EXPERIMENTAL INVESTIGATION AND COMPUTER MODELING OF HEAT AND MASS TRANSFER OF CASSAVA MASH DURING DRYING

BY

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DEDICATION

This work is dedicated to my fiancee Miss Olubukola Ayodele

DECLARATION

I hereby declare that this thesis is a record of my research work. It has neither been presented nor accepted in any previous application for a higher degree.

All sources of information have been specifically acknowledged.

Signature.................................. Date: 20/07/92

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NOMENCLATURE

SYMBOL	Description	Units
A	Drying surface area of the dryer	m^2
A	Exchange surface area of the mash grains	m^2
A_m	Effective area of mass transfer	m^2
c	Heat capacity	kJ/K
C'	specific heat	kJ/kgK
C_g	Specific heat of gari mash	kJ/kgK
C_c	specific heat of calorimeter	kJ/kgK
C_w	Specific heat of water	kJ/kgK
d	Diameter of gari grains	m
d_{av}	Average grain diameter	m
dT	Change in temperature	K
F	drying rate	kg/s
F_1	Initial drying rate	kg/s
F_c	Constant period drying rate	kg/s
F_3	Final drying rate	kg/s
F_f	final drying rate	kg/s
F_e	drying rate at equal Moisture content	kg/s
Fm	Finess modulus	
G	Air mass velocity	kg/s
H_a	Absolute humidity at air temperature	%
H_s	Absolute humidity at saturation temperature	%
H	Absolute humidity	%

H_w	Absolute humidity of water	%
h_r	Coefficient of heat transfer	W/m²k
h	Coefficient of heat transfer	W/m²k
K	Thermal conductivity	W/mk
K_m	Thermal conductivity of moist mash	W/mk
k_m	Coefficient of mass transfer	m/s
L	Mash thickness	mm
M	Mass	kg
M Mev	Moisture evaporated	kg
MC	Moisture content	%
Mc Mc^1	Critical moisture content	%
M_e	equilibrium moisture content	%
M_t	Moisture content at any time	%
M_3, M_f	Final moisture content	%
M_g	Mass of gari mash	kg
M_w	Mass of water	kg
M_c	Mass of calorimeter	kg
M_o	Initial moisture content	%
Mokg	Initial Moisture contents in kg	kg/kg
Mckg	Critical moisture contents in kg	kg/kg
Mc_{db}	Moisture content, dry basis	%
Mc_{wb}	Moisture content, wet basis	%
M_s	Mass of solid	kg
N	Rate of mass transfer	kg/s
n	drying constant	-
P	Pressure	N/m2
P_w	Pressure of water vapour	N/m²

Q	Quantity of heat	J
Q_A	Quantity of heat absorbed by air	J
Q_{Tc}	Quantity of heat conducted by the trough	J
Q_{RF}	Quantity of heat retained by the fryer	J
Q_G	Quantity of heat absorbed by the gari	J
Q_w	Quantity of heat absorbed by the water	J
q	Rate of heat transfer	kJ/s
R	Rate of drying	kg/s
R_c	Constant period rate of drying	kg/s
R_e	equilibrium rate of drying	kg/s
R_f	Final drying rate	kg/s
RH	Relative humidity	%
S	Humid heat	kJ/kg
T_a	Air temperature	°C
T_s	Saturation (surface) Temperature	°C
T	Temperature	°C
T_g	Gari temperature	°C
T_w	Water temperature	°C
T_c	Calorimeter temperature	°C
T_t	Equilibrium temperature	°C
T_p	Fryer temperature	°C
T_x	Temperature along x - axis	°C
T_y	Temperature along Y - axis	°C
T_n	Equilibrium temperature	°C
TT	Total drying time	min
T_1	Drying time at period 1 stage 1	min
T_{11}	Drying time at period 1 stage 2	min

