SIMULATION OF TEMPERATURE IN GRAIN SILO

(A CASE STUDY OF THE STRACTEGIC GRAIN RESERVE - MINNA)

BABATOPE ALBERT , ALABADAN
(PGD/MCS/112/93-94)

A PROJECT SUBMITTED TO THE DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA IN PARTIAL FULFILMENT FOR THE AWARD OF POSTGRADUATE DIPLOMA IN COMPUTER SCIENCE.

FEBRUARY, 1997

CERTIFICATION

I certify that this project was carried out by ALABADAN, Babatope Albert in the department of Mathematics and Computer Science, Federal University of Technology, Minna.

Prince Badamosi (Supervisor) — Date: 1/3/97.

Dr k.R. Adeboye (Head of Department) — Date

External Examiner — Date

Alabadan, B.A.(Student) — Date

DEDICATION

.... to GOD for His Wisdom

ACKNOWLEDGMENT

To God be the glory, honour and strength for His enablement throughout the programme.

I also wish to express my profound gratitude to the following people for all their contributions and help: Prince Badamosi (Project Supervisor), Dr Akin Ajisegiri(Head, Agricultural Engineering Department),Dr K.R. Adeboye (Head, Mathematics/Computer Science Department), Dr S.A. Reju, Mr Yomi Aiyesimi and other lecturers of the programme.

Numerous number of my colleagues also contributed to making the programme interesting. Chief among them are Gbenga Akindele,Gbenga Hammed and Enoho Odemero. Worthy of note are the contributions of Mr Ayodeji of Civil Engineering Department, Mrs Z.D. Osunde of Agricultural Engineering and Omolola Olugbemi.

To all whose names could not be mentioned but made it possible this acquire this knowledge, thank you and God bless.

Alabadan B.A.

LIST OF FIGURES

1. FIGURE 1. : The food Pipeline 7a
2. FIGURE 2. : Interrelations of variables in a Grain bulk 8a
3. FIGURE 3. : A sector of the Grain bin 24a

TABLE OF CONTENTS

Title page		i
Certification		iii
Dedication		iv
Acknowledgment		v
List of Figures		vi
Table of Contents		vii
List of Appendices		ix
Abstract		x
Chapter One		1
1.0	**INTRODUCTION**	1
1.1	Introduction	1
1.2	Statement of problem/Justification	2
1.3	Aims and Objectives	2
1.4	System Methodology	3
1.5	Scope of Study	3
1.6	Limitations to the study	4
Chapter Two		5
2.0	LITERATURE REVIEW	5
2.1	Simulation concepts	5
2.2	Grain Storage	7
Chapter Three		16
3.0	**SYSTEM ANALYSIS**	16
3.1	Temperature movement in stored grain	16
3.2	Evaluation of the Strategic Grain Reserve Projects	17
3.3	Development of Simulation Model	24
3.4	Input variables	32

Chapter Four 33

4.0 SYSTEM IMPLEMENTATION 33

4.1 Assumptions made in Model development 33

4.2 Program Development 34

4.3 Silo Specification, SGR and Grain conditions 38

4.4 Users Manual 39

4.5 Validation of the model 40

Chapter Five 41

5.0 RESULTS, DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS 41

5.1 Results and Discussion 41

5.2 Conclusions 43

5.3 Recommendations 43

References 45

Appendices 47

LIST OF APPENDICES

1. APPENDIX A. : Computer Program in FORTRAN 47

2. APPENDIX B. : Computer Program Output 49

ABSTRACT.

Weather conditions, which are dependent on geographical location, are the most important factors affecting grain storage temperature. The measurement of temperature in bins is used as a method of detecting deterioration of stored grain since temperature is one of the most crucial factors limiting the distribution and abundance of arthropods and fungi that contaminate stored grain.

A mathematical model based on explicit finite-difference method of calculating heat transfer was used to simulate the temperature movement in a cylindrical bin of maize located in Minna with the ambient maximum temperature of 34.2°C for a typical month of January 1995.

Simulation results show that temperature of stored maize increases steadily after each time-step of 3500 seconds from an initial temperature of 12.2°C. After about 24 time-steps, the temperature at the centre of the bin was 13.31°C while the exterior boundary rose to 27.55°C. This shows an increase of 1.11°C and 15.35°C respectively.

The simulation results could not be validated with actual results for lack of temperature monitors at the complex and maize for storage. However, this work would form a good spring-board for predicting the temperatures in stored grain bins.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Preamble.

In many parts of Africa, some crops can be produced throughout the year. Crops such as cereal grains and tubers, including Potatoes are normally seasonal crops. Consequently the food produced in one harvest period, which may last for only a few weeks, must be stored for gradual consumption until the next harvest and seed must be held for the next season's crop. In addition, in a non-controlled market, the value of any surplus crop tends to rise during this period provided that it is in a marketable condition. Therefore the principal aim in any storage system must be to maintain the crop in prime condition for as long as possible.

Crops grown for food fall into two broad categories: Perishable and Non-perishable crops. This refers to the rate at which a crop deteriorates after harvest and thus the length of time it can be stored. Non-perishables are crops that can be stored for over a year, for example, cereal grains while perishables are crops like tomatoes which deteriorate in days.

Grains are widely grown crops in the world and an estimate of over 70% of the total cultivated area is devoted to these crops. They accounts for more than half of the food requirements of the world and are relatively easy to store but a huge amount are still lost during storage.

The main agents that contaminate and destroy stored grain are insects, mites and fungi. The rate of reproduction and growth of these organisms is dependent on several biological are most important. Temperature of the grain is the only variable that can be regulated with little direct damage to the quality of the stored grain and also the only major non-biological variable that can be readily measured and simulated mathematically.

1.2 Statement of Problem.

Warm air can hold more moisture than cold air hence when it cools down, it gets rid of some water in form of dew. These increases if there are large difference between day and nighttime temperature thus making the grains to be wet. The grains get caked and mouldy.

Also as the temperature increases, mould and insects grows faster and the grain respires more quickly. The grain respiration and the insects and mould generates heat which build up hot spots within the stored grain. These spots produces water vapour which leads to the sprouting of the stored grain., Igbeka (1992) recorded that about 50% of the total losses occur during storage.

1.3 Aims and Objectives.

1. To develop a simulation model that can be used to predict the temperature of the stored grain throughout the storage bin.

2. To be able to detect the hot spots in stored grain towards reducing or preventing the storage losses.

3. To develop a more rapid and less expensive method of

measuring the physical factors affecting the temperature of stored grain.

4. To evaluate the suitability or appropriateness of steel silo for storing grains in tropical Nigeria.

1.4 System Methodology

In evaluating the temperature of stored grain in the cylindrical storage bin, the bin is divide into several sectors for ease of analysis with the assumption that the sectors are similar in sizes and are affected by similar temperature conditions.

The temperature of a sector of cylindrical bin are predicted using the finite-difference method of calculating heat transfer under transient conditions (Dusinberre,1961). The sector is divided into a finite number of concentric annuli or spatial elements. The temperature of each spatial element at the end of each time increment is calculated by evaluating the heat balance equation for the elements and time increment Δt.

Equations are developed for the boundary elements and the interior nodes. The model is validated by comparing the predicted result with the actual result.

1.5 Scope of Study

The simulation study would involve the followings:

1. Maize (<u>Zea mays</u>) is the stored grain.
2. Development of a model to simulate the temperature

movement in stored grain.

3. Determination of the effect of variables such as the initial temperature of the grain, the ambient temperature and the material of bin wall on the grain storability.

4. Validation of the model using the Minna Strategic Grain Reserve (SGR) complex as a case study.

5. Development of a program /software using FORTRAN high-level language.

1.6 Limitations to the study.

1. One of the main aims of systems study is to establish optimum parameters for the design, construction and operation of such systems. Simulation models cannot identify optimum solutions, they can only compare several alternative solutions. The result of simulation is therefore a satisfactory solution.

2. The validation of the model cannot be done because the SGR complex in Minna has no appreciable stored grain or maize.

3. Lack of previous temperature movement results of SGR complex.

4. It is difficult to determine the actual effects of each variables on the temperature movements and on the silo performance.

5. For a more reliable and dependable result, long term experimentation is needed is needed for better prediction of the effect of temperature on stored grains.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Simulation Concepts.

