DEVELOPMENT OF INTELLIGENT FARM STORAGE AND PRESERVATION SYSTEM (CASE STUDY: YAM TUBER)

BY

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ABSTRACT

Based on FAO/World Bank report, the value of post-harvest food losses in sub-Saharan Africa is around $4 billion a year and this is mainly due to poor storage condition of the farm products. Yam tuber is one of the most commonly available farm products in West African and it belongs to one of the food items which suffer losses due to poor storage system. Presently, yam tubers are stored via the use of yam barn (of different construction and shapes), delayed harvesting (yams deliberately left in the ground), underground pits and raised huts. Unfortunately, all these storage systems produce unsatisfactory results as the yams are exposed to an uncontrollable environment (temperature, humidity, aeration, insects, rodents etc), thereby causing the tubers to lose its quality as well as to get rotten. Recent advancement in technology can be harnessed to improve the condition of traditional yam storage system. Consequently, this thesis examines simple but effective procedures in alleviating problems associated with traditional yam storage system through: (i) proper choice of construction materials, (ii) proper design of storage system (iii) effective method of ventilating the storage system and (iv) intelligent control of temperature and air flow within the storage system. The effect of outdoor temperature on the indoor temperature was first investigated under the influence of heat of respiration of yam tubers and changing properties of building materials. The timber material was found to have high resistance to outdoor temperature as compared to concrete and brick materials. The ventilation rate for yam storage system has been investigated for single span with single longitudinal roof opening and with both longitudinal roof and vertical side wall openings. The result shows an increase in ventilation rate with increase in window opening angle and temperature difference. The development of Computational Fluid Dynamics (CFD) as a powerful tool for prediction of air-flow around building are presented in this research, COMSOL Multiphysics was used to predict the air-flow distribution in a proposed yam storage system and results have shown acceptable ventilation rates that can be achieved through a cross-ventilation which is capable of removing heat of respiration of yam tuber. Finally, an intelligent control technique for yam storage system based on fuzzy logic controller was developed. The controller was simulated and later validated on the proposed yam storage prototype for different typical levels of input parameters. The results show that, the proposed controller is capable of responding to the changes in temperature conditions by adjusting the window opening angle to keep the internal temperature within acceptable range (13^{o}C-17^{o}C). The controller also satisfies safety requirements due to sudden changes in wind velocity and presence of rain fall.

