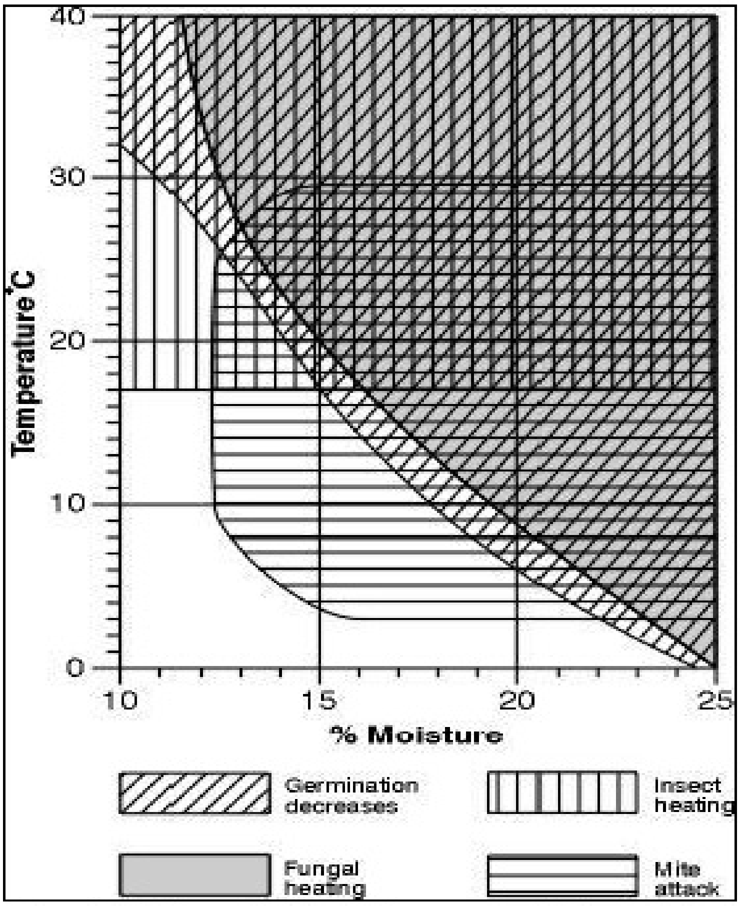


Figure 2-4: Practical farm storage conditions *(Michael et al., 2013)*

The moisture content of grain is defined in two primary methods. The conventional method measures the percentage moisture content by weight (of a sample under test). However, for more accurate and meaningful results in relation to grain quality, the moisture content of the intergranular environment is considered. The Equilibrium Relative Humidity (ERH) helps determine the grains potential to deteriorate. If the ERH exceeds 65%, microorganisms are more likely to multiply. Additionally, to protect grain from mould and bacteria, the ERH should not go beyond 70%. If the ERH does reach these levels, a close eye should be kept on insects and mites, as they are most likely to survive in between 60-80% ERH.

2.4 Grain Drying

Grains are hygroscopic capillary-porous products in which the pores are partially filled with liquid water and partially filled with an air/water-vapour mixture. The water in grains can be classified as follows:

- Water of Composition, which is closely combined with the grain
- Absorbed or ''free'' water not closely combined with the grain

The presence or not of such free water, which is readily usable by developing microorganisms, will largely determine the storability of the grains. Storage of seed grain requires conditions that will not only maintain peak viability but will avoid also all possibility of germination while in storage. High moisture content and low oxygen may decrease viability and therefore should be avoided for seed storage. At the same time, to avoid any danger of germination or fungal and insect damage while in storage, seed should be dried 1–2 percent more than for human consumption. Additionally, it is important to keep the temperature of the seed as low as possible.

The process of drying grain is something like evaporating water from a damp towel by placing the towel in an airstream. You pass air through the grain so that the air can pick up and carry away water. The partial vapour pressure difference between the kernel and the surrounding air makes the moisture evaporate from the kernel surface and/or in the pores *(Donald et al., 1992).* It is a simultaneous heat and moisture transfer process. As air moves up through the grain, it gives up heat which evaporates water from kernel surfaces into the air (or an external drying medium). This process is adiabatic (no heat loss or gain) since it uses no other heat but the heat which is carried in by the airstream. This process of adiabatic absorption can be traced as a line of constant wet bulb temperature on the psychometrics chart (from state A to state B) as sketched in Figure 2-6.

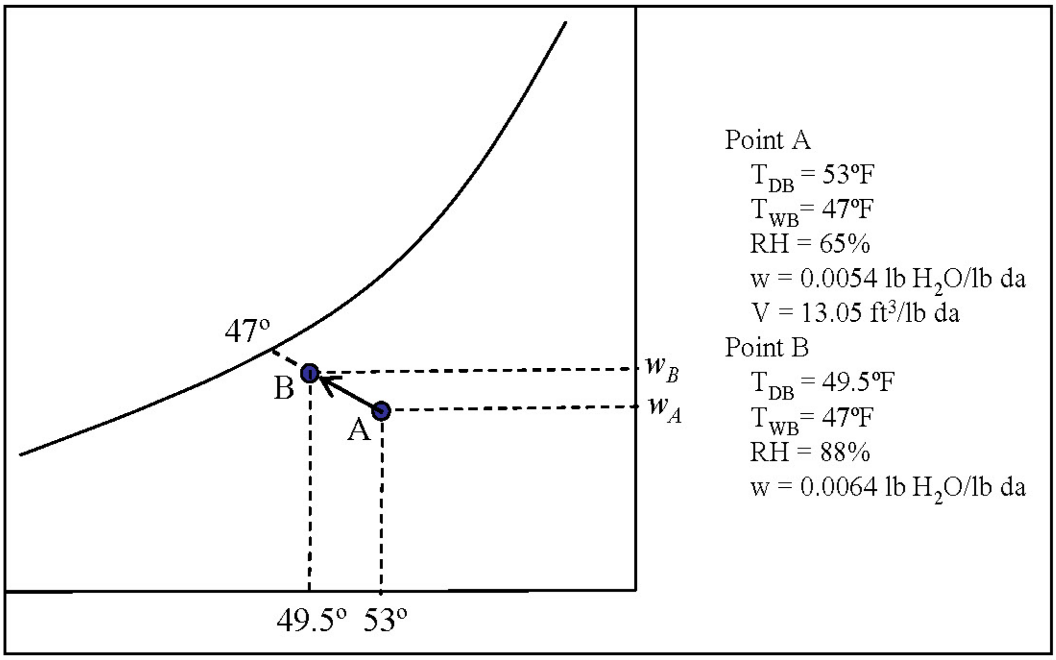


Figure 2-5: Natural-air drying example plotted on psychometric chart. ***(Donald et al., 1992)***

Any hygroscopic material (including grain) has its own characteristic balance (or equilibrium) between the moisture it contains and the water vapour in the air with which it is in contact. As air moves up through the grain, it continues to cool and pick up moisture until it reaches a state of equilibrium with the grain where the net transfer of water between corn and air is zero *(Hurburgh et al., 2004)*. Each food grain has a characteristic equilibrium curve obtained by plotting a graph of moisture content against the relative humidity and temperature of the air. This equilibrium state of a 20% moisture corn can be defined on the psychometric chart as the intersection of the process line and the equilibrium moisture line as shown in Figure 2-7.

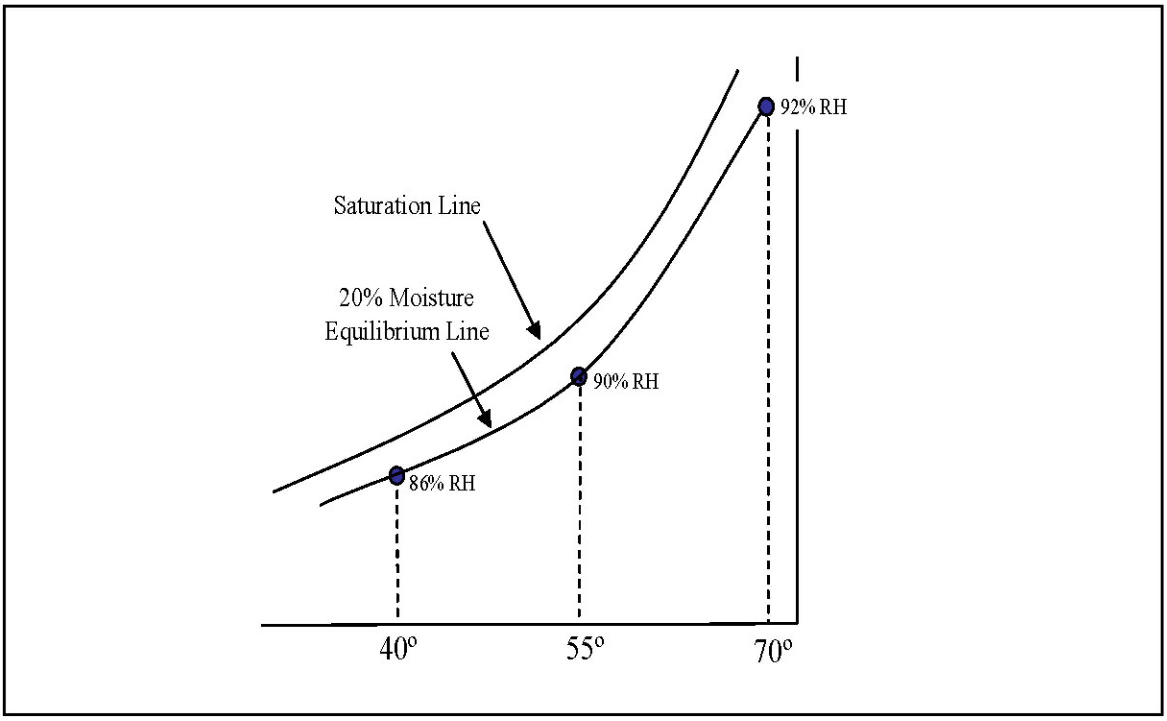
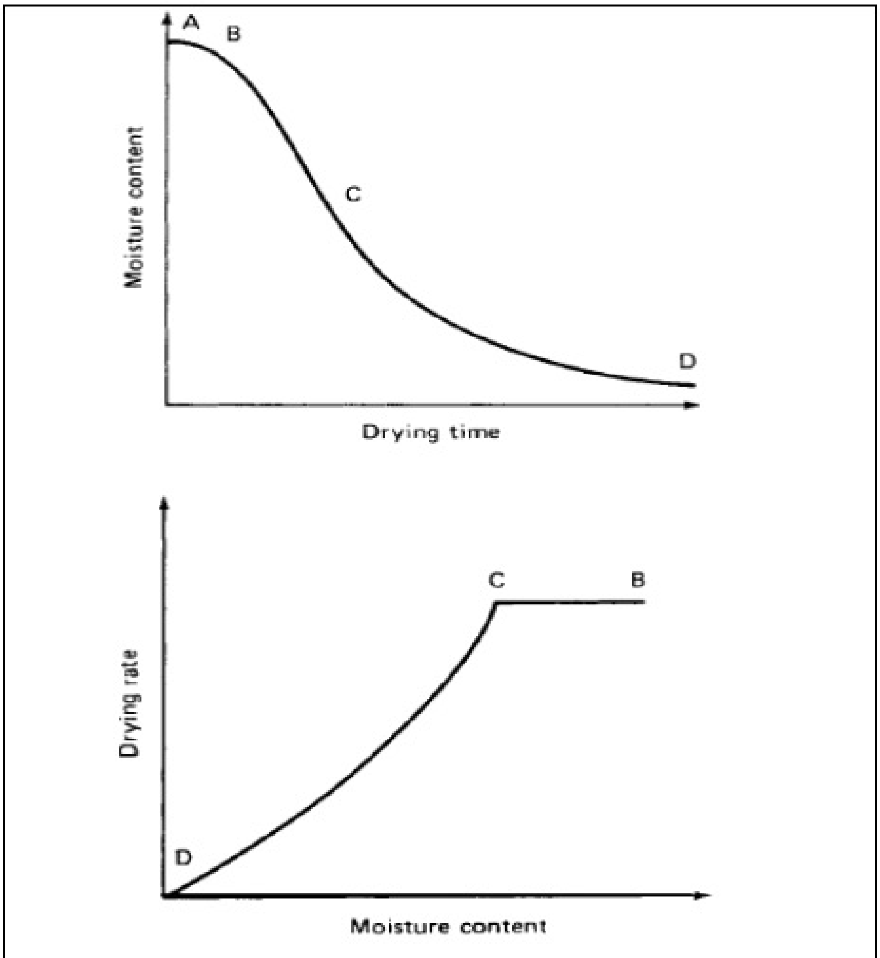


Figure 2-6: Corn equilibrium moisture line ***(Hurburgh et al., 2004)***

Some biological products when drying as a single particle under constant external conditions, exhibit a constant-rate moisture loss during the initial drying period followed by a falling-rate drying phase. Cereal grain kernels however dry entirely within the falling-rate period *(Donald et al., 1992)*



Drying curves. The temperature and humidity of the drying air are constant and all heat is supplied to the food surface by convection.

Figure 2-7: Constant-rate period and falling-rate period during drying *(Donald et al., 1992)*

2.5 Methods of Grain Drying

2.5.1 **Solar grain drying**

Solar air heater is a device in which energy transfer is from a distant source of radiant energy to air. Solar air heaters can be used for many purposes, including crop drying, space heating, and for re-generating dehumidifying agents *(Kalogirou, 2004)*.

There are numbers of configurations and many of which are empirical constructions. They can be classified on the basis of mode such as active, hybrid and passive. A comprehensive review on various designs, construction and operation principles of a wide variety of solar air heater for drying is given by *Ekechukwu and Norton, 1999*. Figure 2-9 shows classification of solar air heaters.

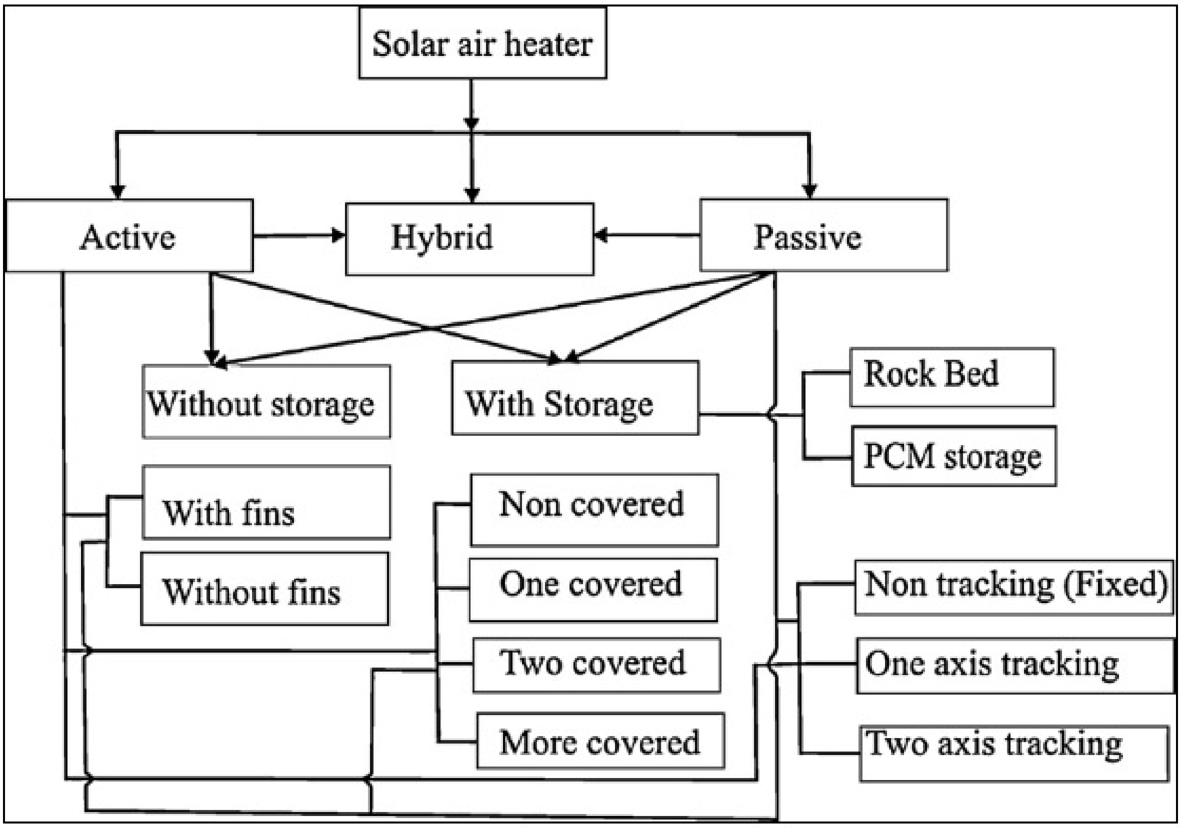


Figure 2-8: classification of solar air heater *(Ekechukwu and Norton, 1999)*.

Radiant energy from the sun reaching the earth's surface is known as shortwave radiation, solar radiation, solar energy or insolation. The total radiation may be. Direct from the sun; diffuse, scattered by the atmosphere; or reflected, from adjacent surfaces. To measure collector performance with high accuracy and repeatability is a must for further developing the solar system market. Only a well-defined performance test allows for comparison of collectors' performance, allows the calculation of the yield of solar systems, and stimulates constructive competition and innovations. In addition, it is a requisite for gaining a deeper understanding of the technology and the research work needed to improve the technology (Kramer, 2013).

i. Solar collector

The units of energy are the average total number of mega joules per square meter per day for each month (MJ/m2 - day). As the cost of a large solar collector required for high temperature, high-speed drying is prohibitive. Solar air heating collectors have some peculiarities which dictate differences in some aspects of performance testing as compared with that of liquid based collectors *(Kramer, 2013)*.

Most solar collector's works with the principle of mass flow dependencies *(Kramer, 2013)*. The efficiency of the collector increases with increasing mass flow, since the heat transfer from the absorber to the heat transfer air improves with increasing mass flow. The lower the mass flow, the more the absorber temperature (T_{abs}) remains above the mean air temperature (T_m), due to the lower heat transfer coefficient. But with a higher absorber temperature (T_{abs}) the heat losses are higher and therefore the efficiency is lower *(Kramer, 2013)*.

Figure 2-10 shows conventional solar air collector parts.

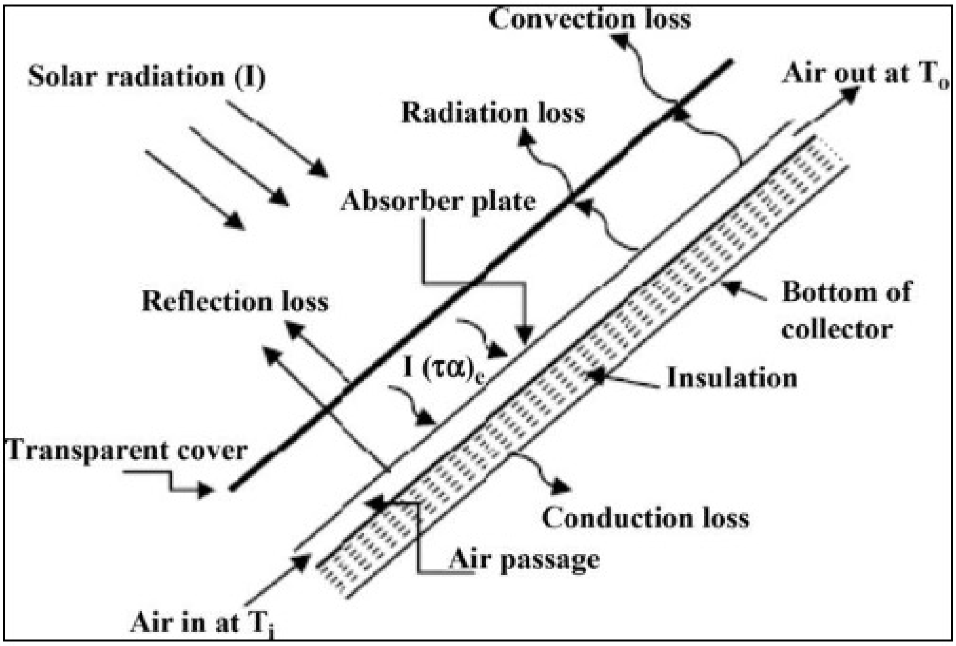


Figure 2-9: Conventional solar air collector *(Ekechukwu and Norton, 1999)*.

The collector efficiency factor (F') was determined by simulations for various mass flow rates in order to determine its influence. Figure 2.10 shows a very strong efficiency increase for mass flow rates up to 200 kg/h (100kg/h/m2), demonstrating the high sensitivity of efficiency to mass flow in this range *(Kramer, 2013)*.