Simulation analysis is a natural and logical extension to the analytical and mathematical models inherent in operations research. It is the only tool that might be used in many situations which cannot be represented mathematically due to the stochastic nature of the problem, the complexity of problem formulation, or the interactions needed to adequately describe the problem under study.

The word simulation has been used rather loosely. Naylor et. al (1966) defined simulation as "A numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical relationship necessary to describe the behaviour and structure of a complex real-world system over extended periods of time".

Simulation has also been described as the process of creating the essence of reality without ever actually attaining that reality itself.

Recent advances in simulation methodologies, software availability and technical developments have made simulation one of the most widely used and accepted tools in system analysis. Simulation modelling is often more of an "art" than a science. This art is best cultivated rather than taught, although the basic tools and modelling logic can be gained through diligent study of simulation methodologies.

The design of a simulation model itself is a critical portion of any study but not the only one with which the user must be concerned.

Simulation process involves:

Pre-simulation Activities.

(Problem definition,System analysis,Objectives and Aims)

↓

Development Activities.

(Design and Implementation)

↓

Operational Activities.

(Tactical design of Implementation)

It is worthy of note that inspite of the availability of simulation as one of the easiest tools in management science, it is also probably one of the hardest to apply properly and perhaps the most difficult from which to draw accurate conclusions.

Among various researchers interested in stored grain is Yaciuk et. al (1975) who developed a simulation model of temperatures in stored grain Canadian Prairies.

2.2 GRAIN STORAGE

2.2.1 POST-HARVEST LOSS AND STORAGE

Accurate and useful assessment of post-harvest losses during storage and distribution requires the study of the whole physical and social system in which the food moves from the producer to consumer in order to identify the points where the most acute food loss occur.

Fig. 1 shows the "Food Pipeline" which indicates the physical and biological ways in which some losses may occur in addition to factors or parts like the human, mechanical and line of transport vehicles through which food passes with greater or lesser efficiency, speed or ease.

The food in the pipeline is propelled by socio-economic and political forces which can slow down or accelerate the food passage from producer to consumer. The ease and speed of movement determine the type and period of storage.

In the storage system of the pipeline, it is said that about 50 percent of the total losses are encountered. (Igbeka,1992). The basic requirement of every system/structure are to keep the grain cool and dry, protect grain from insects and rodents. A grain bulk in storage is a man made ecological system in which living organisms and their non-living environment.interact with each other. Deterioration of stored grain results from interactions among physical, chemical and biological variables and factors and a good understanding of these variables help in the design, effective controls and management of these factors for safe storage.

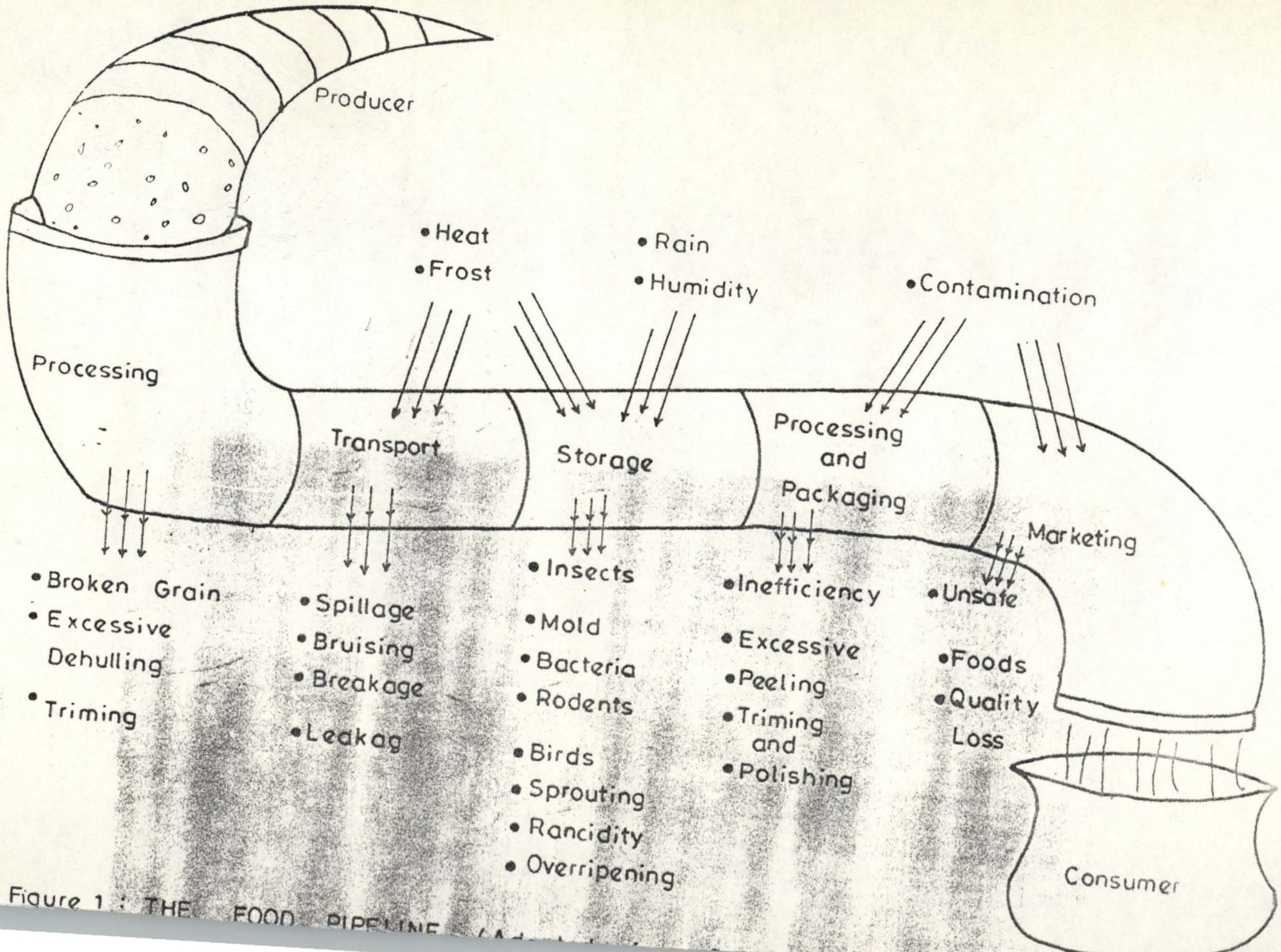

Figure 1 : THE FOOD PIPELINE (Ad...

Important variables are temperature ,moisture, oxygen, geographical location, the structures physical, chemical and biological properties of the grain bulk, micro-organisms, insects, mites, rodents and birds. (Fig. 2) The most important of these variables are temperature, air moisture and crop moisture. The survival of these organisms in any stored products depend on how conducive the three variable are.

2.2.a Temperature

All living organisms have certain temperature tolerant limit within which they can survive. Therefore, the atmospheric temperature , grain temperature and intra-granular air temperature with the grain are important in prolonging the storage life of the grain. Temperature influences the development of microorganisms like mould and insects. Their optimum growth can be observed between 25° C and 30° C which corresponds to a temperature range found in stored products under tropical conditions.

The effect of temperature on an organism is correlated with the amount of moisture present because increase in temperature corresponds with decrease in moisture in the atmosphere. Moisture movement occurs through the grain as a result of diffusion as distinguished from air movement by convection. The thermal diffusivity is a measure of the rate of temperature change and indicate the speed at which temperature equilibrium will be reached.