خلاصة

استنادا إلى منظمة الأغذية والزراعة / تقرير البنك الدولي، وقيمة خسائر الأغذية بعد الحصاد في أفريقيا جنوب الصحراء الكبرى هي في حدود 4 مليارات دولار في السنة، وهذا يرجع أساسا إلى حالة سوء التخزين للمنتجات الزراعية. درنة البطاطا الحلوة هي واحدة من أهم المنتجات الزراعية المتاحة عموما في غرب أفريقيا، وانه ينتمي الى واحدة من المواد الغذائية التي تعاني من الخسائر الناجمة عن نظام التخزين الفقراء. في الوقت الحاضر، يتم تخزين درنات البطاطا الحلوة من خلال استخدام الحظيرة اليام (البناء وأشكال مختلفة)، وجمع تأخير (اليام ترك عمدا في الأرض)، حفر تحت الارض والأكواخ التي أثيرت. للأسف، كل هذه الأنظمة تخزين نتائج غير مرضية كما يتعرض اليام في بيئة يمكن السيطرة عليها (درجة الحرارة والرطوبة والتهوية، والحشرات والقوارض وغيرها)، والتسبب بالتالي في الدرنات لانقاص ونوعيته، وكذلك للحصول على فاسد. يمكن تسخيرها تقدم مؤخرا في مجال التكنولوجيا لتحسين حالة التقليدية اليام نظام التخزين. وبناء على ذلك، هذه الأطروحة يدرس إجراءات بسيطة لكنها فعالة في التخفيف من حدة المشاكل المرتبطة التقليدية اليام نظام التخزين من خلال: (ط) الاختيار السليم لمواد البناء، (ب) تصميم نظام مناسب للتخزين (ثالثا) طريقة فعالة للتهوية ونظام التخزين و (iv) تحكم ذكي لدرجة الحرارة وتدفق الهواء ضمن نظام التخزين. وكان التحقيق لأول مرة تأثير درجة الحرارة في الهواء الطلق على درجة الحرارة داخل المباني تحت تأثير الحرارة للتنفس من درنات البطاطا الحلوة والخصائص المتغيرة للمواد البناء. تم العثور على مادة الخشب لديها مقاومة عالية للحرارة في الهواء الطلق، مقابل مواد الخرسانة والطوب. وقد تم التحقيق في معدل التهوية لنظام تخزين البطاطا الحلوة لفترة واحدة واحدة مع فتح سقف الطولية ومع كل من سقف الطولية والعمودية فتحات الجدار الجانبي. نتيجة حدوث زيادة في معدل التهوية مع زيادة في زاوية فتح نافذة والفرق في درجة الحرارة. وقد تعرض في تطوير ديناميات الموائع الحسابية (CFD) باعتبارها أداة قوية للتنبؤ تدفق الهواء حول المبنى في هذا البحث، وتستخدم للتنبؤ COMSOL Multiphysics توزيع تدفق الهواء في نظام تخزين اليام المقترحة والنتائج أظهرت تهوية مقبول المعدلات التي يمكن تحقيقها من خلال التهوية العرضي الذي هو قادر على إزالة الحرارة من تنفس من درنة البطاطا الحلوة. أخيرا، تم تطوير تقنية التحكم الذكي لنظام تخزين البطاطا الحلوة على أساس وحدة تحكم المنطق الضبابي. وكانت وحدة تحكم محاكاة والتحقق من صحتها في وقت لاحق عن النموذج الأولي اليام تخزين المقترحة لمستويات نموذجية مختلفة من معلمات الإدخال. فقد بينت النتائج أن وحدة تحكم المقترحة قادرة على الاستجابة للتغيرات في ظروف درجة الحرارة عن طريق ضبط زاوية فتح نافذة للحفاظ على درجة الحرارة الداخلية ضمن نطاق مقبول (^{o}C–17^{o}C13). وحدة تحكم يلبي متطلبات السلامة أيضا بسبب التغيرات المفاجئة في سرعة الرياح ووجود سقوط الأمطار.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as thesis for the degree of Master of Science Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degree at IIUM or other institutions.

Abdulazeez Murtala

Signature…………………… Date………………..

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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Affirmed by Abdulazeez Murtala

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Signature Date

To my beloved mum Mrs. Fatima L. Ibrahim

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LIST OF SYMBOLS

ρ	Density of air
ρ_i	Inside density of air
ρ_o	Outside density of air
η	Viscosity of the fluid
β	Roof angle
α'	Side window opening angle
α	Roof window opening angle
ω	Angular frequency
φ	Phase angle
y(t)	Measured output vector
x(t)	Vector of state variables
u(t)	Vector of system inputs
L_0	Length of the yam storage system
k	Thermal conductivity
I	Identity matrix
H_0	Width of the window
h	Height of a roof front aperture
$h_{neutral}$	Height of neutral pressure level
g	Gravitational constant
D	Distance between side window and roof window
c	Specific heat capacity of air
a_w	Water activity
Δp_s	Pressure difference
ΔP_w	Wind pressure
Q_y	Heat of respiration of yam tuber
z_2	Distance between the neutral plane level and the roof window
z_1	Distance between the neutral plane level and the side window
v_w	Mean wind velocity
v_o	Velocity of air
V_n	Volume of component n
U_{ij}	Overall thermal transmittance coefficient
T_o	Outside temperature
T_i	Inside temperature
R_{ij}	Resistance between node i and j
Q_w	Ventilation rate due to the wind
Q_{side}	Ventilation rate through the side opening window
Q_{roof}	Ventilation rate through the roof opening window
Q_T	Ventilation rate due to the temperature
P_w	Mean pressure
P_o	Static pressure
L_n	Thickness of wall n
K_n	Thermal conductivity of wall material