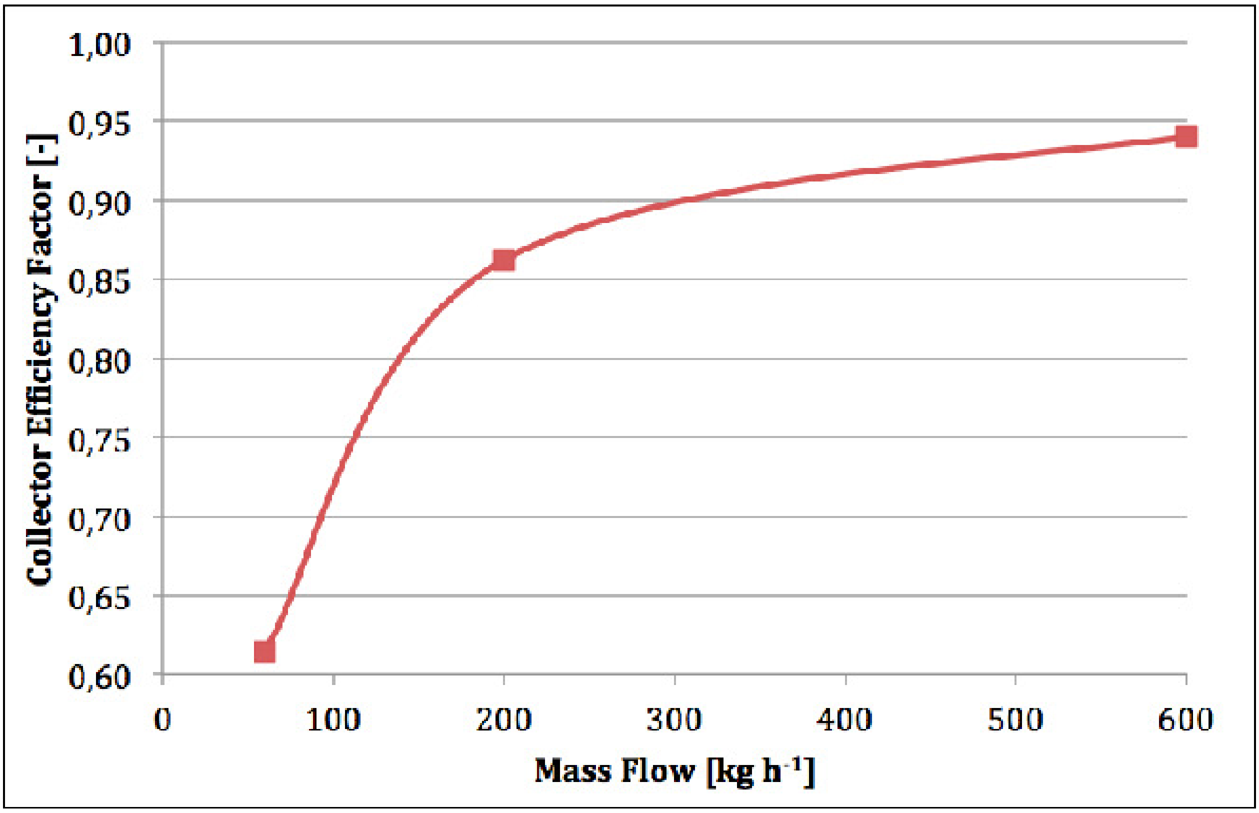


Figure 2-10: simulated dependency of the collector efficiency factor (F') on the mass flow *(Kramer, 2013)*.

2.5.2 Conventional Methods

i. Layer- in – bin dryer

In this method, the bin is filled to a specific depth depending upon seed moisture, the drying unit and bin sizes. This depth is dried down to a state moisture content for storage, before the next layer is added. The drying air is usually controlled by a humidistat set at 55 percent to prevent over drying of the lower layers. Although this method of drying is fairly slow, the seed is uniform dried between the top and bottom of the bin *(Hellevang, 2013)*.

The compounds that make a bin perform as a dryer are fan, heater, operating and safety controls , transition , duct, foundation, ring , false floor , seed leveller, sweep unloaded and unload auger. The layer-bin- dryers range from 21 to 40 feet diameter and 5 to 20 horse power. It is the most efficient but slowest drying method. After the initial layer, fills must be separated by three to four days while each new layer dries.

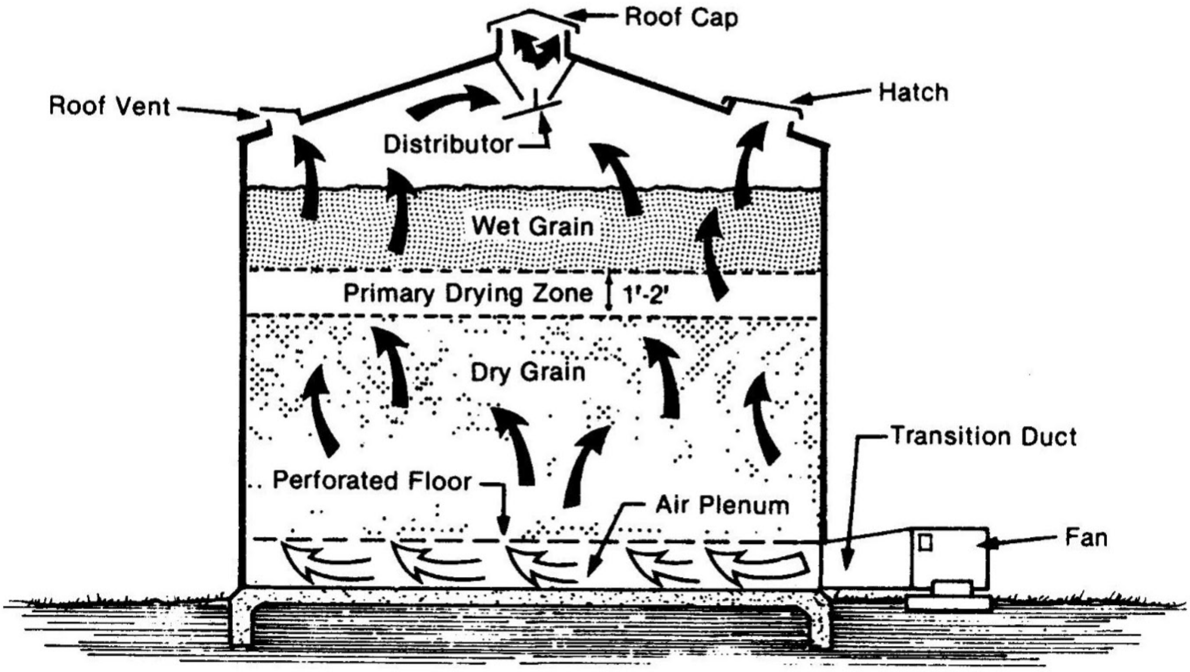


Figure 2-11: layer –in-bin-dryier ***(Hellevang, 2013).***

ii. Batch- in – dryer

In this method of drying, the quantity of seed at a given moisture content can be dried with a given drying unit. The high moisture seed is placed in a drying bin, dried and cooled and removed to a storage bin. The drying equipment used as similar to that of layer drying; the main difference being in higher capacity heaters and fan, grain levellers, sweep unloaders and unload auger equipment.

iii. Cross Flow Dryer

Is the most common type of dryer used as shown in figure 2-14. It is referred to as a cross-flow dryer because the heated air moves across the grain column perpendicular to the flow of the grain *(Hellevang and Wickle, 2013)*.

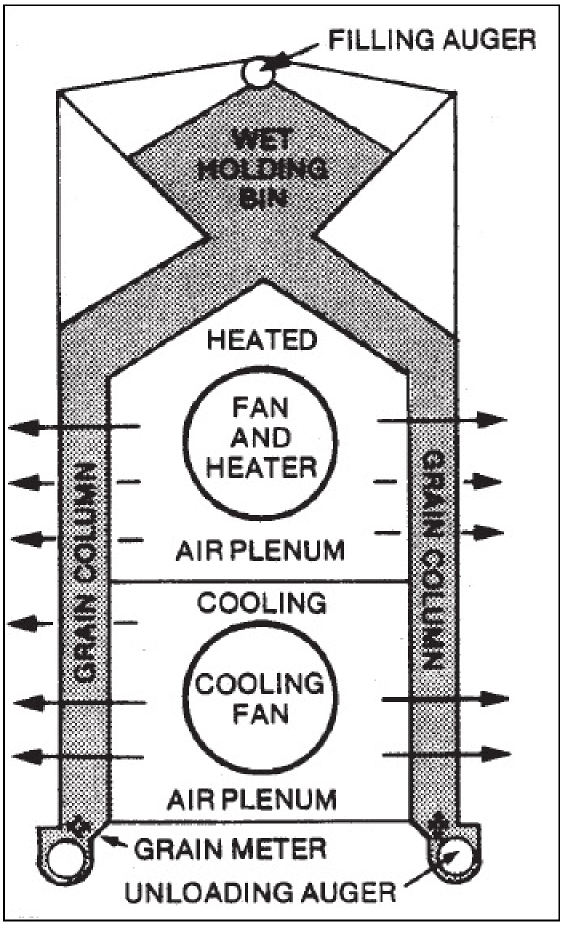


Figure 2-12: Cross flow dryer with forced air drying and cooling *(Hellevang and Wickle, 2013).*

The grain moisture content and temperature varies across the column of a cross-flow batch dryer as shown in Figure 2-15 *(Hellevang and Wickle, 2013)*.

Grain near the inside of the column is at a lower moisture content and a higher temperature than grain near the outside of the column. Therefore, even though the average moisture content may be at 14%, the moisture content of grain near the inside of the column may be 6 to 10%, and grain near the outside of the column may be at 16 to 28% moisture. Also, even though the average temperature may be at 140°F, grain near the inside of the column may be at 200°F, and grain near the outside of the column may be at 80°F.

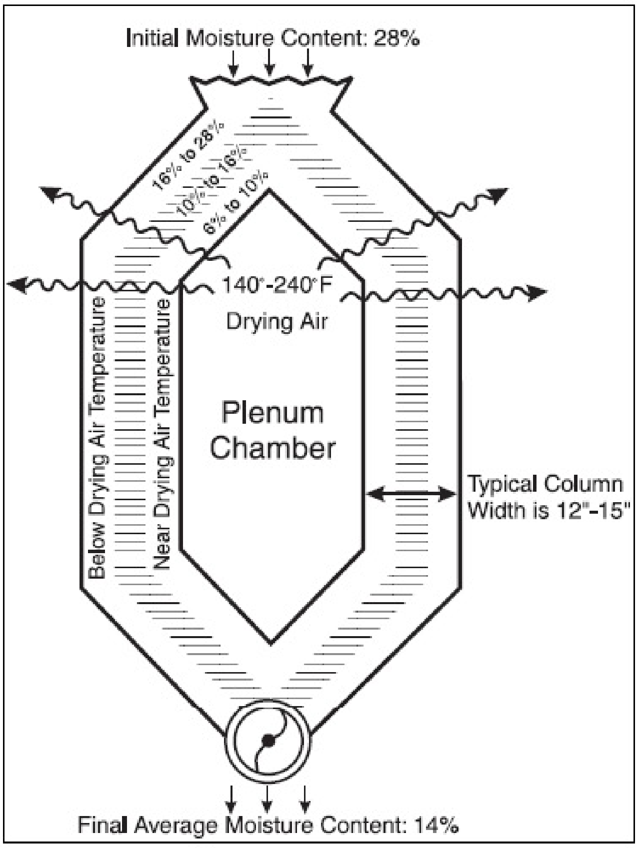


Figure 2-13: Different temperature and moisture zones in a cross-flow dryer *(Hellevang and Wickle, 2013).*

iv. **Batch Dryers**

Batch dryers are bins with an inner air chamber surrounded by two parallel perforated steel walls to contain a designed thickness of seed. The fan heater unit is connected to one end, or side of the plenum as heated air for drying and natural air cooling can be forced through the seed. Batch dryers, generally rectangular or cylindrical, are usually described by the volume in bushes that a dryer will hold per fill e.g. 300 bushel dryer. Fan power ranges from 3 to 30-40 horse power. The number of batches per day may be eight to ten for small dryers but only two or three for large units. Dryer capacities are rated on average moisture removed of ten points.

All batch dryers depend on fast handing. Wet holding capacity is needed to avoid seed receiving, dry seed transfer, and dryer operating cycles. *(Hellevang, 2013).*

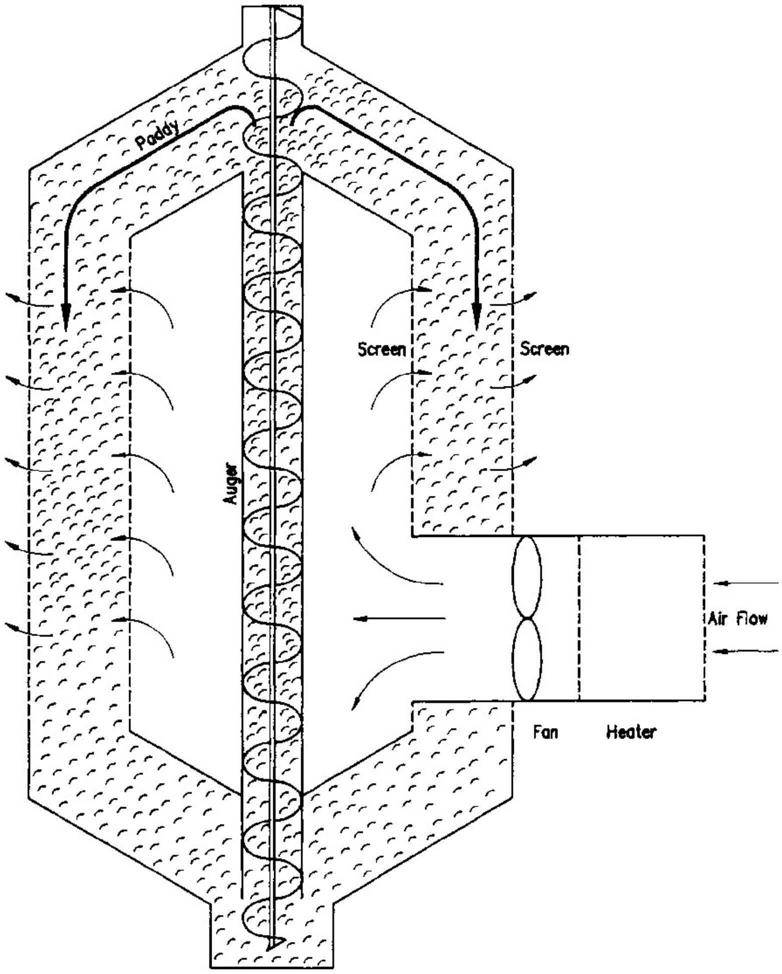


Figure 2-14: Batch drying method ***(Hellevang, 2013).***

2.5.2.4 Continuous Dryers

Continuous flow dryers move seed through heating and cooling sections of the column continuously. Seed flow is controlled by volume metering devices at the lower side of the seed column. Heated air is forced through the upper 2/3 to 3/4 of the seed column at 100 to 150 CFM/bu. Continuous dryer sizes are usually given in bushel/hour capacity at 10 points moisture removal. Power needs are from 7 ½ horse power to 60 horse power. Some dryers use multiple sequence start fan motors to keep starting loads low. *(Hellevang, 2013)*

Wet holding is necessary for both one and two leg system. With one leg, seed from the dryer is accumulated in a dry holding bin for periodic manual transfer. With two legs a low capacity elevator leg moves dry speed to storage continuously.

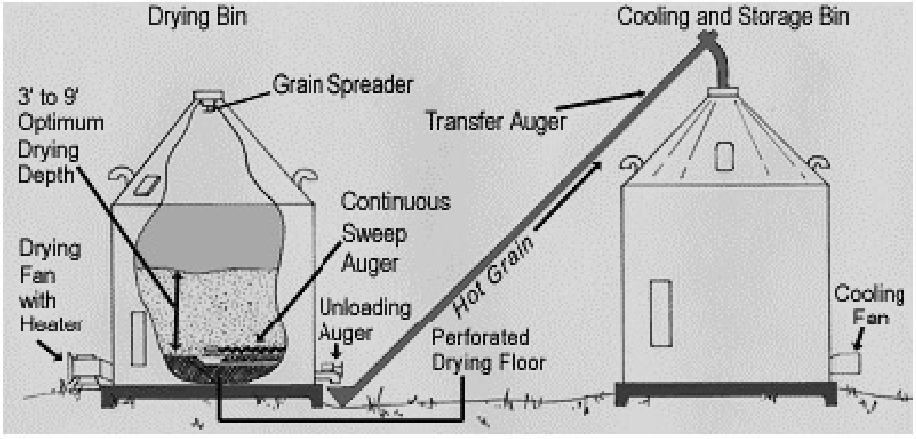


Figure 2-15: Continuous dryer *(Hellevang, 2013)*

Several researchers have used different kinds of desiccant for drying seeds. The desiccants mostly used are:

a) Aluminium silicate- where it showed that drying beads has a higher affinity for moisture than silica gel, with swelling of 20-25 times.
b) Bentonite, having mixed in the ration of 1:1 with corn, showed that it achieved a moisture content percentage of 18% in 24 hours and swelling of 20 times.

There are a number of research on different models used in drying in a number of driers. In bin-drying provides an alternative to traditional drying in terms of achieving good grain quality and saving fossil fuels. In an application and comparison of two mathematical models for simulating grain heat and mass transfer during in-bin drying by *(Jingyun et al., 2012)* mathematical models were used to simulate the drying process in an in-bin dryer. A partial differential model (PDE model) and a logarithmic model (Log model) were used. The two models showed that, they could be used to predict grain temperature and moisture changes during in-bin drying with good accuracy.

2.6 Summary of Literature Review

Several researchers have studied use of desiccants in drying seeds. The studies indicate that several desiccants can effectively be used to dry seeds, these desiccants include: Silica gel, aluminium silicates, bentonite, a combination of desiccants bentonite and calcium chloride and use of Super Absorbent Polymers.

A study was done by Gatwiri to determine moisture sorption in maize seed during hermetic drying using SAP, she found out that high amount of SAP with temperature brings out less moisture content in different ratios of SAP. Another research was conducted by Nyakundi to determine the effect of SAP on aflatoxin in stored maize grain, he found out that SAP reduces aflatoxin contamination, again the increase in the percentage of SAP reduces aflatoxin effect.

SAPs are valued for their high water absorbing properties, and are used in many industries. They are used in manufacture disposable diaper. They are also used in separation science and technology, particularly bio-separation. In agriculture SAP are used in drying seeds and also as additives in agricultural soils to improve soil water absorption and retention.

SAP have several limitations: they are fragile, dehydrate rapidly, decrease of absorption due to saline formation in the soil.

Studies reviewed indicate that SAP can effectively be used in drying seed grains, to use it in drying food grains food safety need to be considered. The study conducted used SAP approved for indirect food contact, Moisture and temperature migration were studied to assess effectiveness of the SAP in grain drying.

3.0THEORITICAL FRAMEWORK

3.1 Model Description of Drying

3.1.1 Drying model

The assumptions used together with the mathematical models are as follows:

a) Maize kernel is a continuous spherical divided into three layers: hull, bran and endosperm.

b) The heat conduction and moisture diffusion processes are unsteady.

c) Heat and mass transfer coefficients are specified at grain boundary

d) Shrinkage or deformation of the Maize seed during drying is negligible.

e) No heat generation inside the maize kernel

f) No effects of radiation.

The simplified differential equation for drying process *(Sereno etal., 1990)* using the Fick's law, it is also the governing equations describing the conservation of heat inside a grain it is described as follows;

$$\frac{\partial X}{\partial t} = \nabla(D\nabla X) \tag{3.1}$$

$$\rho\frac{\partial T}{\partial t} = \nabla(K\nabla T) + L\rho\frac{\partial X}{\partial t} \tag{3.2}$$

Where, X is the moisture content dry base; D is the diffusion coefficient; ρ is the density; T is the temperature; t is the time; K is the thermal conductivity; L is the latent heat of vaporization of water.

When defining boundary conditions it is assumed that surface of the corn seed is in equilibrium moisture content. Finally boundary and initial conditions are defined as followings.

$$X|_s = X_e \tag{3.3}$$

$$X|_{t=0} = X_o \tag{3.4}$$

The above equations systems proves that inner moisture distribution in e.g. corn, *(Sereno etal., 1990)* does not agree with the calculated distribution. Hence the equations system can be solved with the COMSOL Multi-physics software.

In the simplified dryer-capacity model, the grain layer is divided into a number of sub-layers of dissimilar thickness. It is assumed that within the sub-layers the grain and air temperatures are equal; the moisture content and (air/grain) temperature are uniform; and the thin-layer drying equation expresses the drying rate of the grain in a sub-layer. Thus *(Brooker et al. 1992)*:

$$\frac{M_f - M_e}{M_i - M_e} = \exp(-k\Delta t) \quad (3.4)$$

The value of the drying constant *k* for maize is *(Bebalis et al., 2004)*:

$$K = 1941 \exp\{-5032/[1.8(T_i+273)]\}. \quad (3.5)$$

Table 3-1 Mathematical models applied to moisture ratio values.

Model number	**Model name**	**Model equation**	**Reference**
1	Lewis	MR = exp(-kt)	Midilli (2001)
2	Handerson and pabis	MR = a exp (-kt)	Chhinnan, (1984)
3	Page	MR = exp(-ktn)	Agrawal and Singh (1977)
4	Midilli and kucuk	MR = a exp (-ktn) + bt	Midilli et al. (2002)
5	Wang and Singh	MR = 1 + at + bt2	Wang and Singh (1978)

3.1.2 Drying Curves Model

The moisture ratio (*MR*) of maize during drying experiments can be calculated using the following Equation:

$$MR = (M-M_e)/(M_0 - M_e) \quad (3.6)$$

Where *M*, *Mo*, and *Me* are moisture content at any drying time, initial and equilibrium moisture content (kg water/kg dry matter), respectively. The values of *Me* are relatively small compared to those of *M* or *Mo*, hence the error involved in the simplification is negligible *(Aghbashlo et al., 2001)*, hence moisture ratio was calculated as:

$$MR = M/M_0 \quad (3.7)$$

The Exponential model is expressed as:

$$MR = a \exp(-ct) \quad (3.8)$$

For drying model selection, drying curves were fitted to 12 well known thin layer drying models. The goodness of fit was determined using three parameters: coefficient of determination (R^2), reduced chi-square and root mean square error (*RMSE*) using Equations (3.7-3.9), respectively *(Togrul et al., 2003)*.

$$MR = (M - M_e)/ (M_0 - M_e) \quad (3.9)$$

$$R^2 = 1 - \left[\frac{\sum_{i-1}^{N}(MR_{Pre,i}-MR_{exp,i})^2}{\sum_{i-1}^{N}(MR_{Pre}-MR_{exp,i})^2}\right] \quad (3.10)$$

$$x^2 = \frac{\sum_{i-1}^{N}(MR_{Pre,i}-MR_{exp,i})^2}{N-M} \quad (3.11)$$

$$RMSE = (\sum_{i-1}^{N}[MR_{Pre,i} - MR_{exp,i}]^2)^{1/2} \quad (3.12)$$

In the above Equations *MRpre,i* is the *i*th predicted moisture ratio, *MRexp,i* is the *i*th experimental moisture ratio, *N* is number of observations and *m* is number of constants. The higher values for R^2 and lower values for x^2 and *RMSE* are chosen as the criteria for goodness of fit *(Demir et al., 2004).*

3.2 Drying curves

Prediction of the approximate drying period. Seeds dry at an exponential rate until the equilibrium moisture content is reached. The rate of drying of different seed lots of the same species is fairly constant for seeds dried under the same environmental conditions. The length of the drying period can be predicted as follows:

3.2.1 Prediction of the correct drying period by weight loss

Prediction of the correct drying period by weight loss can be determined as follows:

a. Predict the current percentage moisture content and the percentage moisture content required for storage.
b. Weigh the seed sample.
c. Using these three values to calculate the weight of seeds at the required moisture content by using the following formula:

$$\text{Final seed weight} = \text{Initial seed weight x } \frac{(100 - \text{Initial \% moisture content})}{(100 - \text{Final \% moisture content})}$$

Grain drying curves have been developed by different researchers using different methods of drying as shown in figures 3-2, 3-3, 3-4.