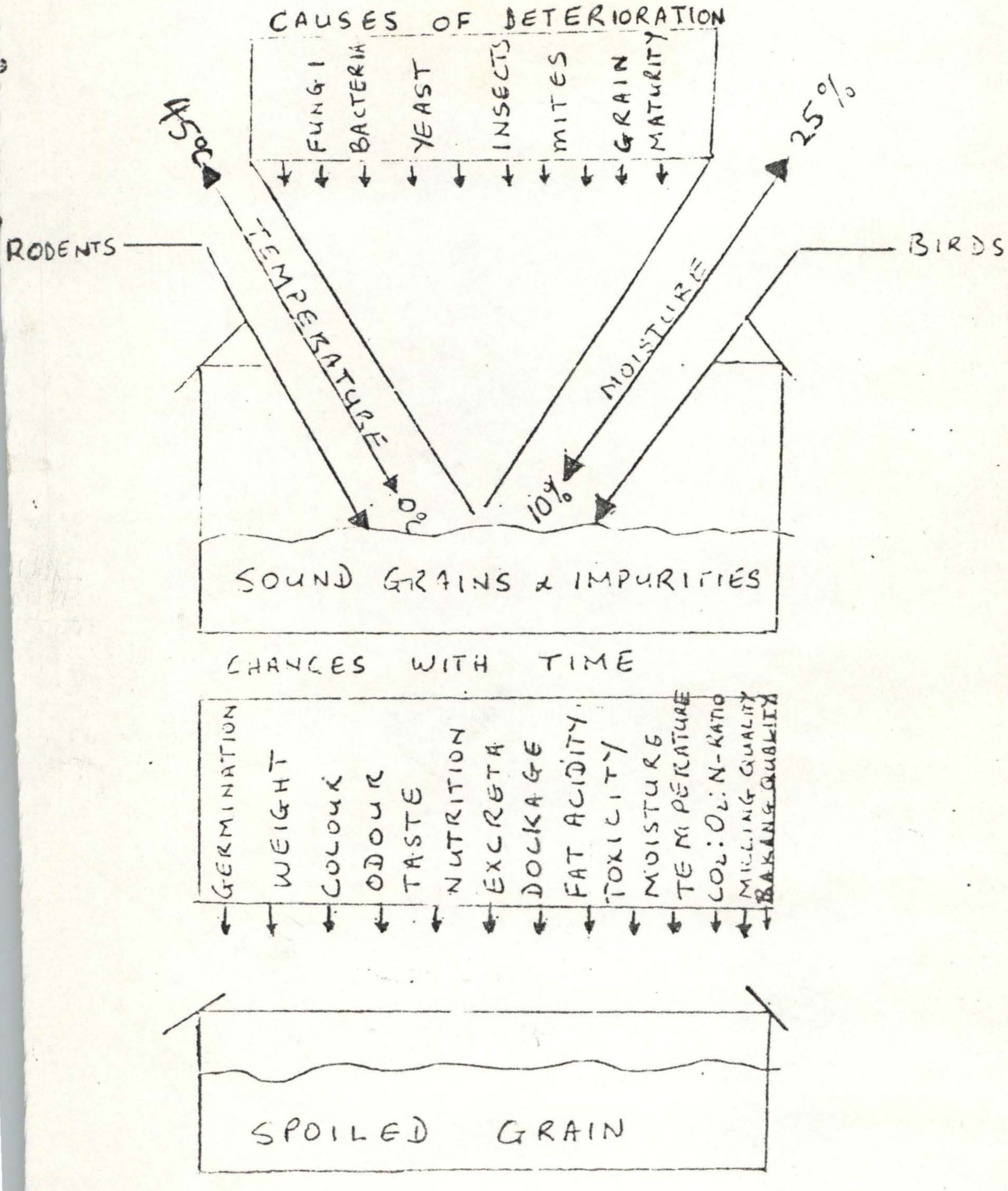

Fig 2 – Interrelations of Variables in a Grain Bulk

(Source – Sinha and Muir 1973)

2.2.1b Heat Transfer

To determine or predict temperature changes in a stored product, it is desirable to know the thermal conductivity, k, and the specific heat, c, of the product. Therefore, The rate of heat transfer , q is

$$q = KA\frac{dt}{dx} \tag{1}$$

where k = thermal conductivity, W/mk

A = cross-sectional area perpendicular to the path of heat flow, m^2

dt/dx = temperature gradient, °C/m

For a steady-state heat transfer, equation (1) becomes

$$q = \frac{K}{X}A[\Delta t] \tag{2}$$

where X = thickness of the material parallel to the heat flow,m

For an unsteady-state (Transient) heat transfer, which is common in storage, the temperature conditions changes with time, equation (1) becomes

$$c\varrho\, dxdydz\frac{\delta t}{\delta x} = kdydz\frac{\frac{\delta t}{\delta x}}{\delta x}dx \tag{3}$$

where, Left Hand side = Heat gain by the grain.

Right Hand side = Heat removed from the surroundings.

Since the thermal properties, specific heat and conductivity remain constant, equation (3) becomes

$$\frac{\delta t}{\delta \theta}=[\frac{k}{c\rho}][\frac{\delta^2 t}{\delta x^2}] \tag{4}$$

The general transient heat transfer equation is represented by

$$\frac{t-t_s}{t_o-t_s}=\Phi[\frac{k\theta}{c\rho r_m^2}][\frac{hr_m}{k}][\frac{r}{r_m}] \tag{5}$$

where,

t = temperature at any time, °C

ts = temperature of surroundings, °C

θ = time, hr

to = initial temperature, °C

rm = cylinder radius, m

k = thermal conductivity, W/mK

h = surface conductance, W/m²

2.2.2 GRAIN STORAGE METHODS IN NIGERIA

Nigeria can be divided into three climatic zones: the lowland humid zone of the south, the guinea savanna of the middle belt and the semi-arid region of the north. It is therefore pertinent to note that because of these climatic divisions, storage systems differ from zone to zone. The major grain crops are Maize, Rice, Sorghum or Guinea corn, Millet and Cowpea. There are two major methods : traditional and modern , of storing grains but the traditional method is still prevalent except for some very big commercial farm units and government farms such as the SGR complexes that practised modern methods.

2.2.2a Traditional Methods

This vary from crib, rhumbus and bags in the north to suspension over fireplace, use of baskets, gourds, storage on decking of building, hanging from roof, stacking on pole and "Oka" structure for cowper in the south. Some of these methods are discussed below:

1. Native Rhumbus: this is a flask-shaped or roughly cylindrical container constructed with mud or woven "zana" grass. It is raised from the ground on short legs. This is very popular in the northern dry savanna zones and is used to store maize,millet,cowper and guinea corn.

The efficiency of this structure is quite high due to its ability to maintain relatively constant temperature inside because mud is a poor conductor of heat. It is unsuitable for other zones due to heavy rains and high termite population.

2. Stacking on Pole and Hanging from Roof: These two techniques are popular in the southern and middle belts of

the country and are used mainly for maize and cowpea. When it is used for cowpea, a special type of woven grass structure is made called "Okpa".

The storability of grains is quite high but these methods are already being discontinued by many farmers because of fire hazard and rat infestation, problem of rain, cases of pilfering and rodents attack.

3. Others: These includes bags, gourd, basket and drum. They are peculiar to cultural and ethic areas and to particular crops but one method which is now getting very popular all over the country is bag or sack storage because of ease in transportation.

2.2.2b Modern methods

There are three very popular methods. These are silo. cribs and warehouse.

1. Silo: This is used mainly for shelled maize throughout the country by commercial units. It involves extra handling processes like shelling, drying and conveying into the silo usually made of metal, concrete or wood. They can generally be classified as horizontal (height is less than the diameter) or vertical (height is greater than diameter) and can be further classified as round, rectangular, cylindrical, and box shaped.

There are cases of grain cake-up and the surface layers rotting or germination in the humid south due to heavy rains and morning condensation which creates dampness of the grain thereby causing increased heat generation and mould infestation. Also differences in daylight and night temperatures result in moisture condensation inside the walls of the silo.

2. Crib: This is an adapted and improved version of the traditional crib storage. It consists of a structure of rectangular plan raised some centimetres above the ground, with sides made of wire netting and reinforced with wood. It is usually sited in a well ventilated area to facilitate aeration and drying of the maize.

It can dry maize harvested at 25% moisture content to 15% moisture content in 3-4 months. It is provided with rodent guards on the legs of the structure to prevent pest damage. It is recommended for medium - scale farmers.

3. Bags(Warehouse) storage : The most popular storage method for all grains because it is easier and quicker to build a warehouse than a silo and coupled with the ease of transporting for marketing.

2.2.3 GRAIN STORAGE IN SILO: NIGERIA EXPERIENCE

1. General

A silo, which is also referred to as a bin, is basically a huge container used for the storage of free-flowing, solid materials such as agricultural produce and cement in the construction industry .

The silo are used mainly for storing grains such as shelled corn (Zea mays); threshed rice (Oryza sativa); sorghum or guinea corn (Sorghum vulgare) and millet (Pennisetum typhoideum). These grains forms a major part of Nigeria's staple food and also serve as feed for livestock.