T_2	Drying time at period 2 stage 1	min
T_3	Drying time at period 2 stage 2	min
Ts_1	Saturation temperature at period 1.	min
Ts_2	Saturation temperature at period	min
t	time	min
t_T	total drying time	min
t_c	constant rate period drying time	min
t_f	falling rate period drying time	min
t_{10}	drying time at period one stage one	min
t_{11}	drying time at period one stage two	min
t_{20}	drying time at period two stage one	min
t_{22}	drying time at period two stage two	min
V	Volume	m^3
W_o	Initial Weight	kg
WTO	Initial mash weight	kg
X	Thickness	mm
ρ	bulk density	kgm^{-3}
ρ_{bf}	bulk density before frying	kgm^{-3}
ρ_f	bulk density after frying	kgm^{-3}
α	thermal diffusivity	m^2/s
λ	Latent heat of vapourization	kJ/kgK
ΔT	Change in temperature	K
dm	Rate of moisture removal	kg/min
dm/dt	Rate of moisture removal	k g/min
θ	Angle	(°)
π	Constant = 3.1416	
μ	Coefficient of friction	

ABSTRACT

This work presents a mathematical model of gari drying in which diffusion of water, moisture evaporation, heat and mass transfer through the porous solids were taken into consideration. Several tests were run using a Laboratory-size dryer for data acquisition with different initial moisture contents of the cassava mash and the drying time monitored.

The effect of such factors as initial moisture content (M_o), mash initial weight (W_{To}), fryer temperature (TP), mash thickness (L), and final moisture content (M_f) were related mathematically to the total time of gari frying (TT).

A computer program was written in FORTRAN LANGUAGE to generate a drying model that was used to formulate appropriate equation for the drying process. Detailed theoretical study of the heat and mass transfer of cassava mash during drying were made and the results showed that drying of gari involved both the constant and falling rate drying phenomena. Microsoft Excel 7.0 Statistical package software was used to analyse the results of the model.

All the measured parameters that is, mash initial moisture content, mash initial weight, trough temperture,mash thickness and the final moisture content have a strong correlation ($R^2 = 0.81$) with the total time of frying (TT). The mash thickness (L) has the greatest effect on the time of frying. A multiple regression was done to develop the relationship between the total drying time(TT) as a dependent variable and initial moisture content (M_o), initial weight(W_{To}), fryer's temperature(TP), mash thickness(L), and final moisture content(M_F) as independent variables.

CHAPTER ONE

1.0 INTRODUCTION

Most agricultural materials are hygroscopic in nature, thus creating unsteady moisture level which leads to their quick quality deterioration. The addition of heat to remove moisture in form of drying serves as a control for moisture build up and hence helps in extending the shelf life of the material.

1.1 Origin of Cassava and its Uses

Cassava (Manihot esculenta crutz) is native to Latin America and to Southern Mexico (FAO, 1989). It is a crop of the lowland tropics, which cannot withstand frost, although it is well adapted to drought. It can be grown in areas where the annual rainfall is as low as 500 mm, provided that there is sufficient water available at planting so that the crop may become established. (Onwueme, 1978). Even in areas where maize or small - grained cereals are cultivated, cassava is also planted as a valuable "food reserve" crop. It is usually the last crop in the rotation, before the land is returned to "bush fallow". It is a heavy calorie-yielding crop ranging from 5 to 20 tonnes per hectare (Kuku, 1985). Nigeria produces about 9% of the total world production of cassava as a result of cassava hybrid introduced by the International Institute for Tropical Agriculture (IITA) Ibadan, an agricultural research institute based at Ibadan, Nigeria (Almazan, 1985).These cassava hybrids can produce as much as between 20 to 30 tonnes per hectare (Onwuneme, 1978 and Kuku, 1985).

Cassava roots are processed by various methods into different products and used in diverse ways according to local custom and preference to provide carbohydrate in the diet. The tubers does not store for long, thus the need for processing (Hahn, 1995). Fresh Cassava tubers contain 60% water (FAO, 1989), these water has to be removed or reduced so as to extend the shelf life. Various processes exists to convert the tubers into various food such as gari, "lafun", Starch, tapioca, chips, fufu, and others. It can also be used as livestock feed, in starch making for textile industries and alcohol industries. Cassava has a major disadvantage in that it contains cyanogenic glucoside which is capable of liberating hydrogen cyanide (HCN) (Coursey, 1973). Owing to the presence of HCN, various methods which bring about a reduction in the toxicity of the roots are employed during the processing (Shery and Marice, 1974; FAO, 1989).