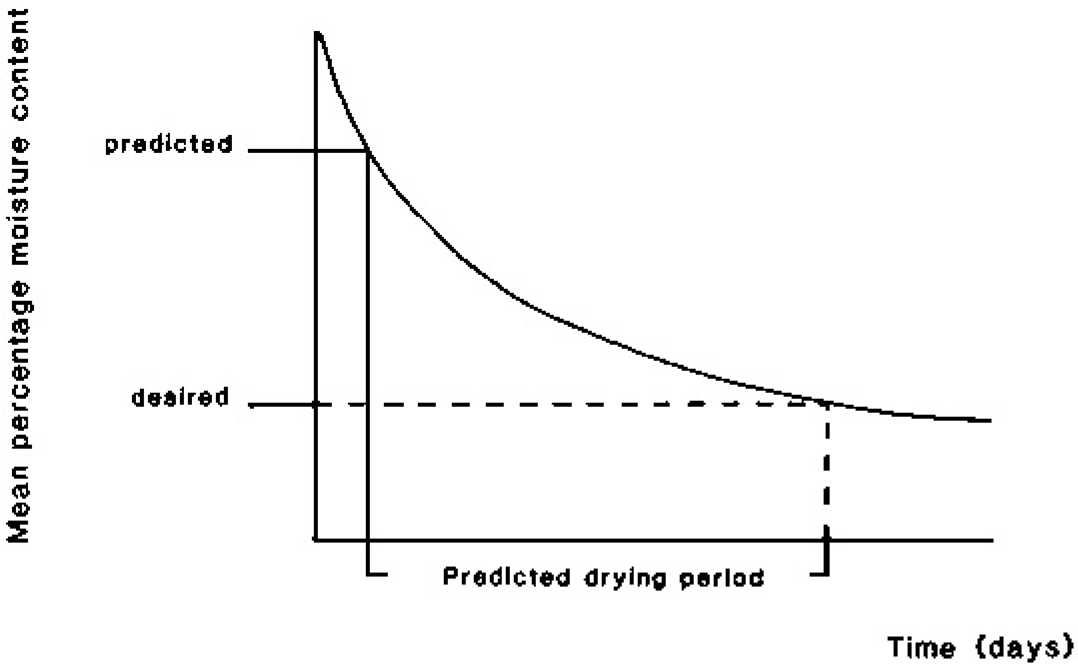


Figure 3-1: A graph of moisture ratio against time in different positions of trying equipment *(ASAE, 2004)*.

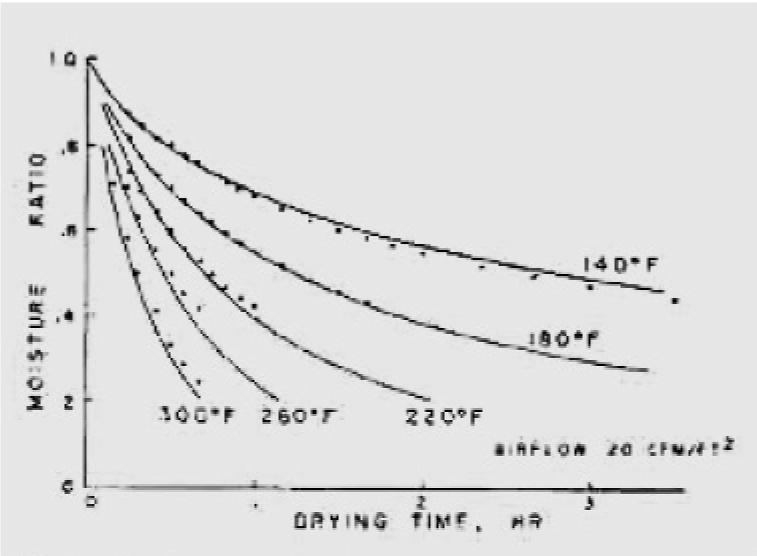


Figure 3-2: Predicted (curves) versus experimental points thin layer drying results *(ASAE, 2004)*

Moisture content against time in different position of a drying equipement in a cross flow dryer.

(ASAE, 2004)

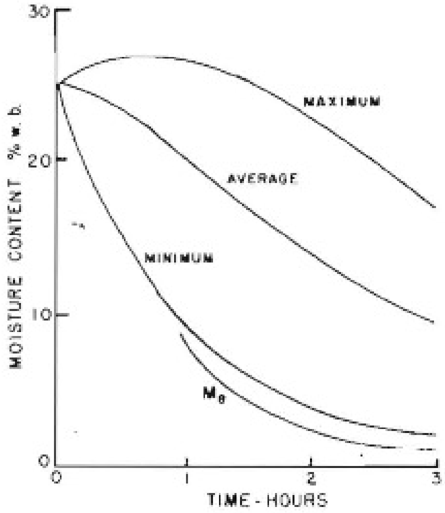


Figure 3-3: Crossflow Dryer. *(ASAE, 2004)*

Grain temperature against time in different positions of a drying equipment*(ASAE, 1968)*

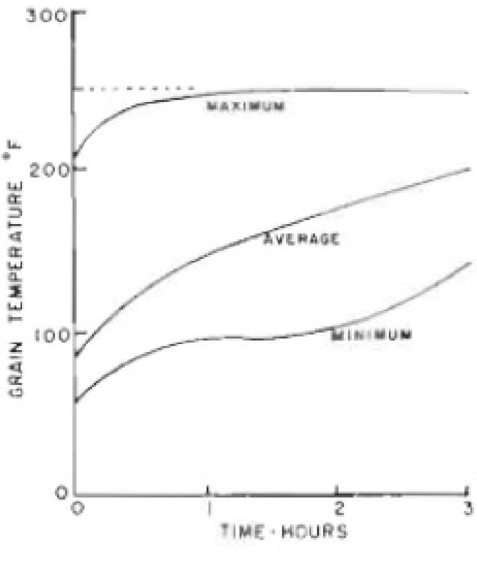


Figure 3-4: Cross flow Dryer *(ASAE, 2004)*

For each and every product, there is a representative curve that describes the drying characteristics for that product at specific temperature, velocity and pressure conditions.

Drying occurs in three different periods, or phases, which can be clearly defined.

The first phase, or initial period, is where sensible heat is transferred to the product and the contained moisture. This is the heating up of the product from the inlet condition to the process condition, which enables the subsequent processes to take place. The rate of evaporation increases dramatically during this period with mostly free moisture being removed *(shah et al., 2011).*

In some instances, pre-processing can reduce or eliminate this phase. For example, if the feed material is coming from a reactor or if the feed is preheated by a source of waste energy, the inlet condition of the material will already be at a raised temperature *(shah et al., 2011).*

The second phase, or constant rate period, is when the free moisture persists on the surfaces and the rate of evaporation alters very little as the moisture content reduces. During this period, drying rates are high and higher inlet air temperatures than in subsequent drying stages can be used without detrimental effect to the product. There is a gradual and relatively small increase in the product temperature during this period *(shah et al., 2011)*

Interestingly, a common occurrence is that the time scale of the constant rate period may determine and affect the rate of drying in the next phase.

The third phase, or falling rate period, is the phase during which migration of moisture from the inner interstices of each particle to the outer surface becomes the limiting factor that reduces the drying rate *(shah et al., 2011).*

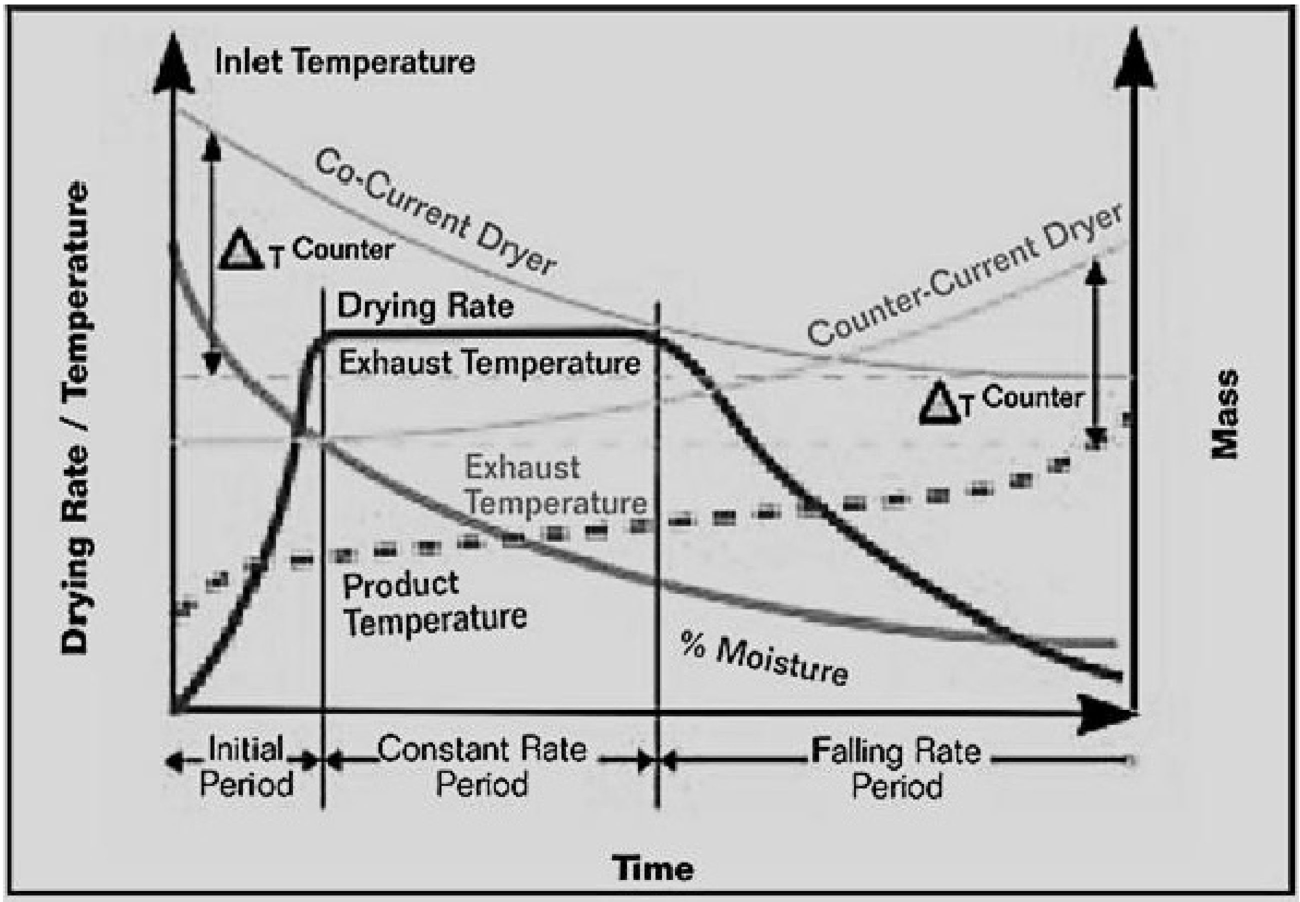


Figure 3-5: Grain Drying curve ***(shah et al., 2011)***

3.4 Moisture Content

No any agricultural product in its natural state is normally dry. Moisture is usually indicated as a percent moisture content for the product. There are two methods for determining moisture content, and this are; wet basis (*m*) and dry basis (*M*) *(Brusewitz., 2004)*.

Measuring moisture content allows control of the drying process such that drying is carried out until a specific level of moisture content is achieved rather than for a fixed time period.

The general governing equation for moisture content are:

$$m = \frac{m_w}{m_w + m_d} = \frac{m_w}{m_t} \tag{3.13}$$

$$M = \frac{m_w}{m_d} \tag{3.14}$$

Where: m = decimal moisture content wet basis (wb)

M = decimal moisture content dry basis (db)

M_d = mass of dry matter in the product

M_w = mass of water in the product

M_t = total mass of the product, water plus dry matter

Moisture content is always represented as a percentage and the relationship between the two equations become;

$$M = \frac{m}{1-m} \text{ or } m = \frac{M}{1+M} \tag{3.15}$$

Use of the wet basis measurement is common in the grain industry where moisture content is typically expressed as percent wet basis. However, use of the wet basis has one clear disadvantage, the total mass changes as moisture is removed. Since the total mass is the reference base for the moisture content, the reference condition is changing as the moisture content changes. On the other hand, the amount of dry matter does not change. Thus, the reference condition for dry basis measurements does not change as moisture is removed ***(Brusewitz., 2004).***

3.5 Equilibrium Moisture Content

A material held for a long time at a fixed temperature and relative humidity will eventually reach a moisture content that is in equilibrium with the surrounding air. This does not mean that the material and the air have the same moisture content. It simply means that an equilibrium condition exists such that there is no net exchange of moisture between the material and the air. This equilibrium moisture content (*EMC* or *Me*) is a function of the temperature, the relative humidity, and the product *(Brusewitz., 2004).*

Numerous equations for EMC curves have been proposed for various products *(Chirfe et al., 1982; ASAE, 2000).* The relative humidity defined by these equations is commonly called the equilibrium relative humidity (*ERH*). Thus, *ERH* is the relative humidity for equilibrium between air and a specific product at a given temperature. Mathematical expression of EMC is as follows:

$$\text{ERH} = \exp\left(\frac{-K}{Me^N}\right) \quad \text{Halsey} \qquad (3.16)$$

$$\text{ERH} = 1 - \exp(1 - K.t.\ Me^N) \quad \text{Henderson} \qquad (3.17)$$

$$\text{ERH} = \exp\left(\frac{\exp(K.t.C.t)}{Me^N}\right) \quad \text{Modified Halsey} \qquad (3.18)$$

Where: *ERH* = relative humidity, decimal

Me = equilibrium moisture content, percent, dry basis

t = temperature, °C

K, N, C = are constants determined for each material

A typical set of equilibrium moisture curves are presented as follows:

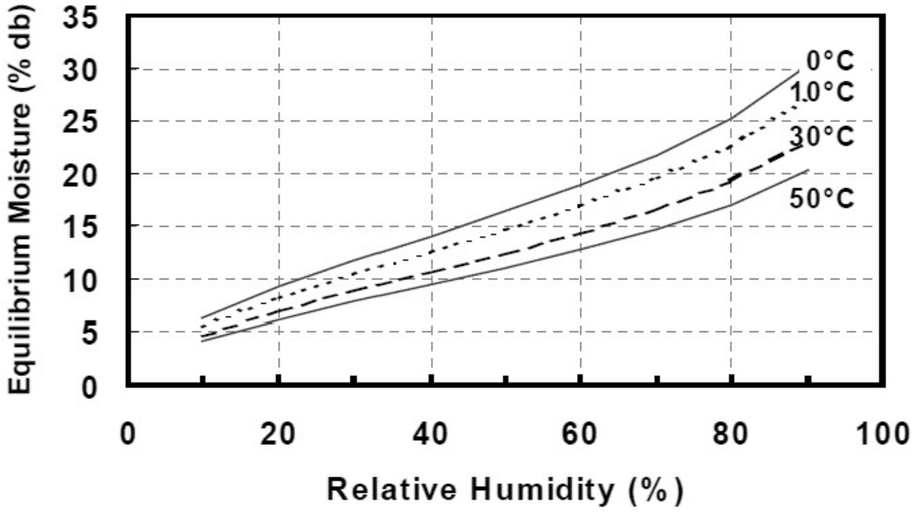


Figure 3-6: Equilibrium moisture curves for shelled corn. Computed from ASAE data *(ASAE, 2000)*.

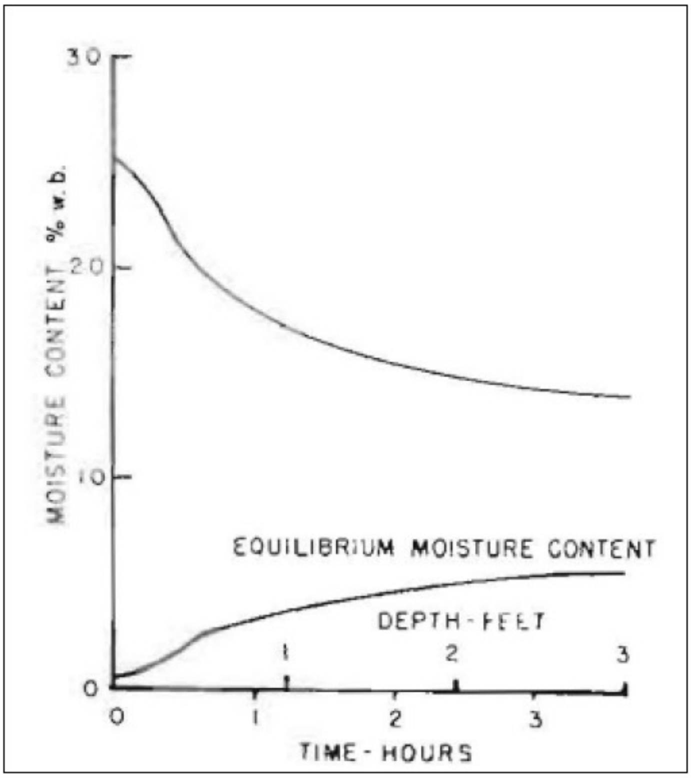


Figure 3-7: Equilibrium moisture content. *(ASAE, 2000)*

4.0MATERIAL AND METHODS

4.1 Identification of affordable and effective super absorbent polymers (SAPs) for inclusion in the construction of storage structures

The experiment was conducted in University of Nairobi Upper Kabete Campus. The first part of the project was identification of the best hydrogels that was used in maize drying. Hydrogels are readily available from plastics dealers and importers, but are manufactured in many grades. After a thorough desk study and ranking of the hydrogels on the basis of the reported properties, one type of SAP was selected for use in the experiment.

The properties taken into consideration were; swelling rate, swelling capacity and strength, affordability and whether the SAP is food grade or not. The SAP selected for grain drying would have to comply with food safety requirements if it is to be allowed for use with substances for human consumption.

There are many materials from which SAPs are made. However, the most commonly available SAP was identified as sodium poly-acrylate. It is currently used in the manufacture of SAPs which are listed as food grade such as the BASF products Luquafleece® and Luquasorb® that are applied in fish and meat packaging containers. BASF Luquasorb® FP 800 was selected for use in the experiment. The SAP is approved for indirect food contact in accordance with the BFR recommendations LIII. It is in granular form of Sodium Poly-acrylate Polymer Product. It was chosen because of the advantage it would have in terms of ease of being lain on the duct walls to absorb moisture from air entering maize drying storage.

4.2 Construction of storage structures and location of the best positions for hydrogels.

Three granaries of dimensions shown in figure 4-1 and volume of 2,865.5cm^3 were fabricated using metallic members with a wire mesh covering to hold maize; the structures were designed to optimize natural ventilation. The silos were put out in the open to study and establish the moisture migration paths so as to determine the best positions to place the hydrogels.

For the purpose of the research, four SAP bags each weighing 250 grams were placed in the SAP section of each silo. The SAP section was constructed between the Bottom West and Center West of the silo.

Maize was purchased dry and wetted in water to 33% (wet basis) moisture content (mc) and the container placed in a cold room at 0 °C so as to avoid germination. After soaking for 24 hours, the maize was removed from the cold room and placed in the pre-fabricated granary.

It was hypothesized that the moisture migration in the granary would be affected by:

- Position of granary in relation to the heat of the sun as the sun moves from east to west. In the morning the east side has more heat. In the evening it is the west. North and south have minimal. Figure 4-1 was divided into E, W, N, S and C to represent East, West, North, South and Center. These were only superficial and not physical divisions that were marked by masking tape
- Gravity: it was likely that water would move downward to bottom of silo. Hence the division 1, 2, and 3.
- Alternating day and night temperatures: To determine the effect of the two parameters (Temperature and Moisture Content), thermometers placed at the various sections were used to record temperature. To determine moisture content sampling was done by drawing samples in all 15 sections {5 (according to the orientation of the sun) * 3(along

the height) = 15 samples}. Readings were taken every morning, midday and evening since after the hot day temperature, vaporization had occurred and in the morning, it was expected that condensation had occurred due to cold night temperatures. The moisture content was taken over a period of 5 days for each of the locations, morning and evening. These readings were taken for 5 days because after that the maize might have germinated.

Curves were then plotted for (1) Moisture Content versus time for different solar orientation and (2) Moisture Content versus time for different heights. The curves (1) and (2) were compared for one in the morning and in the evening. Moisture migration analysis were used to obtain the best position to place desiccant hydrogel in the granary.