2. History of silo in Nigeria

The use of silos as grain storage structure dates back to the mid-50s. The first silo was a twenty-ton Aluminium-type erected at Ilero, Oyo state in 1957 and in 1958, a similar one was erected at Ilaro, Ogun state (Williams, 1971).

These silos were wholly for the storage of maize, made of metal and supplied in pre-fabricated forms by the United States Department of Agriculture (USDA). These imported silos were initially excellent grain storage structures since they had the advantages of large storage capacities but were associated with the problem of tropical climate generally characterized by high temperatures, wide daily temperature fluctuations and relative humidity, the capacities of the silo structures, the cost of acquisition and maintenance.

The first indigenous silo was a ventilated out-door concrete type design and erected by the Institute of Agricultural Research and Training, Moor Plantation, Ibadan in 1965 (Osobu, 1985). . This silo was and attempt to reducing the cost of silos by making use of locally available materials. The number of silo increases to sixteen by 1971 (Williams,1971) erected mainly in the western state of Nigeria.

By 1989, the Federal Government planned to erect twenty new metallic silos. These silos were located all over the country and by 1990 they are at different stages of completion. In addition to these, the government purchased some privately-owned silo complexes and had concluded arrangement to ensure that every state of the country include the Federal capital had a silo complex.

Due to the important nature of silos to the economy and in attempt to reduce stored grain losses due to problems associated with metallic silos, research efforts are being directed towards the use of local materials such as wood products (Mijinyawa,1989) and laterite (Osunade, 1997)

CHAPTER THREE

3.0 SYSTEM ANALYSIS

3.1 Temperature measurement in stored grain

The deterioration of grain is dependent on the temperature, oxygen supply and micro-organisms involved. The relative deterioration rate increases with an increase in temperature and moisture content but the micro-organisms are killed at higher temperature.

The temperature of stored grain gives an indication of the condition of the grain. If overheating is noticed, the grains are moved or mechanically cooled to prevent excessive grain loss. Temperature measurements are also desirable to check the performance of a dryer.

Farm installations are usually too small to justify the cost of expensive electronic equipment. The temperature of grain may be sensed by placing one's hand as far as possible into the bin. A bulb glass thermometer provides a reasonably accurate method with inexpensive equipment. The thermometer bulb is often protected with a metal shield and should remain in the grain for about 30 to 40 minutes before removal for fairly constant reading.

Commercial installations can usually justify electronic systems using thermocouple to sense the temperature. A thermocouple consists of two small wires of different metals joined together by soldering or welding and placed where the temperature is to be determined. the voltage output of a thermocouple varies with the temperature and is measured by a potentiometer. Common wires used for thermocouple are copper and constantan or iron and constantan.

3.2 Evaluation of the SGR Projects

3.2.1 Introduction

The . agricultural sector suffered a period of neglect during the 1970s and 1980s which resulted in stagnation of production and an increasing dependence on imports to meet the basic food needs of the country. To correct this situation the Federal Government of Nigeria placed high priority on the development of agriculture with particular emphasis on intensifying food production. The cornerstones of government's efforts to increase production are: acquisition, clearing and provision of land to small-scale farmers and cooperative societies; introduction of specific policy measures to boost farm inputs , agricultural credit, agricultural insurance and agricultural mechanization; encouragement, provision of support and adequate incentives to private and public sector activities associated with post-harvest handling of food crops to minimize waste and losses.

An integral part of the government's agricultural programme is the strengthening of national food security through improving the availability and access to basic foods. To this end government has adopted a three tiered approach. At the farm level, improved on-farm storage structures are being promoted for the preservation of grain to encourage increased on-farm storage. At the second level, individual state governments are to operate a buffer stock programme to be used for price stabilization during the lean season. At the apex, the Federal Government is establishing the SGR for use in the event of a national food emergency.

To house the grain in the SGR, a silo construction programme was initiated in 1988 under which 25,000 tonnes of storage capacity was to be made available in each state. To solve the series of administrative, design and operational problems associated with silo construction, the Federal Government of Nigeria requested the FAO to provide the services of experts in bulk grain handling and bulk storage structures under its Technical Cooperation Programme (TCP).

The programme of assistance was approved in 1994 under the title "Assistance to SGR scheme, TCP/NIR/4453(A) with the objective of "reviewing the storage design and completed engineering works and recommending modifications to eliminate the problems encountered in order to improve the performance of existing structures and those to be constructed. The total contribution of FAO was US$172,000 and the projet duration was 17 months.

3.2.2 Grain Storage Construction Programme

The storage construction programme for holding the SGR involves the construction of steel bin silo complexes of 25,000 tonnes capacity at 32 locations throughout the country. Although the programme was started in 1988 only 6 sites has so far been commissioned (FAO,1995). The remaining sites are at various stages of completion with work on several sites having come to a virtual standstill due to severe contractual and/or financial decline in the value of Naira.

Under hot and humid climatic conditions prevailing in most parts of Nigeria, the metal bin silos which have to be selected for storage of the SGR are not considered to be as suitable as concrete silos for the medium to long - term storage of grains.

To minimize losses of grains held in the metal bins, primarily from moisture migration and maintain its quality at an acceptable level it will be necessary to rotate the stock at regular intervals. Not only would warehouses be inherently cheaper to construct and maintain than silos, but they would also be constructed from locally available materials thereby eliminating the need for foreign exchange.

A total of 18 sites were visited by the technical team including all those which have been completed and subjected to a detailed technical appraisal. Only 8 (Minna, Lafiagi, Ogoja, Makurdi, Gombe , Gaya, Ibadan and Jos) comprising five which have been completed and three almost completed can be considered as suitable for the short to medium-term storage and management of grains and these only after the modifications and remedial works identified have been completed. The estimated cost of the remedial works identified for these eight silos is some US$3.9 million of which US$3.2 million is foreign exchange.

Apart from the materials for the civil works which can be obtained locally, virtually all of the equipment requirements including the metal bins have to be imported. There are also difficulties in maintenance and the stocking of spare parts because all the equipment supplied to all the five sites were from different contractors and countries, hence cannot be exchanged with each other.

3.2.3 Institutional Consideration

The SGR storage division (SGRSD) is a division within the Federal Ministry of Agriculture and subject to the operational procedures of the Ministry. Such procedures are ill-suited to meet the operational needs of an organization which interferes with and operates alongside the commercial private sector. Consideration therefore needs to be given to restructuring the SGRSD into a corporate body.

3.2.4 Operational Aspects

a. Maintenance and Housekeeping

The level of cleanliness and maintenance of the storage complexes which have been commissioned is generally below an acceptable standard. The situation is made worse by the lack of use of the equipment leading to rusting, reconditioning of moving parts before usage, inadequate funds for purchasing basic requirements, inadequate training of staff, lack of spare parts and basic workshop tools and hand tools.

b. Financial Costs

Establishment of the SGR will require direct funding from the government for the purchase of the initial stocks of grain and for covering the operation and maintenance cost during the first year of operation.

For each silo complex, the cost of initial purchase of 20,000 tonnes of maize is estimated to be some N130 million. With an operating and maintenance cost estimated at N25 million, the cost of establishing and maintaining a reserve per site for one year would be N155 million. For the eight sites considered suitable for storing the reserve in the near future, the cost to government during the first year of operation would be some N1.04 billion for the 32 sites, N4.16 billion.

3.2.5 Recommendations

Given the difficult circumstances of the government, there is a strong possibility that only a proportion of the funds required for establishing the reserve will be made available, even for the initial eight silos which will lead to under-utilization of the available capacity of the silos. Consideration could therefore be given to storing grain from third parties on a commercial basis, for example, individual state governments for their buffer stocks, grain traders and grain processing industries. Alternatively, consideration could be given to leasing the facilities, for example, to large-scale grain traders or industrial processors.

The initial eight silo sites for which estimates of the remedial work required have been prepared, estimates need to be made of the work required to correct the existing design and construction faults at the remaining sites to bring them up to an acceptable operational standard. For those sites where construction is yet to begin, consideration should be given to incorporate either concrete silo structures or house type warehouse. To ensure that the construction and installation faults which have occurred in the past are not repeated , stricter engineering supervision and quality control of the contractors by SGRSD needs to be introduced.

Establishment of an inventory of spare parts for each site and the establishment of separate budget within the overall framework for the financing of the reserve, to purchase and maintain the parts specified. Also, basic hand and workshop tools for undertaking various maintenance and repair tasks should be provided.