C_p	Surface pressure coefficient
A_w	Area of the window
A_n	Surface area of the wall n
ΔP_T	Thermal pressure
U_{o1}	Outside thermal transmittance coefficient
U_{i1}	Inside thermal transmittance coefficient
T_{ai}	Inside temperature
h_{no}	Outside heat transfer coefficient for wall n
$h_{neutral}$	Height of neutral pressure level
C_d	Discharge coefficient
C_1	Thermal capacitance
T_{ao}	Outside temperature

LIST OF ABBREVIATIONS

ACC	Acceptable
ANN	Artificial neural networks
CFD	Computational fluid dynamics
CI	Chilling injury
CIBSE	Chartered Institution of Building Services Engineers
CO	Carbon monoxide
CO_2	Carbon dioxide
D. alata	Dioscorea alata
D. cayenensis	Dioscorea cayenensis
D. trifida	Dioscorea trifida
DAC	Digital to analog converter
DAQ	Data acquisition card
FEM	Finite Element Method
FLC	Fuzzy logic controller
FS	Fuzzy System
GA	Genetic Algorithms
H	High
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
L	Low
LES	Large eddy simulation
MAE	Mean absolute error
Mt	Metric tons
NaCl	Sodium chloride
NPL	Neutral pressure level
O_2	Oxygen
PDE	Partial differential equation
PID	Proportional integral and derivative
PTI	Public transport interchange
PWM	Pulse-width modulation
rh	relative humidity
U-values	Overall thermal transmittance coefficient
VH	Very high
VL	Very low
VV_S_W	Very Very Strong Wind

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

It is estimated that between 25 and 40% of stored agricultural products are loss in the tropics each year because of inadequate storage facilities. Farm products are exposed to insects, rodents, birds and other pests in the field and during storage. In addition, the product may be spoiled by infection from fungi, yeasts or bacteria. In order to minimize the losses during storage it is important to know the best possible environmental conditions for storage of the product, as well as the conditions under which its attackers thrive (Hayma, 2003).

Yam tuber belongs to the genus Dioscorea (Family Dioscoreaceae), which is an important root crop especially in West Africa and it is next to cassava (Opara, 2003; Osunde & Orhevba, 2009). Beside their importance as a food source, yams also play a significant role in the socio-cultural lives of some producing regions such as the celebrated New Yam Festival in West Africa. It is grown primarily in West Africa (90% of world production comes from Nigeria, Ivory Coast, Ghana, Dahomey and Togo). Yam tubers are normally propagated vegetatively by the use of whole tubers or tuber parts (Craufurd, 2001). Yam production is seasonal and its storage under tropical ambient conditions often leads to considerable loss (Passam, 1999). The causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot due to mould and bacteria, and attack by insects, birds, nematodes and rodents. Sprouting, transpiration and respiration are physiological actions which depend on the storage environment (mainly temperature and relative humidity). These physiological changes affect the internal composition of the tuber, resulting in the destruction of edible part or changes in nutritional quality. Several traditional storage systems have being used for yam storage and preservation such as: yam barn, leaving the tubers in the ground until required, underground structures (Opara, 1999) and variant of these procedures. Losses during the storage are known to be high and depending on the species and environment, they may be of the order of 30-60% during the course of three to six months (Passam, 1999).