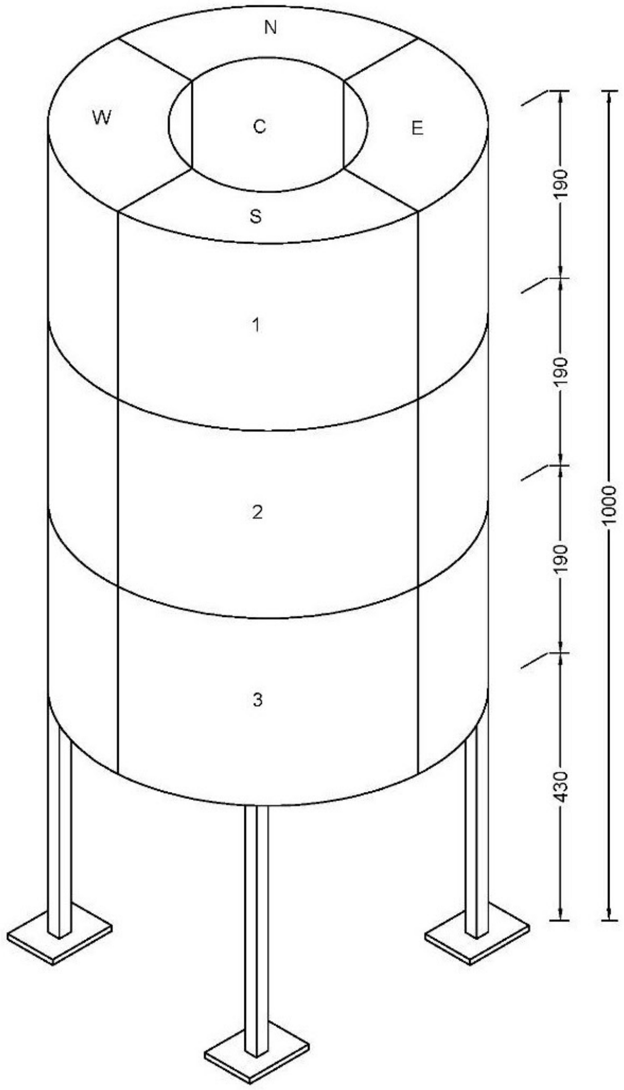


Figure 3-8:: Experimental Maize Silo

4.3 Experiment with SAP

Analysis of moisture migration of maize grains stored in the silo without SAP indicated that Bottom West and Center West had the highest moisture content. A section in the silo was demarcated and isolated in the silo to place the SAP. A section of dimension 15cm height by 15 cm width and 15 cm depth was separated in the silo at sections between the Bottom West and Center West. For each of the three silos, the granular SAP were put in four knitted bags each weighing 250 grams each and placed in the SAP section in silo.

The experiment was conducted like in the previous experiment without SAP, Moisture content of maize grains in the various sections in the Silos with the SAP was monitored for 5 days and the readings recorded for analysis.

Plate 4.1: Silos Used in the Research

4.4 Equipment Used in the Experiment

4.3.1 Moisture meter

To measure the moisture content of sampled maize grains, a grain moisture tester, agrotronix MT-16, was used. The moisture tester is a microprocessor- controlled instrument and provides a direct moisture read out. It can measure moisture in maize grains between 5% and 40%. The equipment has an error of ± 0.5%.

Plate 4.2: Grain Moisture Meter

4.3.2 Thermometer

To measure temperature inside the granary a mercury thermometer was used. To measure the temperature at a given section the probe of thermometers was inserted into section and kept and left for few minutes for temperature reading to stabilize.

4.5 Statistical analysis

The evaluation of the performance of super absorbent polymers was done by modelling the data from the silo with SAP and that without SAP and establishing their degree of fit to the chosen model. Modelling of the drying of maize in a silo with and without SAP required determination of the maize moisture content with time. Maize was put in two sets of silos; one set had no SAP and the other had SAP. The experimental procedure described in Section 3.2 was followed and maize moisture content monitored 5 days. The experiments were conducted in three silos, during analysis the average of three replications was used in plotting graphs

The experimental data was fitted to three different mathematical models. This was performed using MS Excel 2010 in order to select the best model to describe the drying curve of maize under normal environmental conditions and with SAP. The coefficient of determination (R^2) was used to evaluate the goodness of fit of the tested mathematical models to the measured data. The best model was selected based on the highest values of the R^2.

5.0 RESULTS AND DISCUSSION

This chapter presents analysis of data obtained from the experiments conducted and discussions of the analysis. Data on moisture Content and temperature were analyzed for the various silo sections according to depth and orientation, average of the readings obtained from the three silos were used for analysis.

5.1 Vertical moisture and temperature variation

5.1.1 Temperature Variation in Silo

Table 5.1 shows the computed average temperature (°C) for the top, center , bottom sections and the silo average temperatures.

Table 3-2: Average Temperature with Depth in Experimental Silos without SAP

	Day 1		Day 2			Day 3			Day 4		
	Morn	Noon	Morn	Noon	Even	Morn	Noon	Even	Morn	Noon	Even
Time (Hrs) →	**0**	**12**	**24**	**30**	**36**	**48**	**54**	**60**	**72**	**78**	**84**
Section ↓	Temperature Reading (°C)										
Top	27.0	29.0	31.7	34.1	34.2	34.8	37.9	37.9	37.1	32.5	38.1
Center	27.0	29.0	36.3	37.2	39.3	39.4	39.9	42.0	41.9	40.7	42.6
Bottom	27.0	29.0	33.2	36.2	35.4	34.6	37.1	37.9	36.6	37.2	35.8
Silo Average	27.0	29.0	33.8	35.8	36.3	36.3	38.3	39.3	38.5	36.8	38.8

The temperature profile plotted in Figure 5-1 was obtained from Table 5-1. The graph shows average temperature changes for the different sections inside the grain silo.

The equations of the trend lines are presented in Table 5-2

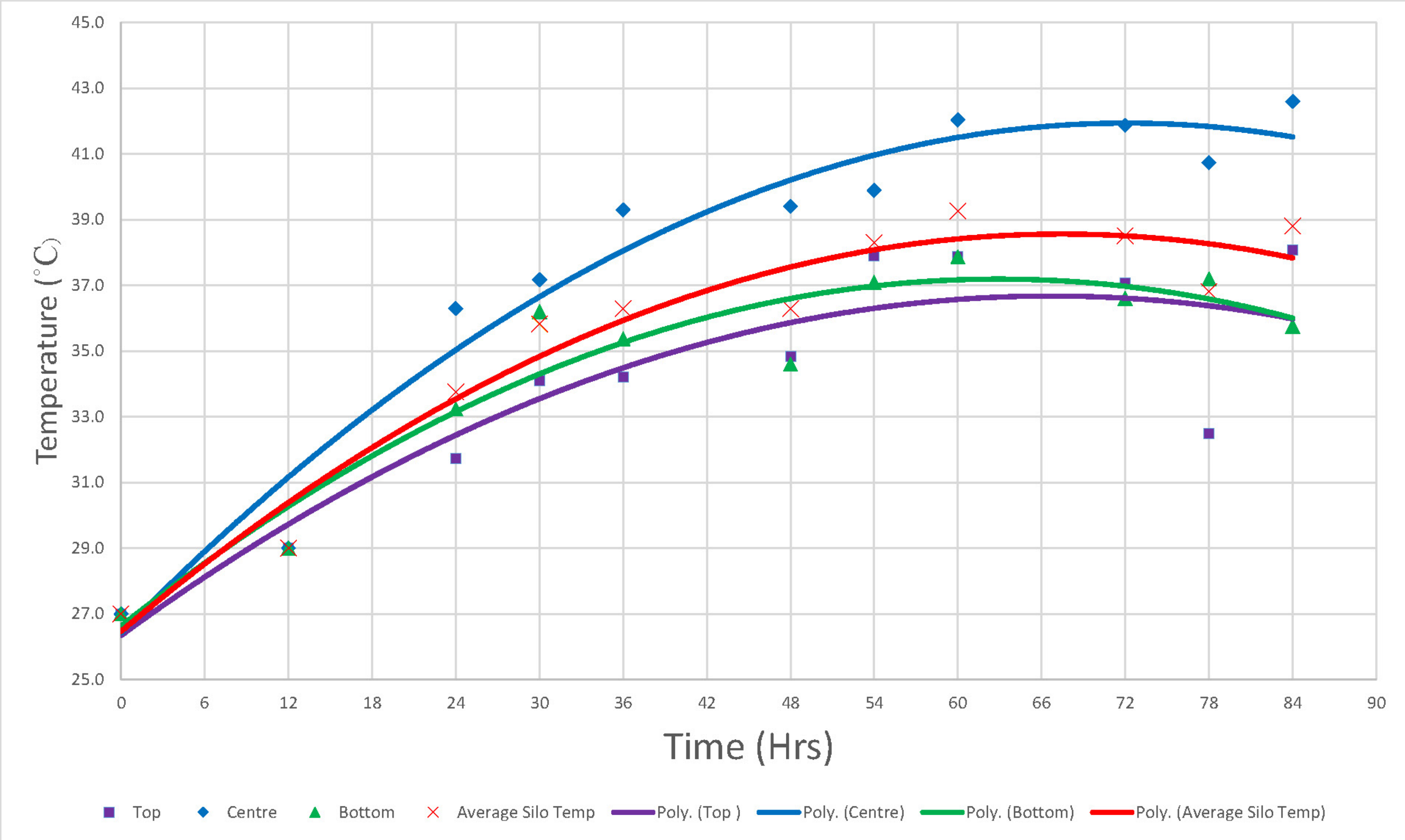


Figure 3-9: Temperature changes with Depth in the silos without SAP

Table 3-3: Temperature Equations of Silo without SAP with Depth

No.	Section	Equation	R^2 Value
1.	Top	$T = -0.0023t^2 + 0.3098t + 26.3$	0.806
2.	Center	$T = -0.00298t^2 + 0.430t + 26.4$	0.953
3.	Bottom	$T = -0.0027t^2 + 0.3358t + 26.6$	0.915
4.	Silo Average	$T = -0.00266t^2 + 0.359t + 26.5$	0.946

Key:

- T: Temperature
- t: Time

The highest temperatures were observed at midday with relatively lower temperatures in the morning and in the evening. Maximum temperatures were observed at the center and bottom section with a high of 56.3^0C at the center - center section of the silo on the fourth day of drying (refer to appendix 3). This was attributed to the greenhouse effect of the silo and also respiration and decomposition from the grains all around.

The top sections had the lowest temperatures compared to the center and bottom sections of the silo. It should also be noted that the temperatures are lower around the walls of the silo rising towards the center where the maximum temperatures are observed. The trend lines that best represent the temperature changes followed second order polynomial equations as presented in Table 5-2.

5.1.2 Moisture Migration in Silo without SAP

The moisture migration pattern for silo without SAP is presented in a 3-D model graph shown in Figure 5.2. The graph was obtained by plotting averaged moisture content recorded in the three grain silos per section. The recorded data on moisture content is presented in the appendix 3. This indicated non-uniform drying and was attributed to moisture migration within the silo.

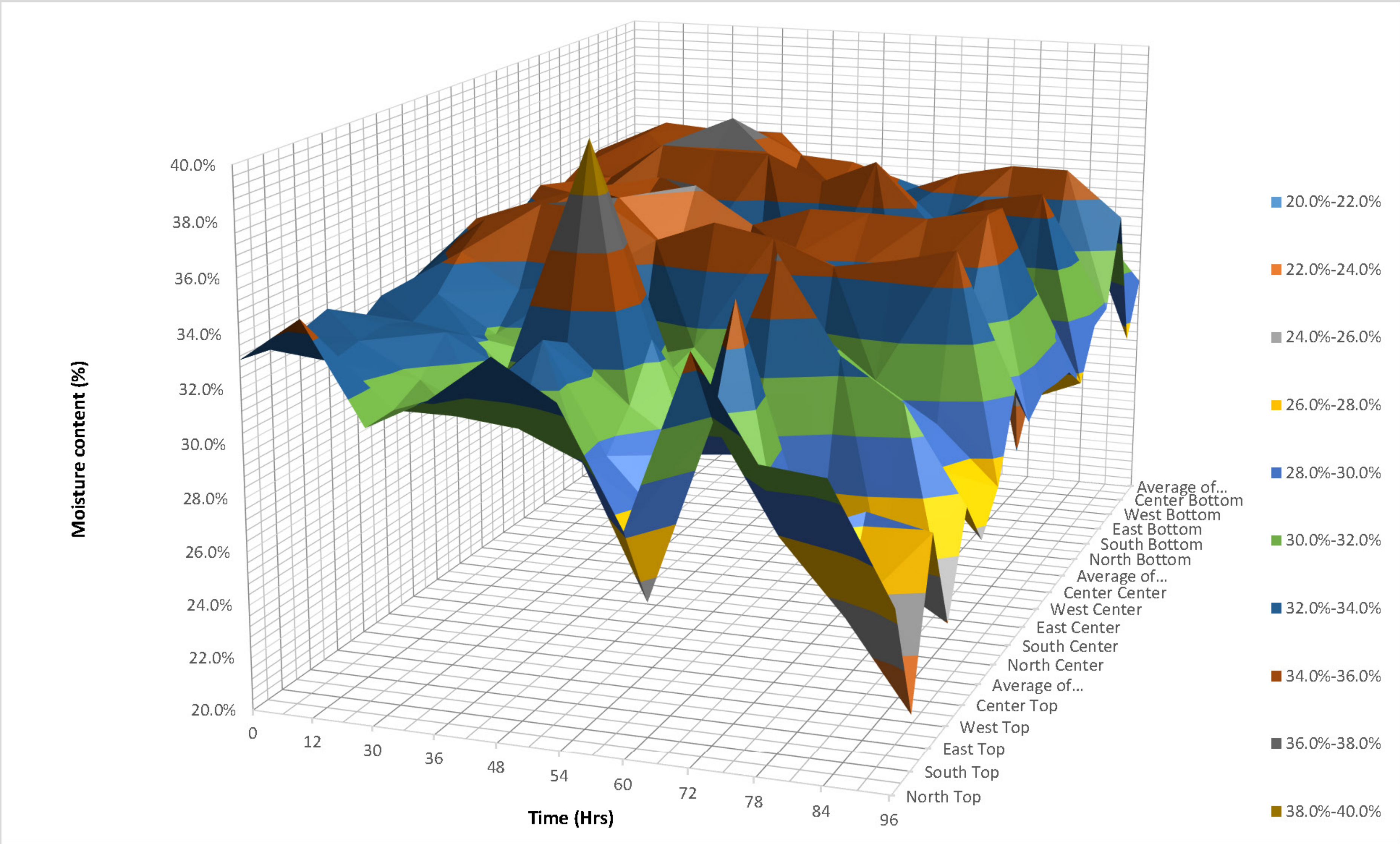


Figure 3-10: Moisture profile within silo without SAP

The series of peaks and troughs without defined order throughout the entire period implied a great deal of moisture variability within the silo. This indicated non-uniform drying and was attributed to moisture migration within the silo.

Table 5-3 shows the average moisture content of the top, center and bottom sections of the silo.

Table 3-4: Average Moisture Content (%) With Depth in Experimental Silos without SAP

	Day 1		Day 2		Day 3			Day 4			Day 5
	Morn	Even	Noon	Even	Morn	Noon	Even	Morn	Noon	Even	Morn
Time (Hrs) →	0	12	30	36	48	54	60	72	78	84	96
Section ↓	Moisture Content (% wb)										
Top	35.5	33.2	31.8	31.1	31.1	31.1	27.8	30.0	28.8	28.2	25.6
Center	35.5	34.6	34.6	35.4	33.5	33.6	33.5	33.4	33.6	33.7	28.6
Bottom	35.5	34.9	34.8	35.2	32.9	33.3	32.6	32.0	30.1	32.3	29.5
Silo Average	35.5	34.2	33.7	33.9	32.5	32.6	31.3	33.0	30.8	31.4	27.9

Figure 5-3 shows the variation of moisture content with time in the silo without SAP over time indicating the trend of moisture migration and the drying curves for the various sections. The outer sections by the end of the experiment had less moisture content than in the center of the silo, this is because the moisture migration absorbed in the center of the silo.

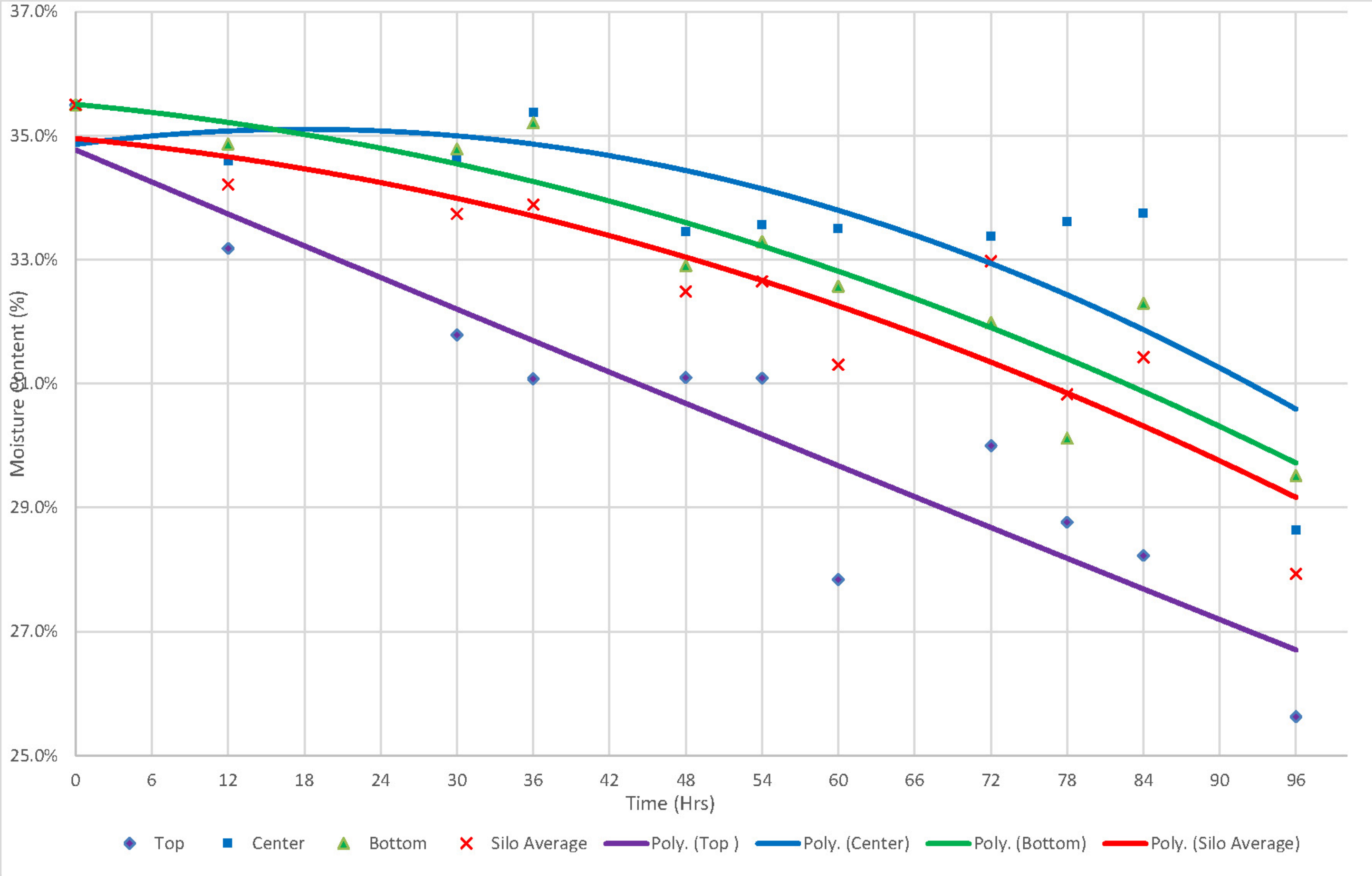


Figure 3-11: Moisture Content (%wb) with Depth in Experimental Silos without SAP

Table 3-5: Drying Equations of Silo without SAP Sections with Depth

Silo Section	Equation	R^2 Value
Top	$M = 2*10^{-7}t^2 - 0.0009t + 0.3477$	0.8744
Center	$M = -7*10^{-6}t^2 + 0.0003t + 0.3486$	0.6627
Bottom	$M = -4*10^{-6}t^2 - 0.0002t + 0.3551$	0.8663
Silo Average	$M = -4*10^{-6}t^2 - 0.0002t + 0.3496$	0.8278

Key:

- M: Moisture Content (% wb)
- t: Time

When the silo was loaded, the highest moisture content, 34.7%, was observed at the bottom as shown in Figure 5.3. This was caused by moisture being drained off due to gravity. There was a rapid constant rate drying for the first three days in all sections of the silo due to the high vapour pressure gradient between the wet maize and the atmospheric air. This was followed by an increase in moisture at the center and bottom section of 35.4% and 35.2 respectively this was attributed to grain respiration.

It was observed that drying occurred faster at the top compared to the center and bottom sections. The top section had opening for ventilation, hence moisture easily escaped to the atmosphere aided by the high vapour pressure gradient between the grains at the top surface of the silo and the atmospheric air. The highest observed moisture content at the top section was 33.4% at the west top with the lowest being 22.1 observed at the south top section. Averagely the moisture content at the top section dropped from 32.9% to 25.6% after the fifth day of drying.

High moisture concentration was observed at the center and bottom section indicating a moisture migration pattern towards the center. It is possible to draw a correlation between the temperature and the moisture content since comparing Figure 5-1 and Figure 5-3 indicates that high temperature regions also have high moisture content. This was because the high temperatures in these regions led to the vaporization of moisture from the grains hence high moisture content.

The average moisture reduction in these two regions (center and bottom) was almost half the change observed in the top section. The moisture content fell from a high of 33.6 to 28.6% in center section and 34.4% to 29.5 in the bottom section. It was for this reason that the best location for the SAP was at the between center section and the bottom. Proper airflow should also be emphasized to enhance moisture distribution and ensure uniform drying of grains.

5.1.3 Effects of SAP on Moisture Profile

The moisture migration pattern for silo with SAP is presented in a 3-D model graph shown in Figure 5-4. The graph was obtained by plotting averaged moisture content recorded in the three grain silos per section. The recorded data on moisture content is presented in the appendix 3.