3.2.6 Site by Site Appraisal: Minna. Niger State

1. General

The site was commissioned in 1989 but has not been fully operational. The location is acceptable with good access road.

2. Findings

a. Layout: The layout is generally good.

b. Cleaner: Poor quality

c. Elevators:

(i) The roof is leaking.

(ii) No easy access for maintenance.

(iii) Ground-water seepage occurs in the elevator pit during the rainy season when the ground water table is high.

d. Storage bins.

(i) The bins were installed on a flat concrete base which allows flow of water into the silos.

(ii) Some of the bins are leaking from the roof.

(iii) The aeration system has no dehumidifier.

(iv) Five temperature monitoring cables were installed in each bin; five sensors per cable. However, some temperature readings were incorrect. Make: Robydome.

e. Bulk loading bin

(i) No loading spout provided to reduce dust while loading the trucks.

(ii) The difference in height between the top of the bin and the distributing chain conveyor on top of the silos is insufficient to obtain an angle of inclination that will be equal to the angle of repose of grains. The current situation results in asymmetrical feeding of the bin and excessive wear of the bin walls.

(iii) Location of the bin is too close to the warehouse.

f. Control room

(i) The room is dusty.

(ii) The installed air-conditioner is not working.

g. Workshop

(i) No service pit has been provided.

(ii) No hoist beam has been provided.

h. Laboratory : All necessary equipment for the most important test to be executed seems to be present.

i. Generator

(i) Only one set of batteries is working for the two generators.

(ii) Start-up equipment for one generator is faulty.

(iii) No automatic start-up for the generators.

j. Drainage system

(i) The site slopes from the gate towards the silo location causes flooding and water seepage in the conveyor systems.

(ii) The drainage network is inadequate, some of the drainage channels have collapsed.

(iii) The central conveyor channel is not draining properly.

(iv) The grids covering the drainage channels at the intake pits are too weak.

3.3 Development of Simulation Model

The temperature of a sector of cylindrical bin are predicted using the finite-difference method (explicit form) of calculating heat transfer under transient condition.

The sector has an included angle of $\Delta\theta$ and a thickness Δz. The sector is divided into a finite number of concentric annuli or spatial elements of equal radii width, Δr, except for the centre and exterior elements which have a width of $\Delta r/2$ (Fig. 3).

The temperature of each spatial element at the end of each time increment is calculated by evaluating the heat balance equation for the element over the time increment Δt. For the interior elements, the heat balance equation consists of the amount of conductive heat inflow into the element through the two opposite faces of the element calculated by the general equation (Fourier's Law) for one dimensional heat conduction.

(1)

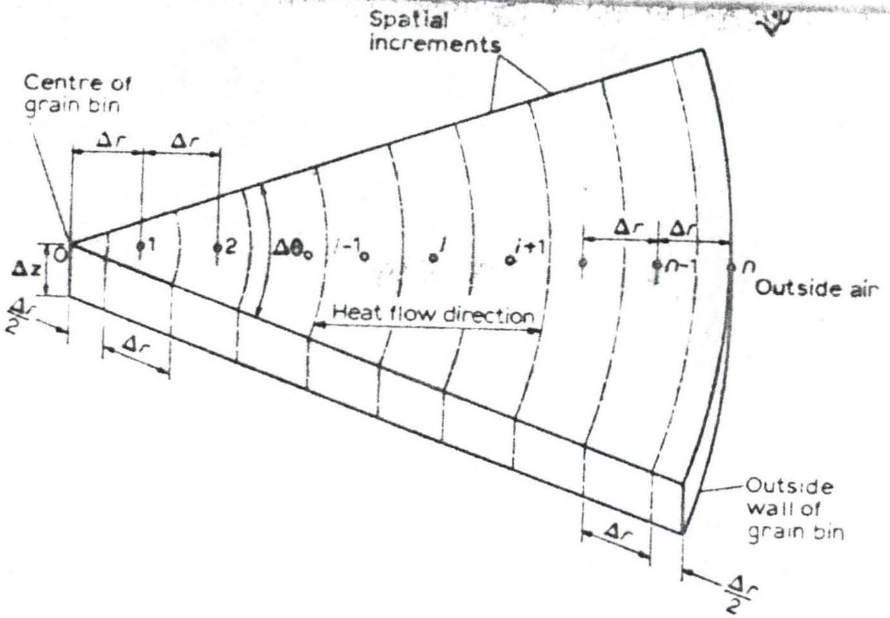

Fig. 1. A sector of the grain bin[6]

$$KA[\frac{\delta T}{\delta r}]$$

(1)

and the change in heat energy stored in the element.

$$V_i Cp[T_1^{/}-T_i]$$

(2)

This transient temperature conduction consists of a one-dimensional time-dependent heat conduction equation, two boundary conditions, and an initial condition. The basic idea of the finite-difference representation of this type of problem is to transform the differential equation and its boundary conditions into a set of algebraic equations.

The sector has a constant properties confined to the region $o \leq x \leq L$, that is subjected to some specified boundary conditions at the surface $x=o$, and $x=L$, with an initial temperature distribution over the region.

The heat conduction equation for this problem is given by

$$\frac{\partial T}{\partial t}[r,t]=\alpha[\frac{\partial^2 t}{\partial r^2}]$$

$$0 < r < L \qquad (3)$$

To obtain the finite-difference form of this differential equation, the r and t domains are divided into small steps Δr and Δt (Fig. 3).

For a M equal intervals and time step of Δt, then

$$r = (m-1)\Delta r \qquad (4)$$

or $\qquad r + \Delta r = m\Delta r \qquad m=1,2,3,\ldots\ldots m,m+1 \qquad (5)$

$t = i\Delta t \qquad i=0,1,2,\ldots\ldots\ldots \qquad (6)$

where M = equal sub intervals over the region $0 \le r \le L$

$$\Delta r = L/M \qquad (7)$$

and the temperature $T(r,t)$ at a location r and time t is denoted by

$$T_m^{\,i} = T[r,t] = T[(m-1)\Delta x; i\Delta t] \qquad (8)$$

To develop the finite-difference equations for each of the M+1 nodes, two distinct groups are considered.

a. Internal nodes, $\qquad m = 2,3,4,\ldots\ldots\ldots\ldots M$

b. Boundary nodes, $\qquad m = 1$ and $m = M + 1$

a. Internal nodes

To develop the finite-difference form, equation (1) is differentiated with respect to space and time variables. The second derivative of temperature with respect to r at a node m and time step $i\Delta t$ is given by

$$\left.\frac{\partial^2 T}{\partial r^2}\right|_{m,i} = \frac{T^i_{m-1} - 2T^i_m + T^i_{m+1}}{(\Delta r)^2} \qquad (9)$$

where,

$$T^{i}_{m-1}$$

(9a)

$$T^{i}_{m+1}$$

(9b)

$$T^{i}_{m}$$

(9c)

that is, (9a) and(9b) are two neighbouring points to the node (9c)

The first derivative of temperature with respect to the time variable t at a position m and a time step i is given by

$$\frac{\partial T}{\partial t}\Big|_{m,i} = \frac{T^{i+1}_{m} - T^{i}_{m}}{\Delta t}$$

(10)

where,

$$T^{i+1}_{m}$$

(10a)

is the temperature at node m at the time $(i+1)\Delta t$

Comparing equations (9) and (10) with (3), the finite difference equation becomes

$$\frac{T^{i+1}_{m} - T^{i}_{m}}{\Delta t} = \alpha \frac{(T^{i}_{m-1} + T^{i}_{m+1} - 2T^{i}_{m})}{(\Delta r)^2}$$

(11)

therefore,

$$T^{i+1}{}_{m} = x[T^{i}{}_{m-i} - T^{i}{}_{m+1}] + [1-2x]\,T^{i}{}_{m}$$

(12)

where i = 0, 1, ...

m = 2, 3, ...M

$x = \alpha\Delta t/(\Delta r)^2 \leq 1/2$ (stability criterion) (13)