It is well known that, the traditional yam storage systems are inefficient as yam tubers are exposed to harsh weather and diseases, leading to very high losses during the storage period. In solving these problems, different storage methods have been proposed and implemented. These include storing the yam tuber in refrigeration at a temperature of about 13^{o}C-16^{o}C (Martin 1984; McGregor, 1987). This method was reported to significantly reduce post-harvest losses, however its adaptation is restricted due to the high degree of technical requirements and the investments required do not allow this process to be successfully applied to the level of the small farm producers at present. Therefore, this research work is thus motivated by the need to develop and implement simple and yet efficient intelligent farm product storage and preservation system (case study: yam tuber). This new proposed intelligent farm storage system would protect the farm products from extreme temperature, high wind, rain, insect and diseases. The research work would also look at the existing traditional yam storage system practice and their limitations for improvement, details design, materials used for the construction of storage system and details analysis of natural ventilation of storage system would be consider in this study, finally, a fuzzy logic controller would be developed for control of temperature and air-flow in to the proposed farm product storage and preservation system.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Losses during storage of root crops, which constitutes large percentage of food supply in West Africa, has been identified as one of the main cause of food shortage in the world (Kates, 1990). Nigeria being the major producer of yam tuber has continued to use traditional approaches for storing of this delicate tuber product, hence the losses during storage of root crops is very high. Factors responsible for these losses include sprouting, transpiration, respiration, rot due to mould and bacteria, and attack by insects, nematodes and mammals.

In solving this perennial problem, different traditional yam storage and preservation techniques have been advocated. This include; yam barn, leaving the tubers in the ground until required, underground structures (Opara, 1999) and variant of these procedures. However, these methods have many drawbacks such as poor ventilation, moisture build up and the direct contact of the tubers. This causes the stored product to become warm and thus promotes rapid spreading of rot which means that storage duration is strictly limited.

In view of these, this work proposes the development of an intelligent farm product storage and preservation system that will be based on fuzzy logic controller. This new storage system will use natural ventilation as a medium of cooling in order to keep the yam tuber in a good condition and overcome many disadvantages of traditional storage system. This includes better sensory quality, lower temperature, good storage and preservation methods and better sanitation.

1.3 RESEARCH OBJECTIVES

The main objective of this research is:

a. To develop a new approach for farm product (yam tuber) storage and preservation system based on fuzzy logic controller for the control of the temperature and the air flow in the proposed storage system.

Therefore, to achieve this objective, the following sub-objectives must be completed.

1. To formulate a new mathematical model of the yam storage system for purpose of investigating control system.
2. To develop an intelligent controller to control the temperature and air flow in the proposed system.
3. To construct a prototype of the proposed storage system.
4. To evaluate the performance of the proposed system.

1.4 RESEARCH METHODOLOGY

In order to achieve the above objectives, the following works are to be conducted:

a. Literature survey of books, articles and journal papers focusing on the concept of food storage and preservation, natural ventilation, fuzzy logic control and thermal modeling of a building are studied and reviewed in this research so as to establish the current state of the art in these areas of research.
b. Development of a mathematical model of the yam storage system for purpose of investigating control system,
c. Analysis of natural ventilation for yam storage system
d. Analysis of fuzzy logic Controller to control temperature, and the air flow to the preservation. This involves the development of intelligent based

microcontroller to control the temperature and the air flow of the preservation system.

e. Simulation of the yam storage system model

f. Experimental implementation and evaluation of the model-base yam storage system.

g. Performance analysis of the fuzzy logic controller.

Figure 1.1 shows the flow chart of the research methodology.