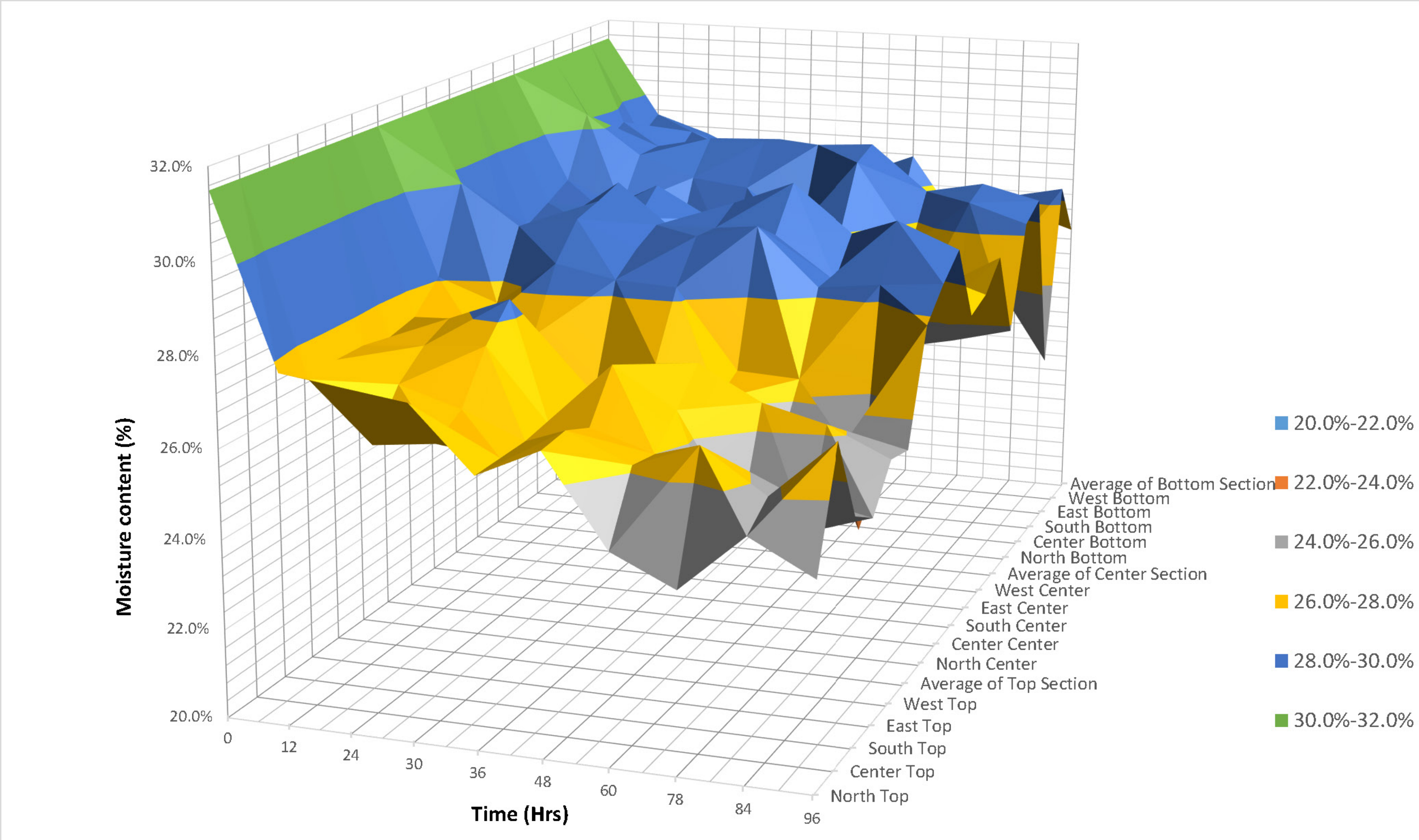


Figure 3-12 : Moisture profile in the Silo with SAP

Table 5-5 indicates the average moisture content in the top, center and bottom sections in the second experiment when SAP was introduced into the silo.

Table 3-6: Moisture Content Variation with Depth in Experimental Silos with SAP

	Day 1		**Day 2**		**Day 3**		**Day 4**			**Day 5**
	Morn	Even	Morn	Noon	Even	Morn	Even	Noon	Even	Morn
Time (Hrs) →	**0**	**12**	**24**	**30**	**36**	**48**	**60**	**78**	**84**	**96**
Silo Section ↓	**Moisture Content (% wb)**									
Top	31.5	27.4	27.2	27.2	26.0	26.8	26.1	25.2	25.4	25.4
Center	31.5	28.5	28.4	29.2	28.4	28.9	28.5	27.9	27.2	28.0
Bottom	31.5	29.5	29.0	28.4	28.5	28.2	28.8	26.8	27.5	27.1
Silo Average	31.5	28.5	28.2	28.3	27.7	28.0	27.8	26.6	26.7	26.8

Figure 5-5 is obtained from Table 5-5. When SAP was introduced into the silo the curves shown were obtained. It can be deduced that moisture variability in the silo without SAP was reduced albeit not completely. This implies a general progressive moisture reduction with reduced moisture variability at every section of the silo.

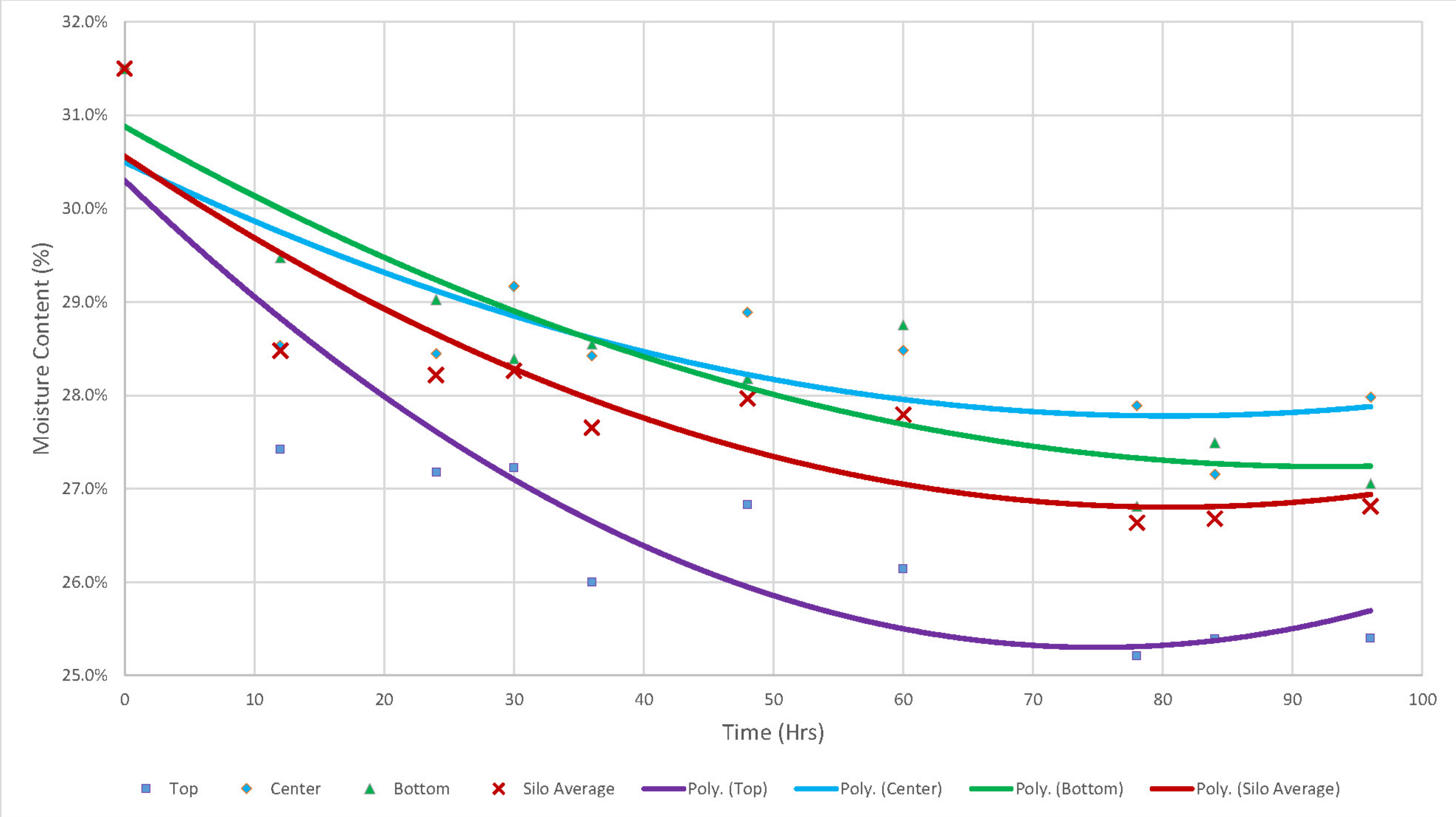


Figure 3-13: Moisture variation in the three sections with time in the silo with SAP

Table 3-7: Drying Equations of Silo Sections with Depth

Silo Section	Equation	R^2 Value
Top	$M = 9*10^{-6}t^2 – 0.0013t + 0.303$	0.824
Center	$M = 4*10^{-6}t^2 – 0.0007t +0.305$	0.645
Bottom	$M = 4*10^{-6}t^2 – 0.0008t + 0.309$	0.850
Silo Average	$M = 6*10^{-6}t^2 – 0.0009t + 0.0.306$	0.821

The top section still dried faster as compared to other sections due to the effects of direct sunlight. There was still evidence of high moisture concentration toward the center and bottom sections where the SAP was located, as shown by Figure 5.5.

The general downward slope of the curves in the silo with SAP showed the positive effect of SAP in taking up moisture from the grain. It can also be seen that in this silo, it took a shorter time to reach relatively the same level of dryness as the silo without SAP

It is necessary to aerate the silo to ensure uniform drying of the grain and reduce the impacts of moisture migration.

5.2 Variation of Temperature and Moisture Under the Influence of External Climatic Conditions

5.2.1 Temperature Variation across the Silo

Table 5-7 indicates the average temperature for the North, South, Center, East and West sections of the silo.

Table 3-8: Temperature Variation with Orientation

	Day 1		**Day 2**			**Day 3**			**Day 4**		
	Morning	**Noon**	**Morning**	**Noon**	**Even**	**Morn**	**Noon**	**Even**	**Morn**	**Noon**	**Even**
Time (Hrs) →	**0**	**12**	**24**	**30**	**36**	**48**	**54**	**60**	**72**	**78**	**84**
Silo Section ↓	Temperature Reading (°C)										
North	27.0	29.0	32.8	33.4	33.4	31.3	35.4	33.3	31.1	29.9	32.9
Center	27.0	29.0	35.9	41.8	39.4	46.2	42.7	48.6	50.9	52.4	55.2
South	27.0	29.0	33.5	34.2	37.2	35.2	38.8	39.3	37.9	32.7	38.6
East	27.0	29.0	33.4	35.3	35.0	32.3	36.2	36.1	33.0	32.8	34.9
West	27.0	29.0	33.2	34.3	37.8	36.5	38.3	38.9	39.6	36.2	39.0

The variation of temperature across the silo was plotted as shown in Figure 5.6

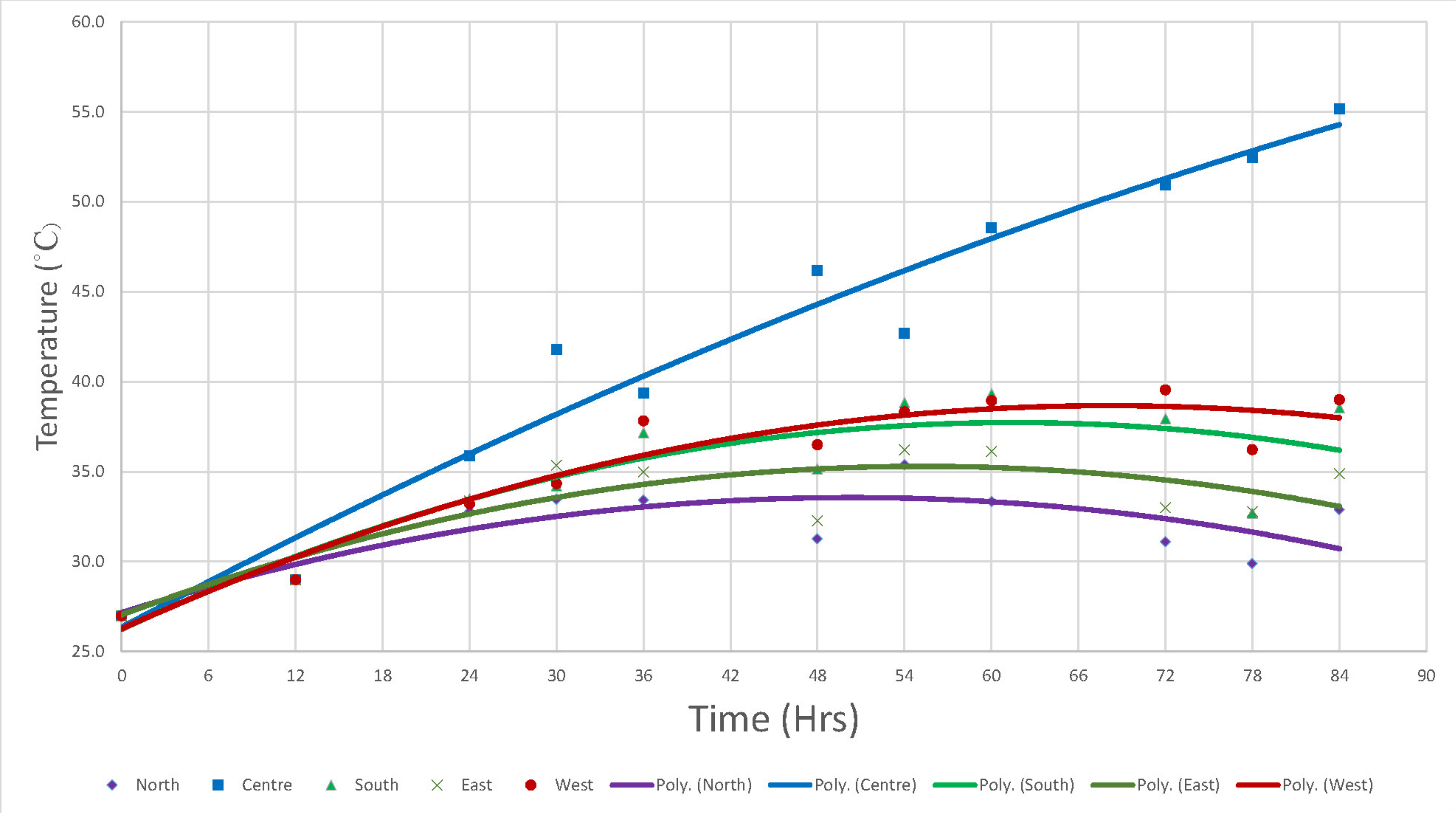


Figure 3-14: Temperature variation across silo (no SAP)

It was a general observation that the temperature rose as from the sides towards the center of the silo. The center section exhibited marked high temperature compared to the other sections. This was attributed to green-house effect within the silo and respiration of the grains. It is evident from the graph that the northern section recorded the lowest temperatures.

Table 5 -8 Presents the Equations for Temperature Changes across Silo without SAP

Table 3-9: Equations for Temperature Changes across Silo without SAP

Silo Section	Equation	R Square Value
North	$M= -2.52E-03x^2 + 2.54E-01x + 2.72E+01$	0.643
South	$M= -3.03E-03x^2 + 3.73E-01x + 2.62E+01$	0.784
East	$M= -2.70E-03x^2 + 2.99E-01x + 2.70E+01$	0.736
West	$M= -2.67E-03x^2 + 3.64E-01x + 2.63E+01$	0.920
Center	$M= -1.15E-03x^2 + 4.29E-01x + 2.63E+01$	0.957

5.2.2 Moisture Variation across the Silo without SAP

Table 5-9 indicates the average moisture content for the North, South, Center, East and West sections of the silo.

Table 3-10: Average Moisture Content Across Silo without SAP

Silo Section	Time (Hrs)										
	0	12	30	36	48	54	60	72	78	84	96
North	35.5	34.3	32.1	32.5	29.9	30.9	27.9	30.4	29.8	28.9	27.1
Center	35.5	34.1	34.3	33.8	34.0	33.4	32.3	34.1	33.0	33.4	27.9
South	35.5	34.1	34.4	34.5	33.9	33.5	32.1	33.2	32.4	31.9	27.3
East	35.5	34.0	33.2	34.5	33.5	31.9	31.4	34.0	30.4	30.8	28.7
West	35.5	34.6	34.7	34.2	34.7	33.5	32.8	33.2	32.0	32.1	28.7
Silo Average	35.5	34.2	33.7	33.9	33.0	32.6	31.3	33.0	31.5	31.4	27.9

Figure 5.7 was obtained Table 5- 9 by plotting the moisture content of the different sections across the silo.

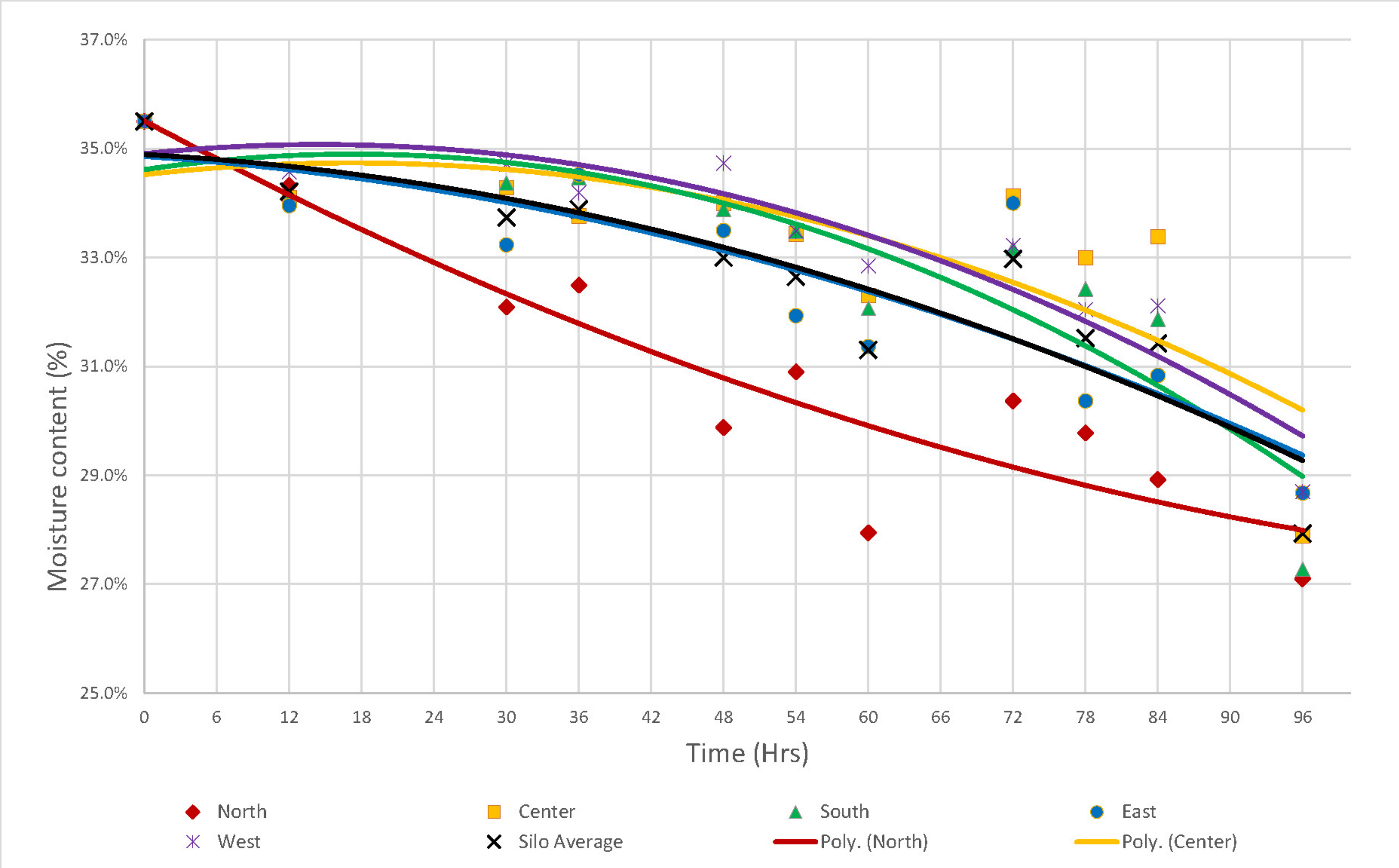


Figure 3-15: Moisture content across the silo without SAP

Table 3-11: Drying Equations for Moisture Content across Silo without SAP

Silo Section	Equation	R Square Value
North	$M = 4x10^{-6}t^2 - 0.0012t + 0.3551$	0.8651
South	$M = -1x10^{-5}t^2 + 0.0003t + 0.3462$	0.8016
East	$M = -4x10^{-6}t^2 - 0.0002t + 0.3486$	0.7375
West	$M = -8x10^{-6}t^2 + 0.0002t + 0.3491$	0.8814
Center	$M = -7x10^{-6}t^2 + 0.0003t + 0.3452$	0.5889
Silo Average	$M = -5x10^{-6}t^2 - 0.0001t + 0.3489$	0.8218

Apart from the north section it was observed that there was no distinct region with a high moisture content. However, it was also observed that the peaks in moisture content kept alternating from one section to another. This was a clear indication that there was moisture migration among the various sections across the silo. It is important to note that the north section had the lowest moisture content, this may be attributed to

5.2.3 Moisture Content across the Silo with SAP

Table 5-11 indicates the average moisture content for the North, South, Center, East and West sections of the silo when SAP was introduced.

Table 3-12: Average Moisture Content with Orientation (SAP)

Date	18th Feb		19th Feb			20th Feb		21st Feb		22nd Feb
	Morn	Even	Morn	Noon	Even	Morn	Even	Noon	Even	Morn
Time (Hrs)	**0**	**12**	**24**	**30**	**36**	**48**	**60**	**78**	**84**	**96**
North	30.5	28.2	27.8	27.7	27.1	27.5	26.4	25.2	24.6	26.1
Center	30.5	29.2	28.2	28.1	27.8	27.9	28.4	27.5	27.6	27.9
South	30.5	28.3	28.3	28.6	28.2	28.4	28.3	27.1	28.0	27.6
East	30.5	28.5	28.3	28.8	28.0	28.7	28.6	26.8	26.2	25.3
West	30.5	28.2	28.5	28.0	27.0	27.3	27.3	26.6	26.9	27.1
Silo Average	30.5	28.5	28.2	28.3	27.7	28.0	27.8	26.6	26.7	26.8

Figure 5.8 presents the curves of Moisture Variation across the Silo with SAP the figure is derived from Table 5-11.