$\alpha = k/\rho c$

b. **Boundary nodes.**

(i) Centre Element: For a centre element, (o), with no heat flow across the centre axis, the heat balance equation is given

$$\frac{K_{0+}[A]\,[T^{i+1}{}_{1} - T^{i+1}{}_{0}]}{\Delta r} = K_{0+}[\frac{\Delta r}{2}\Delta\Theta\Delta Z]\,[\frac{T^{i+1}{}_{1} - T^{i+1}{}_{0}}{\Delta r}]$$

$$= \frac{\Delta\Theta\Delta Z(\Delta r)^2\rho_1 C_1 [T^{i+1}{}_{1} - T^{i+1}{}_{0}]}{8\Delta t}$$

(14)

where k = mean thermal conductivity between adjacent nodes.

$$K_{i+} = \frac{\Delta r}{\sum \frac{L_{ij}}{k_{ij}}}$$

for nodes i and i+1 (16)

$$K_{i-}=\frac{\Delta r}{\sum \frac{L_{ij}}{K_{ij}}}$$

for nodes i-1 and i (17)

The equation can be simplified by defining the dimensionless moduli,

$$M_{i-}=\frac{C_i \rho_i (\Delta r)^2}{K_{i-} \Delta t}$$

(18)

and

$$M_{i+}=\frac{C_i \rho_i (\Delta r)^2}{K_{i+} \Delta t}$$

(19)

Solving equation (13) for the predicted temperature at the end of the time increment and using equation (19),

$$T^{i+1}{}_0=\frac{4}{M_{1+}} T^{i+1}{}_1+[1-\frac{4}{M_{0+}}]\, T_0$$

(20)

For a bin with constant thermal properties , equation (20) becomes

$$T^{i+1}{}_0=\frac{4}{M} T^{i+1}{}_1-[1-\frac{4}{M}]\, T_0$$

(21)

where the dimensionless modulus is constant and equal to

$$M=\frac{C\rho(\Delta r)^2}{K\Delta t} \tag{22}$$

putting equation (22) into (21), equation (21) becomes

$$T^{i+1}{}_0=T^i{}_0+\frac{4\alpha_1\Delta t}{(\Delta r)^2}[T^{i+1}{}_1-T^i{}_0] \tag{23}$$

$$=T^i{}_0+4x[T^i{}_1-T^i{}_0] \tag{24}$$

(ii) Exterior Element

In the case of convection at the boundary surface r=L with heat transfer coefficient hL into an ambient at temperature Ta, but no energy generation in the medium, therefore,

Rate of heat entering the volume = 0 (25)

for all its surfaces at time step i+1

Applying equation (25) to node m = M gives

$$h_L(T_a-T^{i+1}{}_M)+\frac{KT^{i+1}{}_{m-1}-T^{i+1}{}_m}{\Delta r}=0 \tag{26}$$

Therefore,

$$T^{i+1}{}_{m}=\frac{1}{1+\frac{\Delta r h_L}{K}}\left[T^{i+1}{}_{m-1}-\frac{\Delta r h_L}{K}T_a\right] \qquad (27)$$

From the above, equals (12), (24) and (27) are the ones need for purposes of achieving a computer solution.

3.4 Input Variables

The following are the variables that are needed in the development of the simulation model.

QUANTITY	VARIABLE NAME	DIMENSION
Thermal Conductivity of grain, K	RK	W/m.°C
Density of grain, ϱ	RHO	kg/m^3
Heat capacity, C	C	–
Number of internal nodes in the sector, M	M	–
Width of conducting medium (sector), r	R	m
Time increment, ΔT	DELT	sec.
Initial temperature of grain, TI	T(1)	°C
Thermal diffusivity of grain, α	ALPHA	m^2/s
Radius of sector, L	L	m
Ambient temperature, Ta	TINFA	°C
Heat transfer coefficient, HL	HL	$W/m^2°C$
Temperature at node J, T(J)	T(J)	°C
Inner temperature at R=0,m=1 T(1)	T(1)	°C
Surface temperature at R=L,m=M+1 T(M+1)	T(M+1)	°C
ΔRHL/K	DRHkL	–
Maximum number of time steps,	IEND	–
Spatial step size, Δr	DELR	m
$X = \alpha \Delta t/(\Delta r)^2$	X	–

CHAPTER FOUR

4.0 SYSTEM IMPLEMENTATION

4.1 Assumptions made in the development of the model.

Analytical methods have been developed to study temperature movement in cylindrical bins of wheat (Converse et.al, 1969) but the solutions were limited by the initial and boundary conditions. This led to the use of numerical methods with fewer limitations and more degree of accuracy.

In this study, several assumptions were made either because the information was not available to make a more complete model or simplifications were necessary to reduce computer time. Usually, the assumptions were made such that the model would simulate temperature higher than might be expected since deterioration of grains normally increases with increase in temperature of the grain and to give some unknown factor of safety in the results.

Heat transfer by conduction in the vertical direction and by natural convection within the bin were assumed negligible. The heat flow pattern was assumed symmetrical around the vertical axis of the cylindrical bin, that is , the heat flow was entirely radial and so the problem has been treated as one dimensional.

The model was made to simulate the maximum temperatures that will occur around the periphery of the grain bulk before deterioration begins.

The effect of moisture movement was not considered in the model development and the moisture at the pockets were assumed to be below the minimum required for deterioration of grains.

Heat of respiration of the seeds and other organisms in the grain bulk were assumed negligible. A significant quantity of heat is released by the organisms when the grains begin to deteriorate, hence, the model is restricted to sound and relatively dry (<14.5% mc wb) grain.

The temperature of grain at harvest time or after drying as it is put into storage can be as much as 8°C above the ambient air temperature. Storage at this conditions easily aid the grains to be stored are cooled to 12.2°C by some external means or exposing the grains to the natural convection for some days.

It is also assumed that the silo wall was exposed to equal amount of sunshine which is the main source of temperature to the environment and hence any representation of the conditions inside the silo.

4.2 Program development.

4.2a Program Language

There are three categories of programming languages:

(i) the machine language which binary (hexadecimal) codes to represent both instructions and addresses (locations where data is stored).

(ii) the middle level languages adopt mnemonic names for both operand, operators, addresses and instructions. Such languages are machine dependent.

(iii)the high level languages such as Fortran,Basic and Pascal were created to permit the use of english-like expressions making the computer more accessible to more people.

High level or problem oriented languages are relatively easy to write as they use english-like phrases. They are generally portable but require appropriate compilers to translate them into machine code.

Simulation of temperature in grain silo involves finding the numerical solution of heat-conduction equations or relationship , therefore, the best suited high-level language for this type of scientific work is the Fortran.

FORTRAN ; (FORmula TRANslation) has been the most popular language for scientific and engineering software. FORTRAN was developed by John Backus and his team at the International Business Machines (IBM) corporation in the United States of America in 1956. This initial work was revised and extended to Fortran II in 1958, Fortran IV in 1962, Fortran 66 in 1966 and Fortran 77 in 1978. In order that Fortran can cope with recent advances in programming concepts, a new America National Standards Institute (ANSI) committee was inaugurated in 1980 to produce Fortran 90 which incorporates all of Fortran 77 and is largely competitive with the well structure languages like PASCAL and C.

Most major analysis systems in the technological arena have been written in Fortran because it is so portable and enduring and because of its built-in mathematical and trigonometrical functionality. Typical of these are large finite element analysis systems. Also, Fortran's relatively primitive syntax, which translates easily and efficiently into the underlying machine language of the host computer, leads to high speed processing, and increasing important component of any scientific language.

There are however other problem oriented languages which apart from having better structure than Fortran are superior for manipulating text and graphics. Today, over 40 years after Fortran was developed, the language still retains its dominance largely because of huge investment in Fortran code and expertise, vast number of software packages and standard libraries that are written in Fortran which cost billions of Naira to convert to other high level languages like C or Pascal. This means that Fortran will be with us for sometime to come.

4.2b Development of the Fortran Program

The program uses the explicit finite difference scheme to solve the one-dimensional time-dependent heat conduction equation because of its ease in solving the system of algebraic equations that are formed from the transformation of the differential equation.

The numerical computation is made up of the initial temperature distribution within the stored grain, the internal temperature for successive time steps and the boundary conditions. The boundary conditions consists of the centre element where R=0 and m=1 and the exterior element exposed to the heated metal bin wall with R=L and m=M+1. The radius is subdivided into 10 equal divisions.

The main file is linked to the Data and Output files.

The main features of the program and the significance of various statements are as follows.

Lines 6-18 Specify the creation of both the Data and Output files.

Line 20 Write the title of the program.