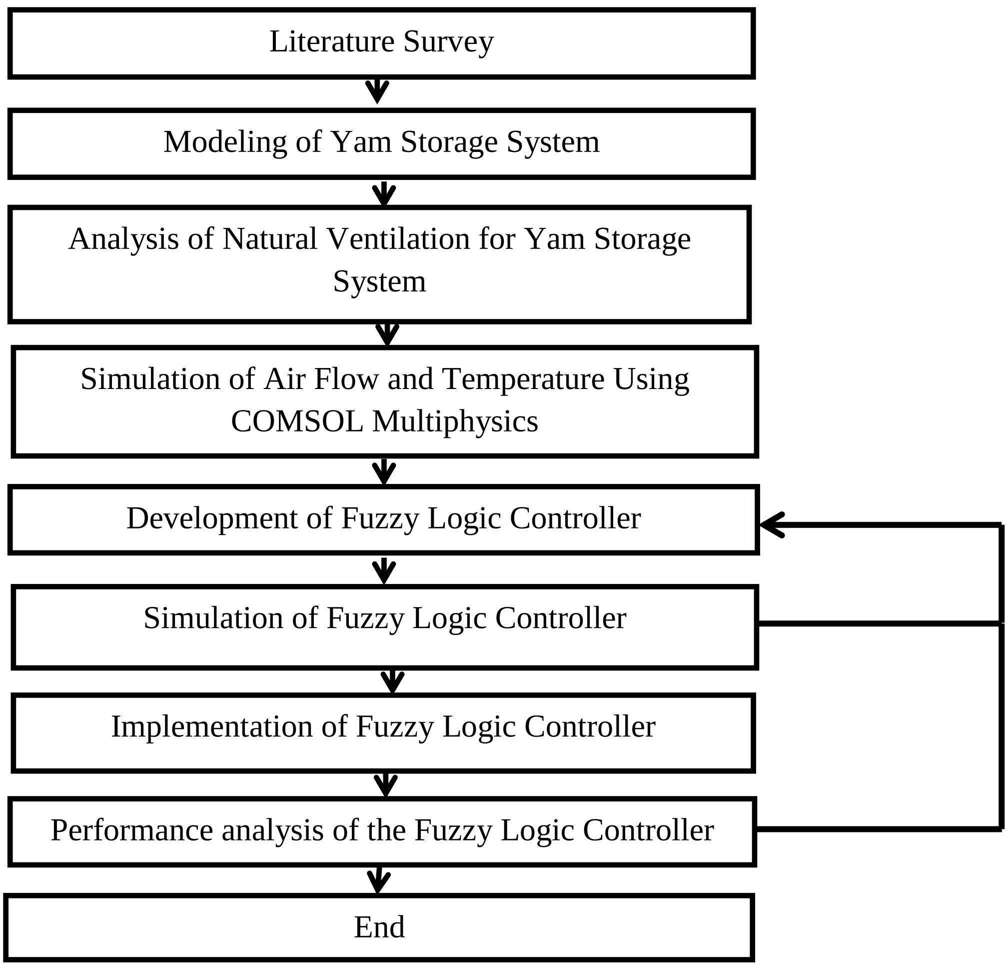

Figure 1.1: Research Methodology Flow Chart

1.5 SCOPE OF THE RESEARCH

The scope of this study is limited to the development of a new method for farm product (yam tuber) storage and preservation system based on fuzzy logic controller for the control of the temperature and the air flow in the proposed storage system.

1.6 ORGANIZATION OF THE DISSERTATION

This dissertation is organized into seven chapters.

Chapter One provides a brief introduction of Yam tuber and traditional way of storage and discussed the objectives, research methodology, scope of the research and the organization of the dissertation.

Chapter Two presents literature review on different method of food storage system and also discusses thermal model of building, natural ventilation, computational fluid dynamics and intelligent control system.

Chapter Three discusses the mathematical model of the yam storage system, design of natural ventilation for yam storage system and simulation of the air flow in yam storage system using COMSOL Multiphysics.

In Chapter Four, development of fuzzy logic controller for yam storage system is discussed, the developed fuzzy logic controller where simulated for different temperature.

Chapter Five discusses the experimental setup and physical parameters necessary for the storage system using data acquisition, potentiometer and temperature sensor.

In Chapter six, the result and performance of the proposed fuzzy logic controller is presented. Chapter Seven discusses the overall conclusions of the research work and significant future direction of the research is highlighted.