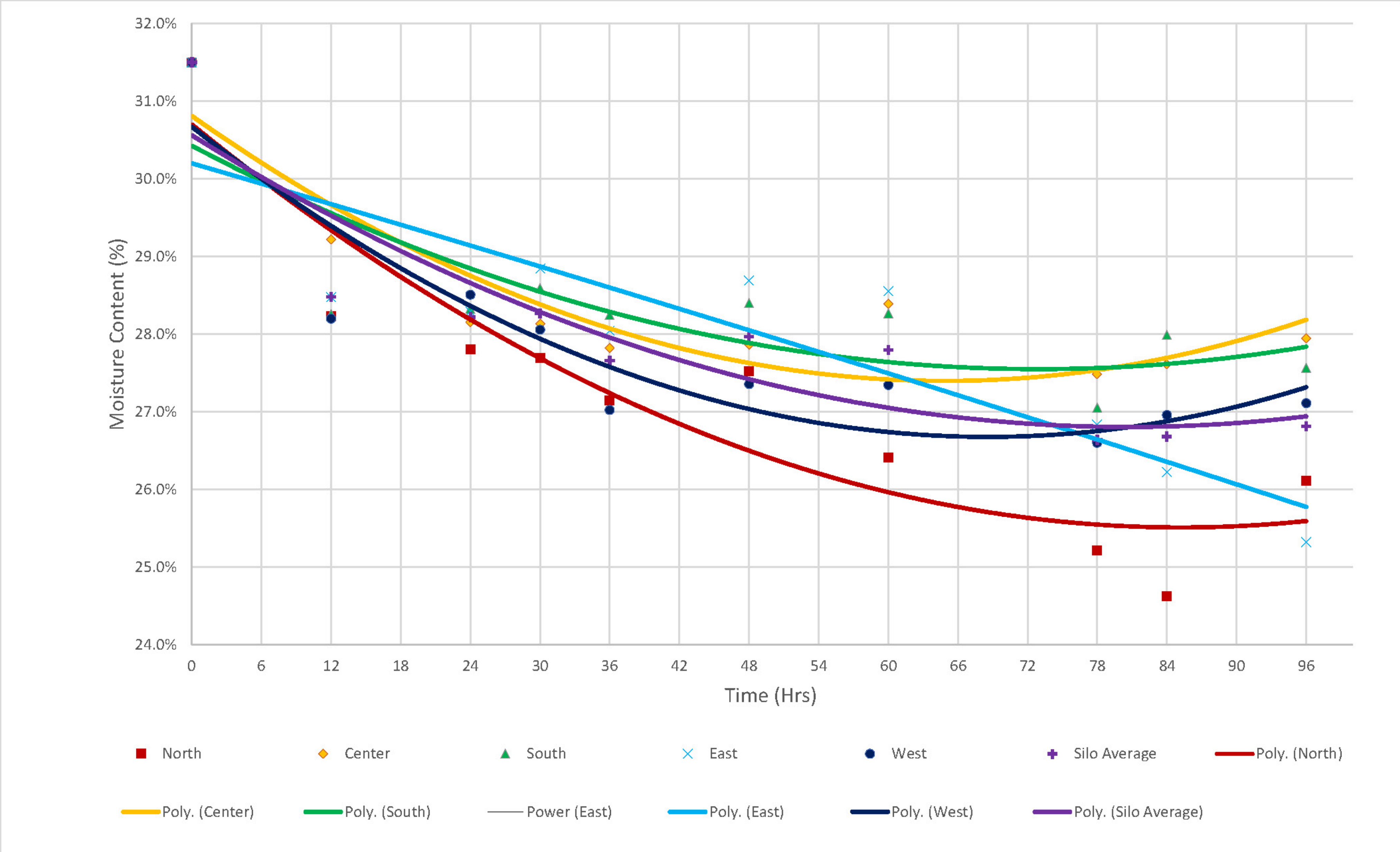


Figure 3-16: Moisture Variation across Silo with SAP

Table 3-13: Drying Equations for Moisture Content across Silo with SAP

Silo Section	Equation	R Square Value
North	$M = 7*10^{-6}t^2 – 0.0012t + 0.307$	0.864
South	$M = 5.4*10^{-6}t^2 – 0.00078t + 0.304$	0.657
East	$M = -2.8*10^{-7}t^2 – 0.0004t + 0.302$	0.769
West	$M = 8.49*10^{-6}t^2 – 0.0012t + 0.307$	0.834
Center	$M = 8.11*10^{-6}t^2 – 0.001t + 0.308$	0.825
Silo Average	$M = 6*10^{-6}t^2 - 0.0009t + 0.305$	0.821

It was observed that just like in Figure 5-7, the north section had the lowest moisture content. The east section experienced quite high moisture content at the beginning of drying but it showed rapid reduction in moisture content towards the end of the drying period. The center section and the south section were the regions with the highest moisture concentration.

It is important to note that there was a general downward trend with respect to moisture content in the various regions across silo when SAP was introduced. This implied the effectiveness of SAP in eliminating moisture migration hence enhancing drying.

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The research objectives were reached in this paper whereby in the first instance, moisture migration in stored wet maize grains was studied. Highest average temperatures were observed in the center section of the silo. Results of the study indicated that SAP ought to be placed in the center section and partly bottom section as these were the areas with high moisture concentration.

The results showed that the Wang and Singh drying model (second order polynomial equations) best described drying of the wet grains in the study for both experimental settings with SAP and without SAP, the model had the highest R-squared values. There was high moisture depletion in the top layer while there was a high moisture concentration at the center and bottom section with the central section having the highest, for both experiments (With SAP and without SAP)

When SAP was introduced in the maize silo, moisture content curves obtained had generally steeper and smoother negative gradient compared to those obtained from silo without SAP whose curves showed a series of negative and positive gradient. This showed that the SAP was able to take up the extra moisture that emigrated into the center and bottom section and those that were brought about by moisture diffusion. The research work indicated that SAP can be used in drying maize grains

6.2 Recommendation

The research work indicated that SAP can effectively be used in drying maize grains. The following are the study recommendations:

I. More research should be conducted to establish the amount of SAP required per kilogram of maize grain.

II. Future research work should consider passing preheated air in the grain to optimise moisture absorption by SAP and improve air circulation in the silo.

III. Studies should be done to evaluated the effectiveness of using SAP fabrics in grain drying. The fabrics can be placed on silo wall or placed in various layers within the grain silo.

7.0 REFERENCES

ABD EI-REHIRN HA, HEGAZY ESA and ABD EL-MOHDY HL, (2004): Radiation synthesis of hydrogels to enhance sandy soils water retention and increase performance, J. Appl. Polym. Sci., 93: 1360-1371.

AGHBASHLO M, KIANMEHR M H, ARABHOSSEINI, A and NAZGHELICHI T (2001). Modelling the carrotth in-layer drying in a semi-industrial continuous band dryer. Czech J. Food Science, 29 (5), 528-538.

AL-HARBI A.R., AL-OMRAN A.M, SHALABY A.A and CHOUDHARY M.I. (1999). "Efficacy of a Hydrophilic Polymer Declines with Time in Greenhouse Experiments." *HortScience* 34(2):

223-224.

American Society of Agricultural Engineers (ASAE) (2004). Thin-layer drying of Agricultural crops.

ANDRY, H., T. YAMAMOTO, T. IRIE, S. MORITANI, M. INOUE and H. FUJIYAMA. (2009). "Water retention, hydraulic conductivity of hydrophilic polymers in sandy soil as affected by temperature and water quality." Journal of Hydrology 373: 177-183.

BHARDWAJ A. K., MCLAUGHLIN R. A, SHAINBERG I and LEVY G. J. (2009). "Hydraulic Characteristics of Depositional Seals as Affected by Exchangeable Cations, Clay Mineralogy, and Polyacrylamide." *Soil Science Society of America Journal* 73: 910 - 918.

ASAE. (2000). *ASAE Standards* D245.5: Moisture relationships of grains. ASAE,

St. Joseph, MI.

BEBALIS, D.A and BELESSIOTIS, V.G (2004). Influence of the drying conditions on the drying constants and moisture diffusivity during thin layer drying of figs. Journal of food engineering V65, P 449-458.

BROOKER, D. B.; BAKKER-ARKEMA, F. W and HALLC. W. (1992). Drying and Storage of Grains and Oilseeds. New York: An AVI Book.

BURG, W.J.V.D. and KLAASSEN, G. (1983). Seed Cleaning. International Agricultural Centre, Wageningen, Netherlands.

CHIRFE J and IGLESIAS H. A. (1982). Handbook of Food Isotherms. Academic Press, New York, NY.

CORREA P.C, BOTELHO F.M, OLIVEIRA G.H.H, GONEI A.L.D, RESENDE O and DE EAVALHO CAMPOS S (2011). Mathematical modelling of the drying process of corn ears. Department of Engenhania Angricola, Brazil.

DANIEL, I. O., K. O. OYEKALE, M. O. AJALA, L. O. SANNI and M. O. OKELANA, (2009). Physiological quality of hybrid maize seeds during containerized-dry storage with silica gel, African Journal of Biotechnology Vol. 8 (2), Pp. 181-186, 19.

DELGADO J.M.P.Q, VAZQUEZ DA SILVA M, NASSER R.O, GONZALEZ M.P and ANDRADE C.T (2009). Water sorption isotherms and textural properties of Biodegradable starch-based superabsorbent polymers.

DEMIR, V., GUNHAN, T., YAGCIOGLU, A.K. and DEGIRMENCIOGLU, A. (2004). Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosystems Engineering 88(3): 325–335.

DONALD, B. B., FRED, B.-A. W. and CARL, H. W. (1992). Drying and Storage Of Grains and Oilseeds. New York: Van Nostrand Reinhold.

EKECHUKWU, O. V.and NORTON, B. (1999). Review of solar-energy drying systems II: an overview of solar drying technology. Energy Conversion & Management, Vol.40(6), pp. 615-655.

EKEBAFEL, L.O, D.E OGBEIFUN, F.E OKIEIMEN. (2011). Effect of Native Cassava Starch-Poly (Sodium Acrylate-co-Acrylamide) Hydrogel on the Growth Performance of Maize (Zeamay) Seedlings, American Journal of Polymer Science 1(1): 6-11 DOI: 10.5923/j.ajps.20110101.02

ELLIOTT E (1997). Superabsorbent Polymers, Product Development Scientist for SAP, BASF Aktiengesellschaft, pages 4-5.

FAO, (2011) Farm structures in the tropics. Design and development, Rome.

BUCHHOLZ F.L. and A.T. GRAHAM, (1997). "Modern Superabsorbent Polymer Technology", Wiley, New York,

GODWIN J.L (2011). Aflatoxin: Occurrence, Prevention and Gaps in Both Food and Feed Safety in North Carolina. North Carolina Department of Agriculture and Consumer services.

HAROLD, C. A., and VANCE, M. R. (2015). Management of Stored Grains with Aeration. University of Minesota | Extension.

HAY, F.R., THAVONG, P., TARIDNO, P and TIMPLE, S. (2012). Evaluation of zeolite seed 'Drying Beads' for drying rice seeds to low moisture content prior to long-term storage. Seed Sci. & Technology, 40, 374-395.

HELLEVANG K.J and WICKLE W.F (2013). Corn drying and storage. NDSU, Extension services.

HURBURGH, C. R., BERN, C. J. and BRUMM, T. J. (2004). Grain Drying Fundamentals.

JAGDEV A. (2007). Preparation of a superabsorbent polymer and exploration of its properties.pg 16

JAYAS, D.S., WHITE, N.D and MUIR, W.E. (1995). (Eds.), Stored Grain Ecosystems. Marcel Dekker, New York, pp. 1–32.

JINGYUN.T.L, HUILING.Z and XIAOGUNG.Z. (2012): Application and comparison of two Mathematical Models for Simulating Grain Heat and Mass Transfer during In-Bin-Drying

KADER, A (2002). Postharvest technologies of horticultural crops. 3rd ed. Univ. Calif. Agr. Nat. Resource, Oakland, publ No. 3311.

KANG'ETHE, E (2011). Situation analysis: Improving food safety in the maize value chain in Kenya.

KEW, (2010). Improving the identification, handling and storage of "difficult" seeds

KIM JJ, PARK K, (1998). Smart hydrogels for Bio-separation, Bio-separation, 7, 177-184,

KITINOJA, L AND GORNY, J.R, (2010). Postharvest technologies for small-scale produce marketers: economic opportunities, quality and food safety. Univ. Calif. Postharvest Hort. Series No.2.

KRAMER K.J (2013). White paper on solar air heating collector. Solar Heating and Cooling programme (SHC).

KURUWITA-MUDIYANSELAGE, T. D., (2008). Smart Polymer Materials, Ph.D. Thesis, Graduate College, Bowling Green State University, Ohio, USA.

LACEY, J., HILL, S.T AND EDWARDS, M.A (1980). Micro-organisms in stored grains: their enumeration and significance. Tropical Stored Products Information 39, 19–32.

LEWIS, L., M. ONSONGO, H. NJAPAU, H. SCHURZ- ROGERS, G. LUBER, S. KIESZAK, J. NYAMONGO, L. BACKER, A. DAHIVE, A. MISORE, K. DECOCK, C. RUBIN, and the Kenya Aflatoxicosis Investigation Group (2005).“ Aflatoxin Contamination of Commercial Maize Products during an Outbreak of Acute Aflatoxicosis in Eastern and Central Kenya,” Environ Health Perspective. December; 113(12): 1763–1767.

LIANG M, LIU Z, ZHAN. R, F and NIU A, (2007): Preparation of superabsorbent slow release nitrogen fertilizer by inverse suspension polymerization, Polym Int., 56: 729-737.

MACHARIA J (2013). Lessons from mitigating post-harvest loss in Tanzania

MONTROSS M. D, MAIER D. E, HAGHIGHI K. (2012). Development of a finite element stored grain ecosystem model. ASAE. Vol. 45(5): 1455–1464

MICHAEL, J. B., LESTER, O. P., & LUTHER, R. W. (2013). Maintaining Quality of On-Farm Stored Grains PB1724. University of Tenesse Extension Services.

MCKENZIE C THOMAS H. P, KARL R, PETER S, ROBERT E. D and JEFF D. (2009).Retrieval of subpixel snow covered area, grain size, and albedo from MODIS.

NADARAJAH A, SANGJOON K, GANESH I, JONATHAN M. F and ALISON L. S (2010). Polyacrylamide Hydrogel Properties for Horticultural Applications.

NAEINI S. A. R. M AND. TABAN, M. (2006). "Effect of Aquasorb and Organic Compost Amendments on Soil Water Retention and Evaporation with Different Evaporation Potentials and Soil Textures." Communications in Soil Science and Plant Analysis 37: 2031-2055.

NAVARRO, S., NOYES, R., ARMITAGE, D., and MAIER, D. (2002). Objectives of Aeration. In the Mechanics of Modern Grain Aeration Management. New York: CRC Press.

NYAKUNDI L.O (2014). Occurrence of aflatoxin contamination on maize in the lower eastern Kenya and evaluation of superabsorbent polymers in management. Department of plant science and crop protection, University of Nairobi.

ODIER, G.O, SIEBENMORGEN, T.J and WIEDOWER, A.C (2011). Research scale drying of rough rice using silica gel.

PROBERT R.J (2003). Seed viability under ambient conditions, and the importance of drying. Seed accumulation Department, Royal Botanic Gardens, Kew, Wakehurst place, Ardingly. West Sussex, Uk.

RIGAS F and CHATZOUDIS, G. K. (1998). "Macroreticular Hydrogel Effects on Dissolution Rate of Controlled-Release Fertilizers." Journal of Agricultural and Food Chemistry46: 2830-2833.

SANNINO A., ESPOSITO A., DE ROSA A., COZZOLINO A., AMBROSIO L., NICOLAIS L.,(2003). Biomedical application of a superabsorbent hydrogel for body water elimination in the treatment of edemas, J Biomed Mater Res, 67A, 1016-1024,

SCHMIDHALTER U and GEESING, D. (2004). "Influence of sodium polyacrylate on the water-holding capacity of three different soils and effects on growth of wheat." *Soil Use and Management* 20: 207-209.

SERENO, A.M and MEDEIROS, G.L (1990). A simplified model for the prediction of drying rates for foods. Journal of food engineering. V12.

SINHA, R.N (1995). The stored-grain ecosystem. In: Jayas, D.S., White, N.D., Muir, W.E. (Eds.), Stored Grain Ecosystems. Marcel Dekker, New York, pp. 1–32.

SINHA, R.N and MUIR, W.E., (1973). Grain Storage: Part of a System. The Avi Publ. Co. Inc., Westport,

SOJKA CT, R.E LENTZ, R.D., SHAINBERG I, and CARTER D.L. (1992). "Preventing Irrigation Furrow Erosion with Small Applications of Polymers." Soil Science Society of America Journal 56(6): 1926-1932.

STURTON, S. L., BILANSKI, W. K., and MENZIES, D. R. (1983). Moisture Exchange between Corn and the Dessicant in an Intimate Mixture. Can. Agric. Eng. 25: 39-141.

SHAH, A., DARR, M.J., WEBSTER, K., HOFFMAN, C. (2011). "Outdoor Storage Characteristics of 311 Single-Pass Large Square Corn Stover Bales in Iowa." Energies 4: 1687-312-1695.

TAHAT M.A (2001). Historical review of liquid desiccant evaporation cooling technology.

TALBOT M.T (2002). Moisture migration in stored grains. University of Florida.

THORUWA, T. F. N., J. E. SMITH, A. D. GRANT and C. M., (2007). Developments in solar drying using forced ventilation and solar regenerated desiccant materials. http://www.ku.ac.ke/images/stories/docs/publications/engineering/novel_low_cost_cac2_based_desiccant.pdf.

TOGRUL I. T. and PEHLIVAN D. (2003). Modelling of drying kinetics of single apricot. *Journal of Food Engineering* 58:23–32.

WEINBERG Z.G, YAN Y, CHEN Y, FINKELMAN S, ASHBELL G and NAVARRO S (2008).The effect of moisture level on high-moisture maize (Zea mays.) under hermetic storage conditions—in vitro studies. Department of Food Science, Agricultural Research Organization, the Volcanic Centre, Bet Dagan 50250, Israel.

XIE X, BAHNEMANN J, WANG S, YANG Y and HOFFMANN M.R (2016). 'Nano filtration' Enable by Super-Absorbent Polymers Beads for concentrating micro-organism in water samples.