Line 23 Specify the input data, which include M, α, L, Δr, k, Ta and hL.

Lines 28-31 Specify the initial temperature distribution. The "DO LOOP" was used because the temperature was assumed to be uniform.

Lines 32-35 Compute the permissible value of the time step Δt from the relation $\Delta t = X(\Delta r)^2/\alpha$.

Lines 36-45 Compute the internal node temperatures for the successive time steps for m=2 to M from the relation

$$T^{i+1}{}_{m}=X(T^{i}{}_{m+1}+T^{i}{}_{m-1})+(1-2x)\,T^{i}{}_{m}$$

Lines 46-49 Compute the temperatures at the boundary nodes m=1, R=0 and m=M+1 , R=L depending on the boundary conditions used.

Lines 54-56 Print the node temperatures at various times.

Line 59 Print the headings : Time(sec.) and Temperatures at internal nodes.

The program print out is contained in Appendix A

4.3 Silo Specifications, SGR and Grain conditions.

4.3a Silo Specifications.

Capacity, C = 2,500 MT

Height, H = 11m

Diameter, D = 20m

Material of Construction = Galvanized sheet metal

Gage = 22 inch

Density, ρ = 7840 kg/m³

Thermal Conductivity, K = 45.8318 W/mK

4.3b Minna SGR Ambient conditions.

SGR ambient temperature = 34.2°C (Jan. 1995)

Wind force observed = 3 - 6mm (Jan. 1995)

Total Rainfall = 0mm

Relative Humidity (09h) = 34%

4.3c Grain conditions.

Initial grain temperature = 12.2°C

Initial grain moisture content = 12% wb

Grain type = Maize

Thermal conductivity, K = 0.1600 W/m°C

Density, ρ = 711.29 kg/m³

Thermal capacity, c = 1.950 KJ/Kg°C

4.4 Users Manual

The program uses the Fortran 77 compiler with the RM/Forte version 1.01 which is user - friendly.

The project, Temperature Simulation in Grain Silo, under the filename Silo1.For can be access for editing, compilation, linkage and running. Both the data and output file names are supplied during the running of the program and each of these files can be edited.

The program allows the compiler to read the data in the data file using its own format while the output file is edited for conformity to the desired format.

The following information are relevant :

Fortran compiler	RM/Forte version 1.01
Project name	SILO1
Project Filename	SILO1.FOR
Project description	Temperature Simulation in Grain Silo
Linker name	Microsoft
Executable Filename	SILO1.EXE
Data Filename	SILO.DAT
Output Filename	SILO.OUT

Logging into the system or forte environment is done by typing FORTE at the A prompt after the insertion of the diskette. This leads to the main menu titled RM/Forte projects. Highlights at this menu include the Name (of projects), Description (of projects) and Date last modified.

Any key pressed leads to the sub menu which allows either entering an existing project, a new project or Quit from

RM/Forte environment. These are represented by Enter,N,or Q keys respectively.

Choosing the Enter key enable the user to enter the project name and description as required by the system after which the Fortran program can be entered line by line using the A key which stands for ADD line. The program is then compiled using the C key, and linked using the L-key. However, the Forte environment or the system permits the compilation and linkage processes to be carried out together using the Make (M) key. If the program is free of errors (compilation and warning) , the running of the program takes place using the R-key.

During the running process, the system would ask for both the Data and output filenames which allows the system to search for data in the data file for the running of the program and send the result to the output file.

The Escape key (Esc) would take the user back to the sub menu for a repeat of any operation after which working in the environment can be ended by using the Q key to quit or log out from the environment.

4.5 Validation of the simulation result.

The results of the simulation cannot be validated with the actual temperature distribution existing within the stored maize in the SGR complex because the complex temperature monitors were in bad states and more importantly no grains was stored in the silo during the course of this study.

CHAPTER FIVE

5.0 RESULTS, DISCUSSION, CONCLUSION AND RECOMMENDATIONS.

5.1 Results and Discussion.

The results of this project is shown in Appendix B. The computation was done using a time step of 3500.00 seconds for 24 consecutive steps. the step i = 24 corresponds to the time, t = 24 x 3500 = 84000 seconds (25 hours).

The sector of radius 10m was divided into 10 divisions at 1m intervals or nodes at which the temperature of the stored grain were computed or observed.

The silo was treated as a shallow or small bin since the diameter is higher than its height. This implies that the heat flow from the bin wall have an appreciable effect on the grains at the centre which also goes with the fact that the temperature of small (shallow) bins increases quickly with increase in ambient temperature but has been found to cool more rapidly than the deep one.

The initial temperature of the grain in this study was 12.2°C while the maximum temperature of the environment was 34.2°C for the month of January 1995 as reported by the meteorology department of Minna Airport.

The simulation result after the first time step of about an hour was observed to be uniform throughout the nodes at this initial stage. At the end of the second time step, there is an observed change at the outside boundary node because of it contact with the bin wall that is heated by sun radiation.

The temperature of successive nodes increases steadily towards the centre node until after the tenth time-step (35000.00 seconds) when the centre node recorded an increase of 0.01°C in temperature.

After about 24 hours of simulation, the centre node temperature increased to 13.31°C amounting to an increase of 1.11°C while the exterior node increased to 27.55°C corresponding to an increase of 15.35°C in temperature. This trend is in accordance with the general and normal behaviour of shallow bins in which temperature increases rapidly towards the centre and also shows that the heat flows from the outside to the centre.

The ambient temperature was greater than the exterior temperature of 27.55°C because of the losses due to convection , radiation and also the material of the bin wall.

With increase in ambient temperature especially in March which normally has the highest maximum temperature in any typical year, the stored grain temperature would definitely increase which may allow for more reproductive cycles of grain insects in small bins. This situation may become worse when the heat of reproduction and respiration of these insects and the stored grains themselves are taken into consideration thereby leading to deterioration of the stored grains.

The result of the simulation may be a little bit different from the actual situation present in the silo due to the changes in daily situation diurnal and night temperatures. Also, seasonal changes in atmospheric temperature cause temperature patterns throughout the grain bins to be similar to sine curves.

Nevertheless, the results would provide a strong base for monitoring temperature movement in the bins for easy detection of hot spots of deterioration.

5.2 Conclusions.

The result of the simulation could not be validated because of lack of installed temperature monitors and stored grains. However, it is hope that the program would be useful to effectively predict temperature movement in grain bins. It would be an important spring-board for further improvement so as to be able to carefully measure or locate pockets of stored grain deterioration.

5.3 Recommendations.

a. A practical and actual test should be undertaken to validate the simulation results.

b. The simulation results should be improved upon to take into account the day and night-time temperatures.

c. A means for better understanding of the system should be considered whereby both the moisture movement in the stored grain as well as the heat of respiration of the stored grain should be taken into consideration.

d. Due to the high maximum temperature of the environment of study, materials with lower thermal conductivities such as wood products should be used as bin construction materials.

e. Small time steps should be used to increase the accuracy of the results.

f. Complete numerical data on the effect of temperature on the storage life of grains must be prepared before a rational grain storage system can be designed and operated successfully.

g. Insulation can be provided to reduce the effect of the ambient conditions on the temperature and moisture gradients in the grain bulk.

h. Two-dimensional heat conduction approach should be used for detailed and complete numerical computation.

REFERENCES

1 Converse,H.H.;A.H.Graves and D.S.Chung, 1969: Transient heat transfer within Wheat stored in a cylindrical bin. ASAE, St. Louis. Paper No. 69-855, P24. In: Yaciuk et.al (1975), Journal of Agricultural Engineering Research, 20,245-258

2 Dusinberre,G.M., 1961: Heat transfer calculations by Finite Difference. Scranton: International Textbook Company, P293. In: Yaciuk et.al (1975), Journal of Agricultural Engineering Research, 20, 245-258

3 FAO, 1995: Technical cooperation programme: Assistance to the Strategic Grain Reserve Scheme in Nigeria. Terminal statement prepared for the Government of Nigeria by the Food and Agriculture Organization of the United Nations, Rome. PP1-9

4 Igbeka,J.C., 1992: Interrelations of variable and factors of deterioration in stored grains. Lecture delivered at the Induction course for Engineers and Pest Control Officers of Strategic Grain Reserve complexes. Held at Crop Storage Unit , Ibadan. Feb. 26-28. PP1-7

5 Naylor,T.H.,1966: Principles of Operation research. John Wiley, New York

6 Mijinyawa,Y., 1989: The use of wood products in the design and construction of a grain silo for the humid tropics. Ph.D. Thesis in the department of

Agricultural Engineering, University of Ibadan, Ibadan. PP13-16

7 Muir,W.E., 1970: Temperature simulation in grain bins. Canadian Agricultural Engineering. 12(21)

8 Osobu,A., 1985: In: Mijinyawa, 1989: The use of wood products in the design and construction of a grain silo for the humid tropics. Ph.D. Thesis in the department of Agricultural Engineering, University of Ibadan, Ibadan. PP13-16

9 Osunade, A., 1997: Personal communication. Department of Agricultural Engineering, Obafemi Awolowo University, Ile-Ife.