1.2 Cassava Mash Production

Cassava roots are peeled and washed, they are then grated and left for 3 - 5 days to ferment, this fermentation process is responsible for either bland or acid taste that characterizes cassava product in several parts of the world (Kwatia, 1986). Dehydration is the next step in which water is removed from the fermented mash by placing several weights on the sack containing the mash to reduce the moisture level. Presently, several forms of hydraulic press jacks are in use for this purpose as reported by Kwatia, (1986). The dehydrated cassava mash is then sieved using sieves made out of metal or local plant material. Sieving is done to remove the excess fibrous material and to separate individual particles in preparation for frying. The product at this stage is called sieved cassava mash, and it is the raw material used in gari frying. Figure 1 shows the flow chart for gari processing.

1.3 Gari Frying

Gari is hygroscopic in nature, that is, it is capable of retaining moisture in a bound form within its structure. Drying on the other hand means the removal of liquid from the moist material by evaporation, this is a complex process which has received much attention and is well described by IITA, (1990). Frying of gari can be divided into two stages. These are the gelatinization of gari particles and drying. During drying, gari particles are continuously stirred in the frying pan to ensure uniform frying and to prevent burning. When heat is applied, it is transferred by conduction through the wall of the dryer to the moist mash and evaporation of water occurs. Frying is one of the methods used to reduce the cyanogenic glucoside content of