8.0 APPENDICES

Appendix 1: Drawings

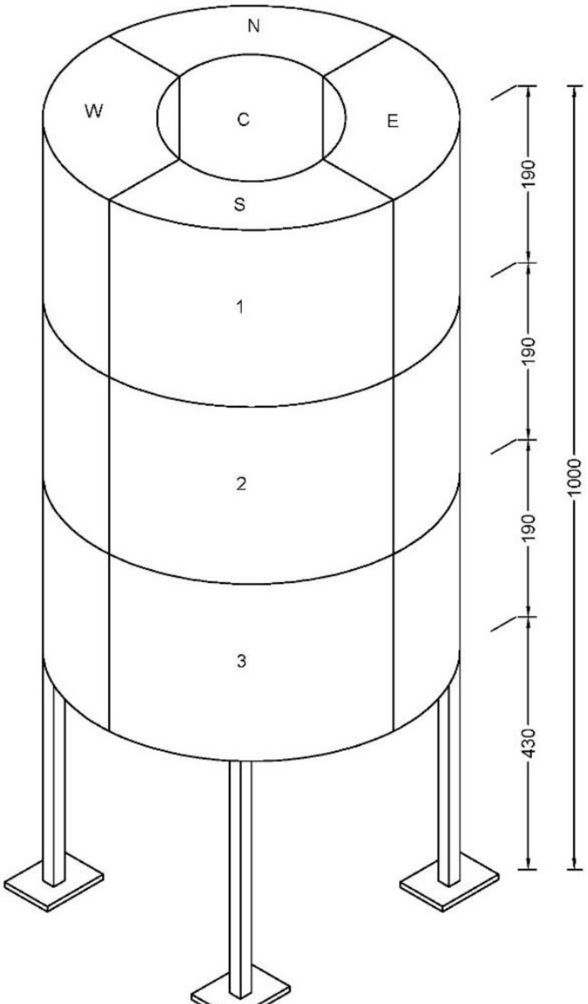


Figure 3-17: Silo Dimensions

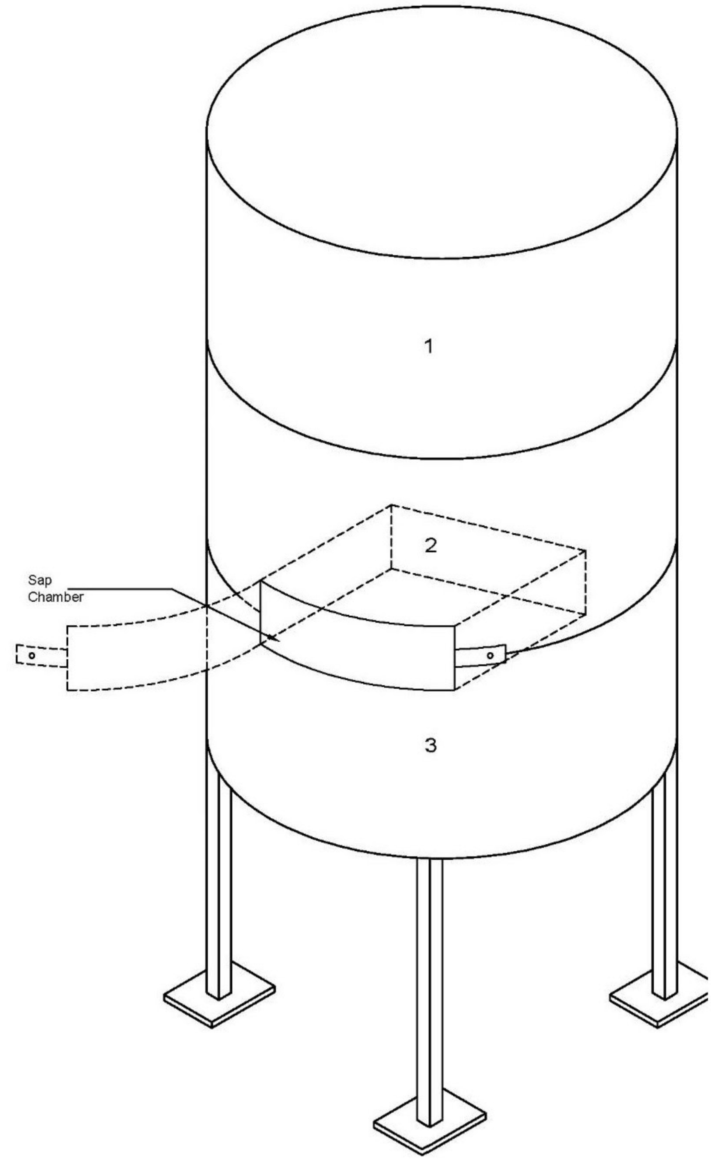


Figure 3-18: SAP Chamber

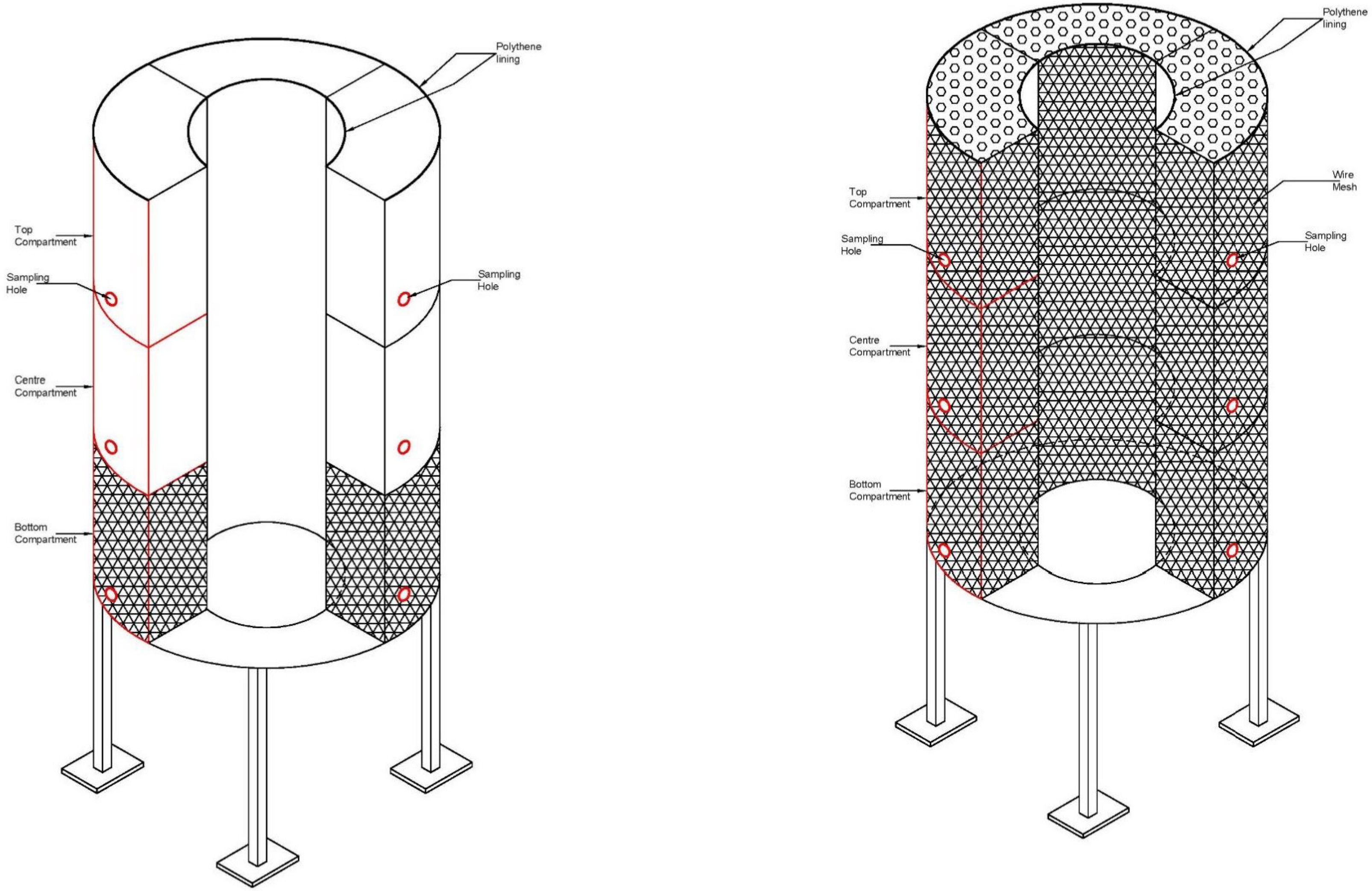


Figure 3-19: Section Description

Appendix 2: Silo Photos

Plate 8.3: Fabricated silo with Maize grain

Plate 8.4: Temperature Reading in the Grain Silo

Plate 8.5: Maize Sampling in Silos with Maize Grains

Appendix 3: Experimental Data

A3.1 Experiments Without Super Absorbent Polymer

Table 3-14: Recorded Moisture Content (%) In Silo 1

Date	17th Feb 2014	18th Feb 2014		19th Feb 2014			20th Feb 2014			21st Feb 2014			22nd Feb 2014
Section	Even	Morn	Even	Morn	Noon	Even	Morn	Noon	Even	Morn	Noon	Even	Noon
North Top	35.5	33.8	35.0	30.3	30.6	30.1	31.2	35.5	31.1	33.6	31.3	30.1	23.8
North Center	35.5	32.6	33.6	31.0	31.9	30.9	27.1	29.9	27.7	27.1	26.0	27.6	24.1
North Bottom	35.5	34.0	32.9	29.3	30.6	30.0	28.5	25.4	25.9	24.9	26.5	25.9	23.0
East Top	35.5	33.6	32.6	32.1	32.6	31.5	33.2	32.9	34.7	35.7	30.5	32.4	29.9
East Center	35.5	33.2	33.8	29.1	31.3	34.3	31.0	26.0	31.4	25.6	29.7	27.1	26.0
East Bottom	35.5	34.0	33.9	28.9	33.2	36.7	28.2	31.5	27.7	27.9	24.4	25.7	26.8
South Top	35.5	33.5	32.0	30.7	33.0	33.4	29.8	33.1	26.6	34.0	34.6	25.4	21.7
South Center	35.5	33.3	35.0	31.1	34.1	35.5	35.6	34.1	34.6	33.7	35.8	34.4	29.4
South Bottom	35.5	33.0	32.2	31.8	34.7	34.5	36.6	33.6	34.4	33.4	35.3	34.4	30.1
West Top	35.5	33.7	32.7	29.8	34.1	31.6	35.2	31.6	29.8	31.8	25.7	22.4	26.9
West Center	35.5	34.1	34.4	31.6	34.8	31.4	36.1	35.1	35.2	35.2	34.6	36.1	28.4
West Bottom	35.5	33.9	35.5	31.9	34.6	33.3	34.7	35.3	32.9	35.0	33.8	33.4	32.8
Center Top	35.5	31.9	30.9	30.1	33.1	27.9	32.1	29.9	30.5	36.3	31.4	27.8	30.3
Center Center	35.5	33.3	33.9	29.3	34.4	34.9	34.0	33.9	33.7	32.9	34.0	33.5	28.6
Center Bottom	35.5	33.9	34.7	29.5	33.7	36.1	33.1	32.1	32.2	32.0	29.9	32.5	29.4

Table 3-15: Recorded Moisture Content (%) in Silo 2

Date	17th Feb 2014	18th Feb 2014		19th Feb 2014			20th Feb 2014			21st Feb 2014			22nd Feb 2014
Section	**Even**	**Morn**	**Even**	**Morn**	**Noon**	**Even**	**Morn**	**Noon**	**Even**	**Morn**	**Noon**	**Even**	**Noon**
North Top	35.5	32.4	34.4	30.5	31.9	31.9	36.3	32.4	24.5	35.2	28.3	31.7	27.0
North Center	35.5	32.5	34.4	29.9	31.4	32.7	28.1	30.5	27.4	28.7	31.9	26.3	26.1
North Bottom	35.5	34.1	32.9	29.0	31.6	30.5	26.6	27.6	29.0	29.1	26.6	26.2	30.4
East Top	35.5	32.3	34.5	32.0	31.2	31.5	34.6	24.7	23.4	33.6	22.0	20.7	24.8
East Center	35.5	33.1	35.1	29.8	34.2	37.3	34.4	35.8	36.7	38.6	35.3	36.3	29.8
East Bottom	35.5	33.5	33.4	29.6	36.1	37.0	36.4	35.8	35.7	35.7	36.1	35.3	30.9
South Top	35.5	32.1	33.1	30.4	30.2	30.1	29.9	28.7	26.8	31.4	26.1	22.9	22.4
South Center	35.5	32.1	33.8	31.3	37.4	36.3	34.3	36.9	35.8	36.3	33.1	35.9	33.0
South Bottom	35.5	34.0	36.0	31.6	37.1	36.7	36.4	35.7	36.2	34.7	35.3	36.4	28.9
West Top	35.5	32.6	32.8	29.1	31.3	33.5	33.6	32.3	25.5	25.6	26.8	28.8	23.9
West Center	35.5	32.6	35.6	31.4	35.6	36.7	36.4	35.5	35.9	34.4	34.9	35.1	30.1
West Bottom	35.5	33.9	35.1	31.8	36.6	36.7	35.7	35.9	36.9	34.2	36.0	35.7	32.7
Center Top	35.5	31.0	33.5	30.2	30.0	29.3	34.5	34.0	26.4	36.9	29.7	34.2	26.5
Center Center	35.5	33.1	34.1	29.2	35.3	36.0	31.7	31.6	32.7	33.9	32.3	33.5	28.4
Center Bottom	35.5	33.8	35.9	29.7	36.6	34.1	33.1	34.3	35.6	31.6		32.1	27.4

Table 3-16: Recorded Moisture Content (%) in Silo 3

DAY	17th Feb 2014	18th Feb 2014		19th Feb 2014			20th Feb 2014			22nd Feb 2014		21st Feb 2014	
		Morn	Even	Morn	Noon	Even	Morn	Noon	Even	Morn	Noon	Even	Noon
North Top	35.5	33.0	34.8	30.1	30.6	34.7	34.5	29.9	29.3	35.6	33.8	30.9	29.2
North Center	35.5	33.4	35.1	31.1	35.8	36.7	31.9	33.6	31.5	32.0	34.1	33.7	30.8
North Bottom	35.5	35.0	35.8	29.3	34.4	34.9	24.7	33.3	25.1	27.1	29.5	27.9	29.5
East Top	35.5	33.2	31.6	31.9	31.2	28.9	32.8	30.9	23.1	37.5	27.3	32.2	29.1
East Center	35.5	34.9	34.4	29.9	34.8	36.3	35.6	34.9	34.2	36.7	34.0	34.7	29.2
East Bottom	35.5	35.7	36.3	29.4	34.5	37.2	35.3	34.9	35.4	34.7	34.0	33.1	31.6
South Top	35.5	33.1	32.9	30.4	30.1	29.8	32.9	27.8	21.7	29.9	23.1	27.6	22.2
South Center	35.5	34.5	36.8	31.0	36.4	37.3	34.7	36.2	35.5	33.1	35.4	35.7	28.2
South Bottom	35.5	34.7	35.2	31.2	36.3	36.6	34.8	35.3	37.0	32.0	33.1	34.1	29.6
West Top	35.5	33.9	33.5	29.3	33.3	29.9	29.9	28.4	32.2	30.8	23.8	24.8	20.9
West Center	35.5	35.9	35.1	31.7	36.9	37.3	36.1	33.7	35.6	37.1	37.0	36.3	28.3
West Bottom	35.5	36.4	36.5	31.6	35.3	37.3	34.9	33.6	31.6	34.9	35.8	36.4	34.3
Center Top	35.5	33.5	33.4	30.5	33.6	32.1	34.4	34.2	32.0	35.6	37.0	31.5	25.8
Center Center	35.5	35.4	33.8	29.5	35.4	37.0	34.8	35.8	34.6	35.4	36.1	40.0	29.2
Center Bottom	35.5	35.5	36.7	29.6	36.5	36.5	34.6	35.1	33.0	32.6	35.5	35.4	25.4

Table 3-17: Recorded Temperature in Silo 1

DAY	18th Feb 2014	19th Feb 2014			20 th Feb 2014			21 st Feb 2014		
Section	**Morn**	**Morn**	**Noon**	**Even**	**Morn**	**Noon**	**Even**	**Morn**	**Noon**	**Even**
North Top	27.0	28.00	33.00	30.0	28.00	32.00	32.00	28.0	27.00	30.0
North Center	27.0	32.50	34.00	31.0	30.50	32.00	29.00	28.0	29.00	29.0
North Bottom	27.0	32.00	34.00	30.0	30.50	34.50	30.00	32.0	28.00	35.0
East Top	27.0	32.00	34.50	37.0	31.50	31.00	40.00	33.0	33.00	33.0
East Center	27.0	36.00	34.50	34.0	29.00	32.00	35.00	34.0	32.00	32.0
East Bottom	27.0	32.00	34.00	29.0	29.00	28.00	28.00	35.0	27.00	28.0
South Top	27.0	30.00	31.00	34.0	28.50	40.00	39.00	37.0	33.00	34.0
South Center	27.0	34.50	36.50	38.0	38.00	40.50	43.00	41.0	42.00	41.0
South Bottom	27.0	32.50	34.00	36.0	29.50	38.00	40.00	37.50	37.00	36.0
West Top	27.0	30.00	30.00	34.0	33.50	35.50	40.00	42.00	36.00	34.0
West Center	27.0	34.00	36.50	40.0	37.50	37.00	41.00	43.00	37.00	42.0
West Bottom	27.0	33.50	35.00	38.0	36.50	35.50	42.00	42.00	36.00	39.0
Center Top	27.0	32.00	40.00	33.5	46.60	45.00	46.00	48.00	54.00	55.0
Center Center	27.0	38.00	43.00	44.0	50.00	51.00	48.00	53.00	54.00	56.0
Center Bottom	27.0	33.00	42.00		48.00	49.00	46.00	50.00	54.00	

Table 3-18 : Recorded Temperature in Silo 2

DATE	18th Feb 2014	19th Feb 2014		20th Feb 2014			21st Feb 2014		
Section	**Morning**	**Morning**	**Noon**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**
North Top	27.0	32.00	32.00	28.0	35.00	30.0	33.0	26.00	35.0
North Center	27.0	35.00	34.50	30.00	33.00	34.0	30.0	29.00	34.0
North Bottom	27.0	34.00	35.00	33.00	34.00	35.0	31.0	34.00	30.0
East Top	27.0	31.50	32.00	30.00	46.00	30.0	27.0	27.00	31.0
East Center	27.0	34.00	46.00	35.00	45.00	42.0	36.0	39.00	43.0
East Bottom	27.0	33.00	35.00	31.50	38.00	39.5	32.0	34.00	37.0
South Top	27.0	32.00	32.00	32.50	32.00	30.0	33.0	29.00	35.0
South Center	27.0	36.00	37.00	41.00	43.00	43.0	48.0	45.00	42.0
South Bottom	27.0	33.00	34.50	36.00	45.00	40.0	34.0	35.00	41.0
West Top	27.0	32.00	32.00	33.50	37.00	26.0	32.0	29.00	36.0
West Center	27.0	34.50	37.00	40.00	41.00	43.0	39.0	43.00	42.0
West Bottom	27.0	33.00	36.00	34.50	39.00	36.0	35.0	37.00	43.0
Center Top	27.0	35.00	41.00	45.00	42.00	48.0	53.0	46.00	52.0
Center Center	27.0	40.00	43.00	48.00		50.0	56.0	47.00	56.0
Center Bottom	27.0	38	42		42	50	53		

Table 3-19 : Recorded Temperature In Silo 3

DATE	18th Feb 2014		19th Feb 2014			20 th Feb 2014			21 st Feb 2014		
SECTION	**Morning**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Noon**	**Evening**
North Top	27.00	29.00	32.00	30.50	35.50	36.00	43.00	41.00	34.00	28.00	34.00
North Center	27.00	29.00	35.50	31.50	38.00	36.00	40.00	40.00	33.00	39.00	36.00
North Bottom	27.00	29.00	34.00	36.50	36.00	29.50	35.00	29.00	31.00	29.00	33.00
East Top	27.00	29.00	31.00	35.00	32.00	31.50	33.00	37.00	35.00	34.00	37.00
East Center	27.00	29.00	37.00	32.50	40.00	41.50	36.00	39.50	37.00	37.00	43.00
East Bottom	27.00	29.00	34.00	34.50	38.00	31.50	37.00	34.00	28.00	32.00	30.00
South Top	27.00	29.00	31.50	33.00	35.00	34.00	35.00	36.00	32.00	34.00	37.00
South Center	27.00	29.00	37.50	37.50	42.00	41.50	43.00	46.00	45.00	40.00	44.00
South Bottom	27.00	29.00	34.50	32.50	38.00	35.50	33.00	37.00	34.00	33.00	37.00
West Top	27.00	29.00	31.00	30.50	35.00	35.00	37.00	40.00	38.00	32.00	33.00
West Center	27.00	29.00	37.00	36.00	42.00	42.00	48.00	43.00	50.00	42.00	42.00
West Bottom	27.00	29.00	34.00	36.00	38.00	36.00	35.00	39.50	35.00	34.00	40.00
Center Top	27.00	29.00	36.00	45.00	36.00	49.00	45.00	53.00	51.00	53.00	55.00
Center Center	27.00	29.00	43.00	38.00	44.00	51.00	34.20	54.00	55.00	56.00	57.00
Center Bottom	27.00	29.00	39.5	41.5	40	36	33.9	53.5	45	54.5	56

A3.1 Experiments Without Super Absorbent Polymer

Table 3-20 : Recorded Moisture Content (%) in Silo 1

DAY	Day 1	Day 1	Day 2	Day 2	Day 2	Day 3	Day 3	Day 4	Day 4	Day 5
	Morning	Evening	Morning	Noon	Evening	Morning	Evening	Morning	Evening	Morning
North Top	31.5	27.0	27.1	27.2	26.0	25.1	25.4	25.1	23.4	24.8
Center Top	31.5	27.5	27.0	27.0	26.0	27.3	25.2	25.1	29.0	26.7
South Top	31.5	27.1	27.3	27.4	26.0	24.8	26.2	24.9	26.1	25.0
East Top	31.5	27.2	28.5	29.8	26.0	27.1	28.3	24.6	25.6	23.4
West Top	31.5	26.0	28.0	29.9	26.0	24.9	28.8	27.1	24.9	24.9
Average of Top Section	31.5	27.0	27.6	28.3	26.0	25.8	26.8	25.4	25.8	25.0
North Center	31.5	26.1	26.9	28.4	26.8	27.8	26.5	25.2	23.8	26.7
Center Center	31.5	29.4	26.2	28.9	29.6	28.3	29.5	28.5	29.2	27.9
South Center	31.5	27.3	27.8	28.5	27.2	28.8	28.6	27.9	29.7	29.7
East Center	31.5	28.1	28.5	29.6	30.0	31.4	30.7	29.5	28.4	28.0
West Center	31.5	27.9	28.3	28.4	27.0	29.4	25.2	26.5	22.3	26.7
Average of Center Section	31.5	27.8	27.5	28.8	28.1	29.1	28.1	27.5	26.7	27.8
North Bottom	31.5	29.8	29.7	26.2	24.4	28.8	29.0	26.4	25.0	27.1
Center Bottom	31.5	30.5	29.1	28.6	28.3	26.8	29.7	27.6	28.8	27.8
South Bottom	31.5	32.5	30.0	29.6	30.1	30.2	31.6	28.9	27.9	28.7
East Bottom	31.5	30.5	28.5	30.1	27.5	29.9	27.6	26.6	27.5	24.4
West Bottom	31.5	29.9	29.6	24.8	27.9	25.0	26.9	29.6	28.1	30.2
Average of Bottom Section	31.5	30.6	29.4	27.9	27.6	28.1	29.0	27.8	27.5	27.6

Table 3-21 :Recorded Moisture Content in Silo 2

DAY	Day 1	Day 1	Day 2	Day 2	Day 2	Day 3	Day 3	Day 4	Day 4	Day 5
SECTION	**Morning**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Evening**	**Noon**	**Evening**	**Morning**
North Top	31.5	29.8	28.5	27.2	26.0	26.1	22.9	23.0	25.1	26.7
Center Top	31.5	27.4	26.0	26.0	26.0	24.4	27.7	28.3	24.3	26.5
South Top	31.5	27.5	26.2	24.9	26.0	27.4	25.4	24.0	25.5	24.8
East Top	31.5	27.2	27.0	26.8	26.0	27.0	25.5	24.0	22.2	26.5
West Top	31.5	28.1	28.5	28.9	26.0	27.6	25.9	26.0	25.1	26.5
Average of Top Section	31.5	28.0	27.2	26.8	26.0	26.5	25.5	25.1	24.4	26.2
North Center	31.5	28.5	26.6	28.2	29.4	28.4	26.4	27.6	23.0	29.4
Center Center	31.5	30.2	29.9	29.9	28.5	28.7	30.5	27.9	27.2	29..4
South Center	31.5	29.2	30.6	29.3	30.4	28.4	28.9	28.2	29.6	27.6
East Center	31.5	26.9	29.2	30.9	27.9	28.5	29.3	28.3	28.3	27.5
West Center	31.5	27.8	28.6	28.2	28.6	28.1	29.4	29.3	27.1	27.5
Average of Center Section	31.5	28.5	29.0	29.3	29.0	28.4	28.9	28.3	27.0	28.0
North Bottom	31.5	27.5	26.4	27.5	29.7	27.2	29.0	24.0	26.1	25.0
Center Bottom	31.5	29.8	30.1	28.4	29.7	28.4	29.2	27.5	28.5	28.4
South Bottom	31.5	27.5	28.5	30.2	29.8	28.8	29.1	28.4	28.3	29.0
East Bottom	31.5	29.1	30.6	28.6	31.4	28.8	29.4	28.0	25.8	23.0
West Bottom	31.5	28.9	28.7	28.8	27.4	27.2	26.2	21.1	28.9	27.1
Average of Bottom Section	31.5	28.6	28.9	28.7	29.6	28.1	28.6	25.8	27.5	26.5