10 Williams,S.K.T., 1971: In: Mijinyawa, 1989: The use of wood products in the design and construction of a grain silos for the humid tropics. Ph.D. Thesis in the department of Agricultural Engineering , University of Ibadan, Ibadan. PP13-16

11 Yaciuk,G; W.E., Muir and R.N., Sinha, 1975: A simulation model of Temperatures in stored grain. Journal of Agricultural Engineering Research 20,245-258

APPENDIX A

```
rte Version 1.01          08-May-96 15:22:30                              F
: SILO1.FOR                                                               Opt

C       COMPUTER PROGRAM TO SIMULATE TEMPERATURE MOVEMENT IN
C       GRAIN SILO USING EXPLICT UNSTEADY STATE HEAT CONDUCTION
C       METHOD AND FORTRAN PROGRAMMING LANGUAGE
        CHARACTER *37 TITLE
        DIMENSION T(100), TNEW(100), R(100)
          character*60 FIN,FOUT
C       ------------------------------------------------------------------
          write(*,200)
          read(*,210) FIN
          write(*,205)
          read(*,210) FOUT
C =======================================================================
          open (unit=30,file=FIN,status='OLD')
          open (unit=40,file=FOUT,status='UNKNOWN')
C =======================================================================
 210      FORMAT(A60)
 200      FORMAT(/,3X,'INPUT DATA FILENAME  ==>  ')
 205      FORMAT(/,3X,'OUTPUT DATA FILENAME  ==>  ')
        WRITE (40,50)
 50     FORMAT (5X,37H TEMPERATURE SIMULATION IN GRAIN SILO/)
        WRITE (40,55)
 55     FORMAT (5X,50H DATA ARE:M,ALPHA,RL,DELR,IEND,X,RK,TINFA,HL,D
        READ (30,*) M,ALPHA,RL,DELR,IEND,X,RK,TINFA,HL,DRHKL
        DELR = RL/FLOAT(M)
        DO 600 I =1,M+1
        R(I) = DBLE(I-1) * DELR
 600    CONTINUE
C       THE INITIAL TEMPERATURE DISTRIBUTION IS GIVEN BY
        DO 100 I = 1, M+1
        T(I) = 12.2
 100    CONTINUE
C       COMPUTE THE VALUE OF TIME STEP
        DELT = X * (DELR)**2/ALPHA
        WRITE (40,280) DELT
 280    FORMAT (3X, 'TIME STEP : ',G11.4, ' SEC' )
C       COMPUTE INTERNAL TEMPERATURE FOR SUCCESSIVE TIME STEPS
        WRITE (40,70) (R(J),J=1,M+1)
        WRITE (40,80)
        ICOUNT = 0
        COUNT = ICOUNT
        WRITE (40,90) COUNT, (T(J),J=1,M+1)
 30     ICOUNT = ICOUNT + 1
        DO 40 J = 2,M
        TNEW(J) = X * (T(J-1)+T(J+1))+(1.0-2.0*X)*T(J)
 40     CONTINUE
C       THE BOUNDARY CONDITIONS ARE COMPUTED AT R=0 AND R=L
        DRHKL = DELR * HL/RK
        T(M+1) = 1.0/(1.0+DRHKL)*(T(M) +DRHKL*TINFA)
        T(1) = T(1) + 4*X*(TNEW(2)-T(1))
C       SUBSTITUTE NEW TEMPERATURES
        DO 150 J = 2,M
        T(J) = TNEW(J)
 150    CONTINUE
```

APPENDIX A

```
rte Version 1.01          08-May-96 15:22:30                    Pa
: SIL01.FOR                                                     Opti

 C        PRINT TEMPERATURES
          WRITE (40,90) ICOUNT*DELT, (T(J),J = 1, M)
 90       FORMAT (1X,F11.2,2X,100(5F10.2/14X))
          IF (ICOUNT.LT.IEND) GO TO 30
 70       FORMAT (/10X,2HX=,2X,100(5F10.2/14X))
 80       FORMAT (/3X,10HTIME(Sec.),18X,29HTEMPERATURE AT INTERNAL NODES
          STOP
          END

BER OF WARNINGS IN PROGRAM UNIT: 0
BER OF ERRORS   IN PROGRAM UNIT: 0

BER OF WARNINGS IN COMPILATION : 0
BER OF ERRORS   IN COMPILATION : 0
```

APPENDIX B

TEMPERATURE SIMULATION IN GRAIN SILO

DATA ARE: M, ALPHA, RL, DELR, IEND, X, RK, TINFA, HL, DRHKL

TIME STEP : 3500.00 SEC

X=	0.00	1.00	2.00	3.00	4.00
	5.00	6.00	7.00	8.00	9.00
	10.00				

TIME (Sec.)	TEMPERATURE AT INTERNAL NODES				
0.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.20	12.20	12.20	12.20
	12.20				
3500.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.20	12.20	12.20	12.20
7000.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.20	12.20	12.20	17.44
10500.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.20	12.20	14.40	18.28
14000.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.20	13.13	15.11	20.30
17500.00	12.20	12.20	12.20	12.20	12.20
	12.20	12.59	13.57	16.45	21.07
21000.00	12.20	12.20	12.20	12.20	12.20
	12.36	12.84	14.37	17.18	22.12
24500.00	12.20	12.20	12.20	12.20	12.27
	12.49	13.28	14.91	18.07	22.73
28000.00	12.20	12.20	12.20	12.23	12.33
	12.73	13.63	15.55	18.70	23.40
31500.00	12.20	12.20	12.21	12.26	12.46
	12.94	14.06	16.07	19.35	23.88
35000.00	12.21	12.21	12.23	12.32	12.58
	13.21	14.43	16.60	19.87	24.35
38500.00	12.22	12.22	12.26	12.39	12.74
	13.46	14.83	17.07	20.38	24.73
42000.00	12.25	12.24	12.30	12.48	12.89
	13.73	15.19	17.52	20.82	25.09
45500.00	12.28	12.27	12.35	12.58	13.07
	13.99	15.56	17.93	21.23	25.40
49000.00	12.32	12.31	12.41	12.69	13.25
	14.26	15.70	18.32	21.59	25.69

£50

52500.00	12.38 14.52	12.36 16.23	12.48 18.69	12.81 21.94	13.44 25.95
56000.00	12.45 14.78	12.42 16.54	12.57 19.02	12.94 22.25	13.63 26.18
59500.00	12.52 15.04	12.49 16.84	12.66 19.34	13.07 22.55	13.82 26.40
63000.00	12.61 15.29	12.58 17.13	12.76 19.64	13.21 22.82	14.02 26.60
66500.00	12.71 15.53	12.67 17.41	12.87 19.92	13.36 23.07	14.21 26.79
70000.00	12.81 15.77	12.77 17.67	12.99 20.19	13.51 23.31	14.41 26.96
73500.00	12.93 16.00	12.88 17.93	13.12 20.44	13.67 23.53	14.60 27.12
77000.00	13.05 16.22	13.00 18.17	13.25 20.68	13.83 23.74	14.80 27.27
80500.00	13.18 16.44	13.13 18.41	13.39 20.91	13.99 23.94	14.99 27.41
84000.00	13.31 16.66	13.26 18.63	13.53 21.13	14.16 24.13	15.18 27.55

TEMPERATURE SIMULATION IN GRAIN SILO

DATA ARE: M,ALPHA,RL,DELR,IEND,X,RK,TINFA,HL,DRHKL

10,1.2E-4,10.00,1.00,24,0.42,0.16,34.20,0.21,1.04,1.00