Table 3-22: Recorded Moisture Content in Silo 3

DATE	Day 1	Day 1	Day 2	Day 2	Day 2	Day 3	Day 3	Day 4	Day 5
SECTION	**Morning**	**Evening**	**Morning**	**Noon**	**Evening**	**Morning**	**Evening**	**Evening**	**Morning**
North Top	31.5	26.5	27.2	27.8	26.0	28.8	25.8	27.5	22.3
Center Top	31.5	27.0	25.0	25.5	26.0	28.5	25.5	24.0	28.0
South Top	31.5	27.6	27.5	27.4	26.0	27.1	26.4	24.8	25.5
East Top	31.5	27.8	27.1	26.3	26.0	28.3	26.0	24.8	24.1
West Top	31.5	27.7	27.0	26.3	26.0	28.1	27.2	28.6	25.3
Average of Top Section	31.5	27.3	26.7	26.7	26.0	28.2	26.2	25.9	25.0
North Center	31.5	29.6	29.2	29.2	28.8	28.6	26.5	22.3	27.5
Center Center	31.5	30.5	31.2	29.3	28.2	30.5	28.5	28.7	29.1
South Center	31.5	27.5	27.5	30.8	29.6	30.1	29.6	29.4	29.7
East Center	31.5	30.0	27.9	28.7	28.0	28.4	30.0	28.0	26.0
West Center	31.5	29.0	28.3	29.2	26.3	27.9	27.6	30.3	27.9
Average of Center Section	31.5	29.3	28.8	29.4	28.2	29.1	28.4	27.7	28.0
North Bottom	31.5	29.3	28.7	27.5	27.2	26.9	26.2	25.4	25.5
Center Bottom	31.5	30.7	28.9	29.6	28.1	27.9	29.7	28.8	28.6
South Bottom	31.5	28.1	29.6	29.2	29.1	30.0	28.6	30.6	28.1
East Bottom	31.5	29.5	27.4	28.8	29.6	28.8	30.2	25.4	25.0
West Bottom	31.5	28.5	29.6	28.0	28.0	28.0	28.9	27.3	27.9
Average of Bottom Section	31.5	29.2	28.8	28.6	28.4	28.3	28.7	27.5	27.0

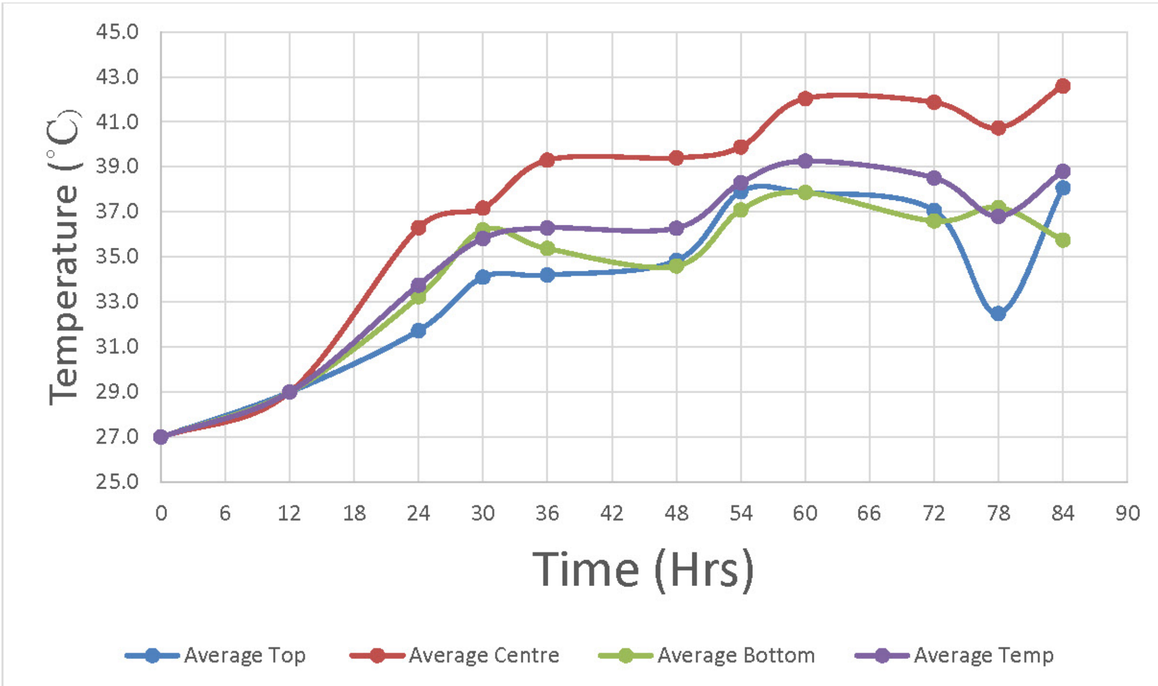


Figure 3-20: Graphs of temperature changes in various sections within the silo without SAP

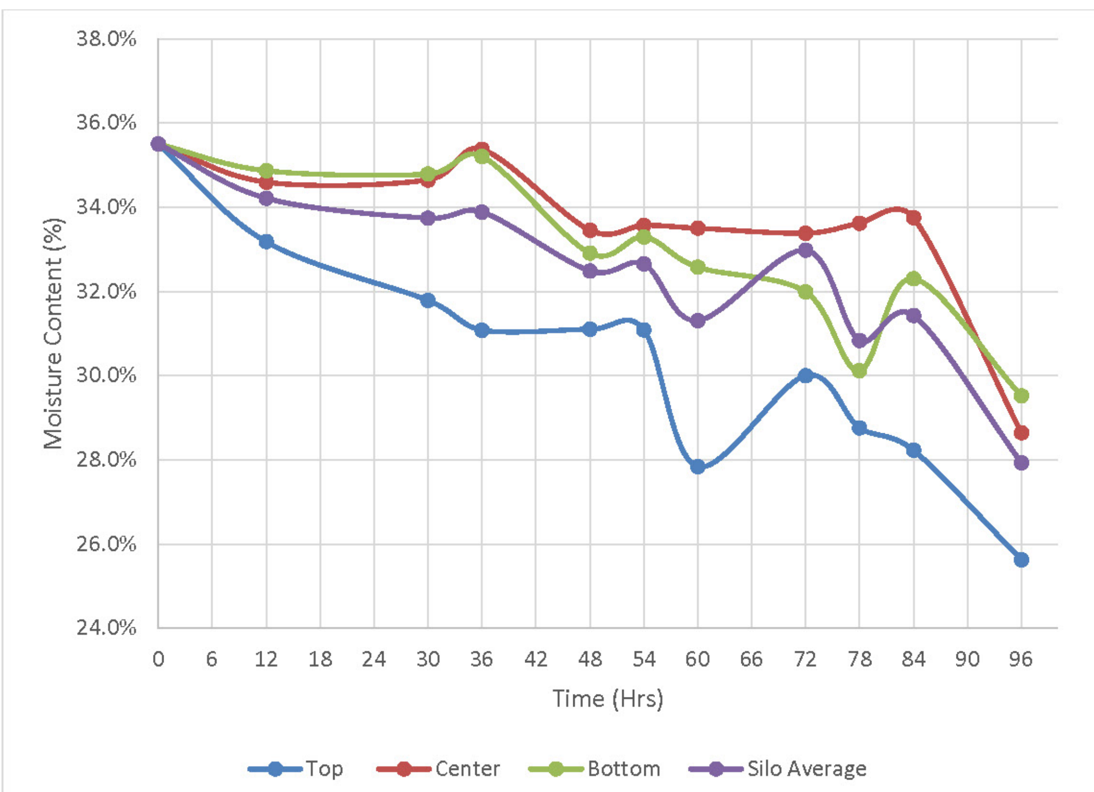


Figure 3-21: Changes in Moisture Content (%) with Depth in Silo without SAP

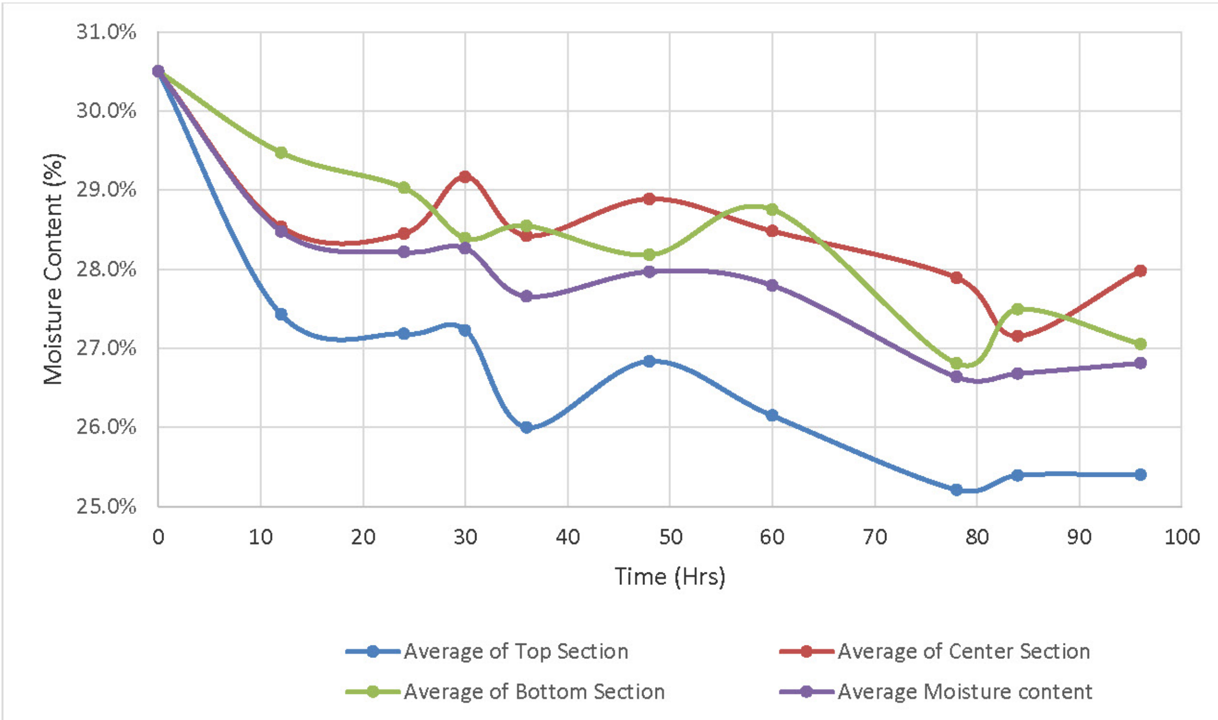


Figure 3-22: Graph of moisture variation with depth in silo with SAP

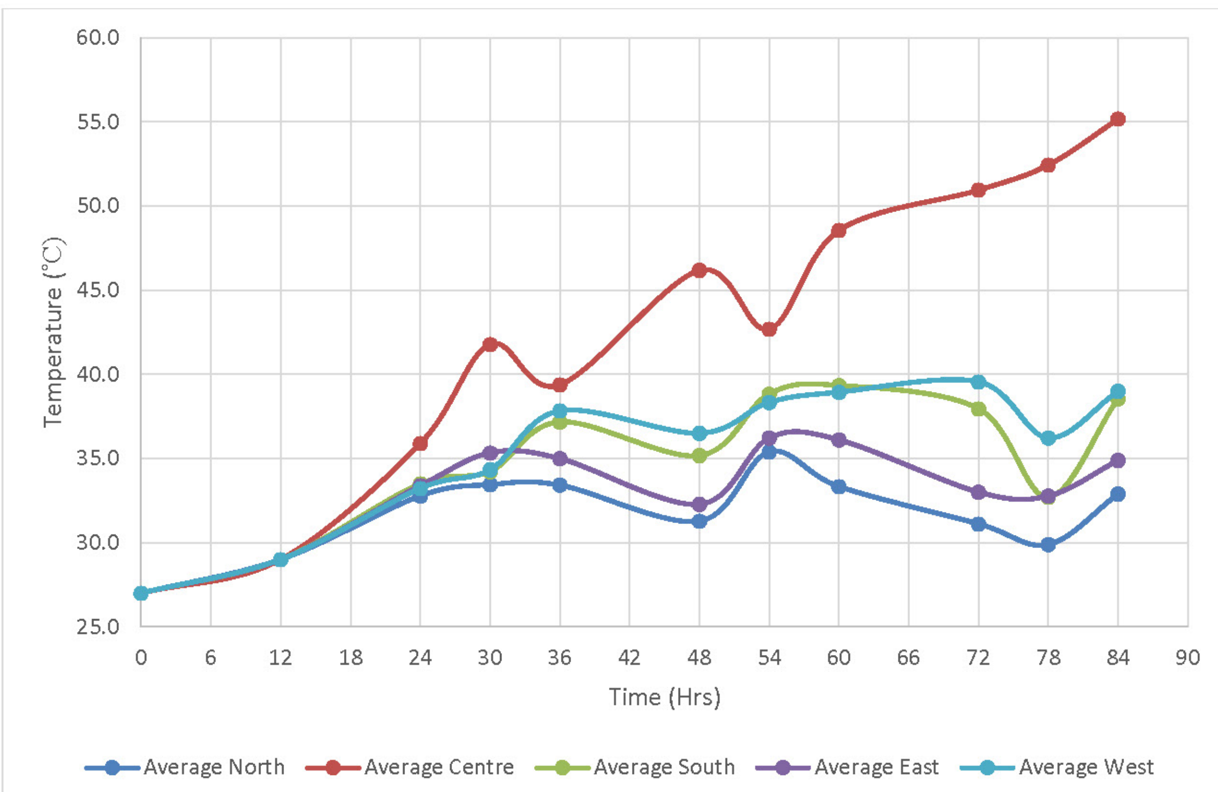


Figure 3-23: Temperature variation across the silo (without SAP)

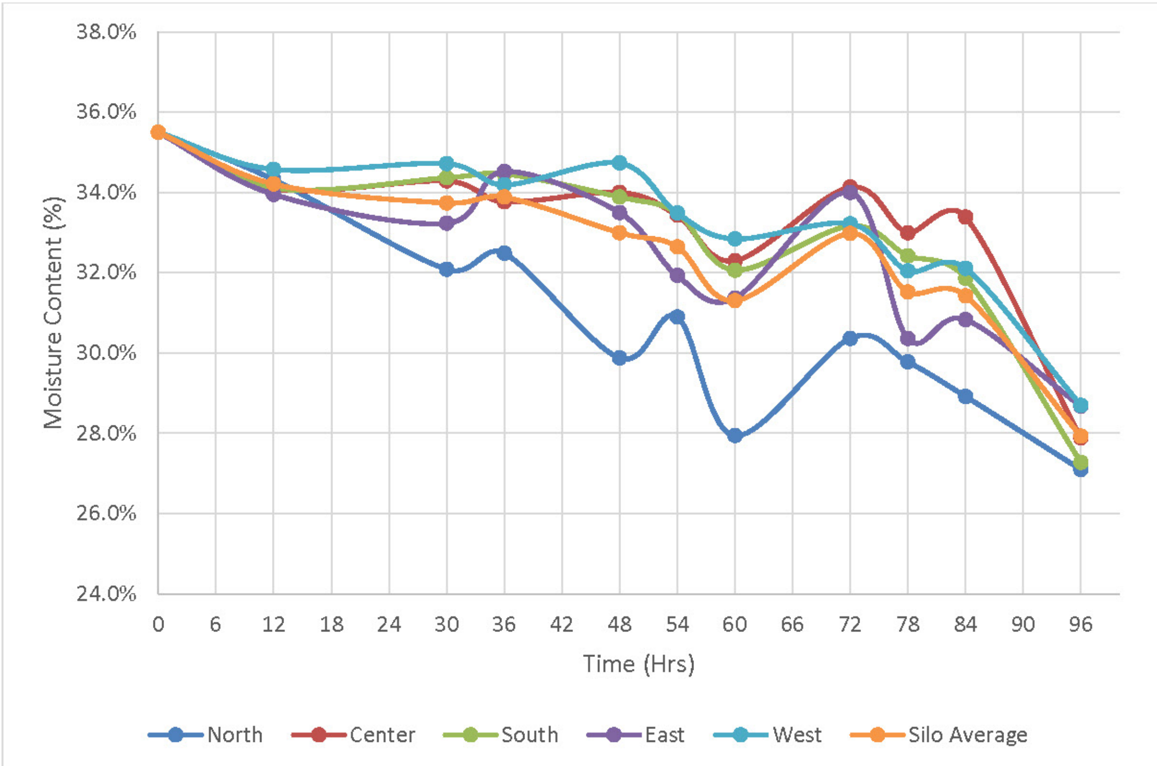


Figure 3-24: Graph of changes in moisture content across the silo with no SAP

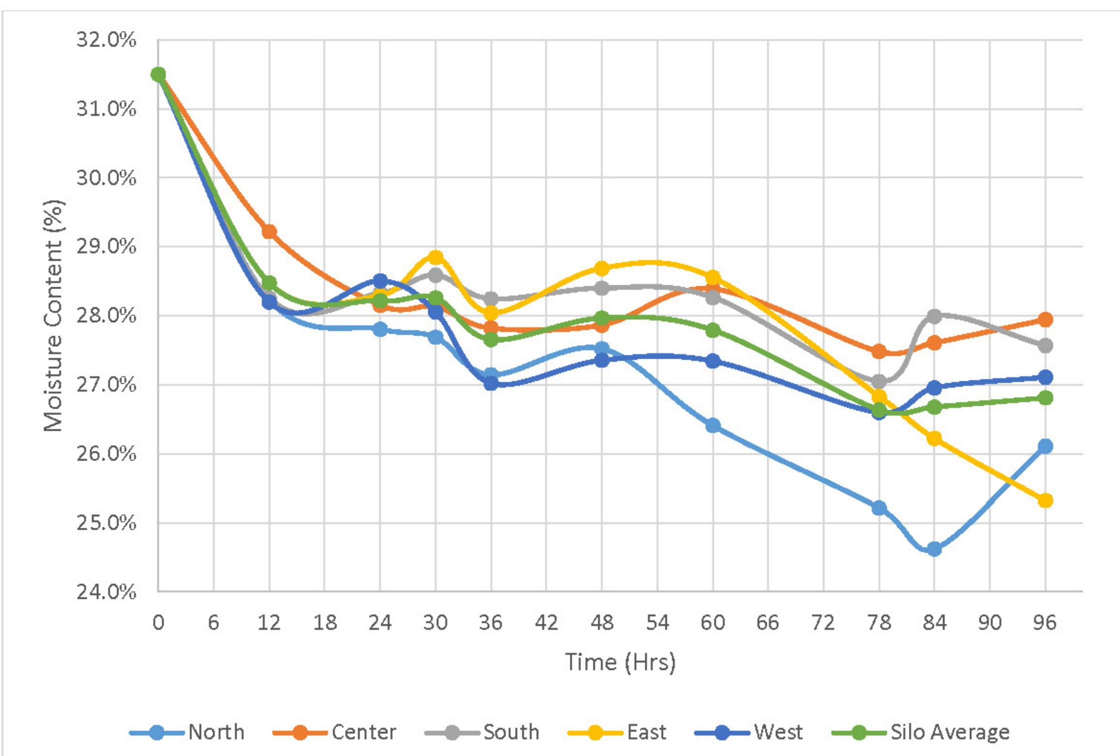


Figure 3-25: Graph of changes in moisture content across Silo with SAP

Appendix 4: List of Terminologies and Definition

Drying: is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid.

Desiccant: is a hygroscopic substance that induces or sustains a state of dryness in its vicinity

Hydrogel: are products which constitute a group of polymeric materials, the hydrophilic structure of which renders them capable of holding large amounts of water in their three-dimensional networks.

Aflatoxin: Is a toxic substances produced by fungus (Aspergillus flavus) that are produced especially in stored agricultural crops e.g. Maize by moulds.

Moisture: Refers to presence of liquid i.e. water, often in trace amounts. Present in air (humidity), foods etc.

Temperature: Is an objective comparative measure of hotness or coldness of a material

Silo: Is a structure that is used to store bulk grain e.g. maize, rice, wheat etc.

Grain: are small, hard, dry seeds, with or without attached hulls or fruit layers, harvested for human or animal consumption.

Gel: Is a semi rigid colloidal dispersion of a solid with a liquid or gas, as jelly, glue etc.

Biopolymer: Are complex molecules with biological activity. Are made up of repeating chemical blocks.

Hygroscopic: Is the ability of substances to attract and hold water molecules from the surrounding environment.

Migration: Is the movement from one place to another temporary or permanent.

Batch: is a quantity of material prepared or required for one operation

Perforated: Having holes

Psychrometric: is a tool used in the field of engineering concerned with the determination of physical and thermodynamic properties of gas-vapour mixture.

Conductivity: is the degree/ rate to which a material conducts electricity

Diffusion: process in which molecules mix as result of kinetic energy of random motion

Shelled: removal from the husk e.g. grain

Profile: Is a concept in unified modeling language

Respiration: a process that takes place in the cells of an organism that converts biochemical energy from nutrients into Adenosine triphosphate (ATP) and then release waste product.

Ventilation: is the process of changing or replacing air in any space to provide high indoor air quality.

Vaporization: is the transition from liquid phase to vapour phase

Distribution: is the way things are spread out or divided in space

Model: An imperfect or idealized representation of a physical system.

Fabricated: is to construct especially from prepared components

Absorbent: Ability to soak up liquid easily e.g. sponge