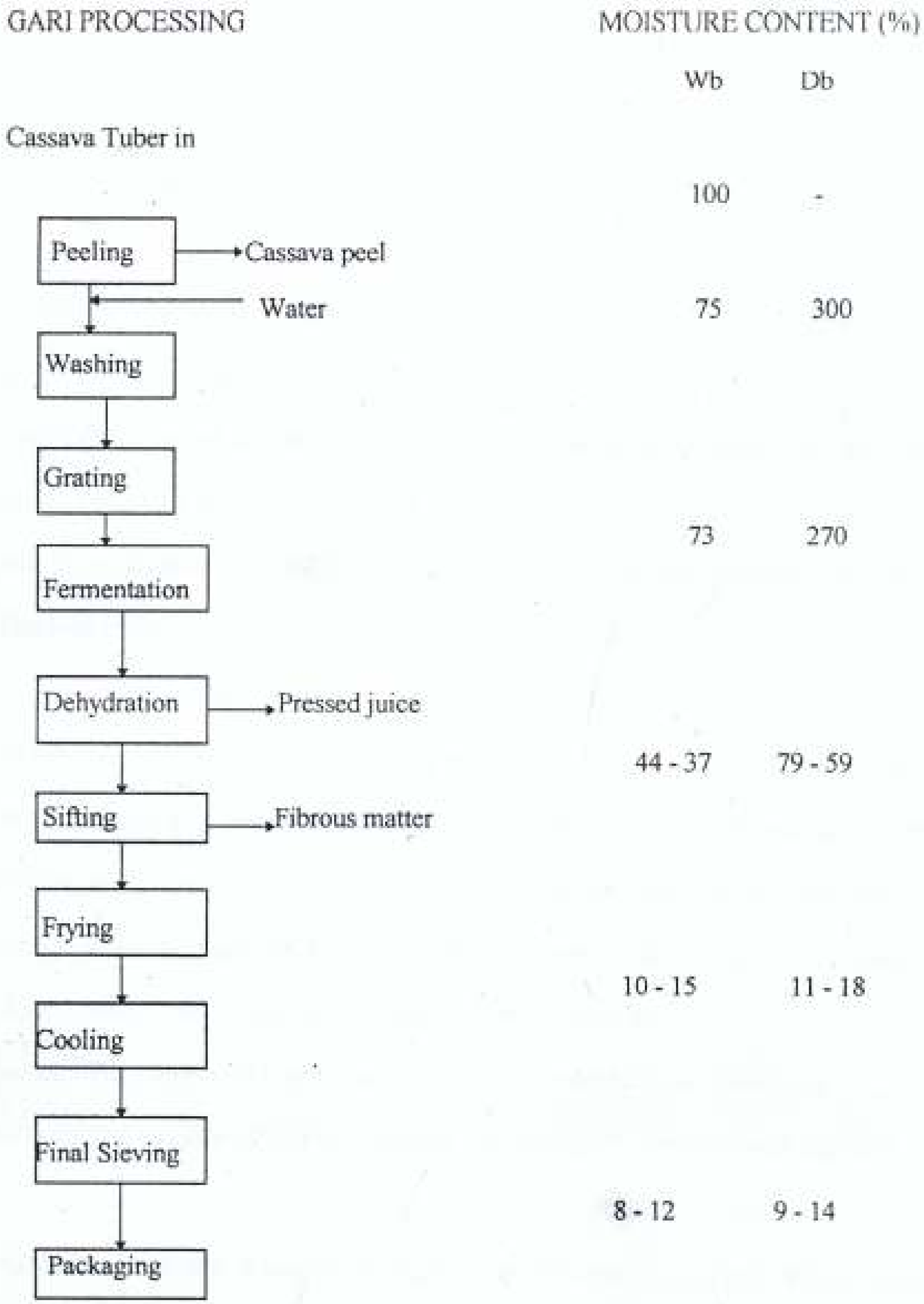


Figure 1: Flowchart for gari processing

Source: Odigbo and Ahmed, (1982)

gari, this is because heat breaks the cyanogenic compound and makes it less poisonous (Almazan, 1986).

During drying, there is a combination of capillary flow of water and diffusion of vapour which controlled the internal moisture transfer, water is squeezed out of the solid and the solid begins to shrink. At a certain critical moisture content (cmc) 30%wb, dry patches begin to exist on the surface while drying progresses (Bennet and Myers, 1983). Several methods exists in the practice of gari frying which ranges from the local method to medium scale and large scale mechanized method as described by Kwatia (1986). Also, various frying machines have been developed. These include the local fryers (the Raids gari fryer) and the more complex FIIRO - Newel Dunford complete gari processing plant (Kwatia 1986).

1.4 Heat and Mass Transfer

Many industrial operations involve the transfer of heat and mass from one phase to the other. Heat is a form of energy transmitted from one medium to another by means of a difference in their temperature. Heat transfer as carried out industrially involves the contacting of a hot phase and a cold phase, separated by a well defined boundary. Three major mechanisms of heat transfer have already been established (Cornwell, 1981). These are.

i. Molecular: The transfer of heat by molecular action referred to as conduction.

ii. Turbulent: The transfer of heat by a mixing process usually referred to as convection.

iii. Emission: This is the transfer of heat energy or its absorption without physical contact (radiation). These mechanisms can occur singly or simultaneously. The rate of heat transfer q is obtained from the following relationship:

$$q = hAdT \qquad (1)$$

where

q = rate of heat transfer,J/s

h = heat transfer coefficient,Wm^2/K

A = Area of heat transfer,m

dT = Change in temperature,K

When faced with the problem of separating components out of a homogeneous mixture, the diffusion properties of the constituents of the mixture is used to effect the separation. As wet cassava mash is heated in the fryer, the mash absorbs heat energy, get hot and gives off water vapour. Drying separates a liquid from a solid by vapourizing the liquid resulting from heat and mass transfer processes (Foust et al., 1980). Latent heat of vapourization of the liquid (water) must be supplied before evaporation occurs. In every case involving mass transfer, heat must also be transferred (Foust et al., 1980) and diffusion occurs in at least one phase and often in both. Analogous to heat transfer, mass transfer rate is obtained from

$$N = -K_m A\,(\rho_{bf} - \rho_f) \qquad (2)$$

where

N = rate of mass transfer,kg/s

K_m = coefficient of mass transfer,kg/m^{2}s

A = Area of mass transfer,m^2

ρ_{bf} = Density of the moist mash,kg/m^3

ρ_f = Density of the dried mash,kg/m^3

When a solid dries, two fundamental simultaneous processes occur as follows:

i Heat is transferred to evaporate the liquid and,

ii Mass is transferred as a liquid or vapour within the solid and as vapour from the surface.

The factors governing these processes determine the drying rate of solid as liquid water diffuses through the solid toward the surface, vapourizes and diffuses as vapour into the air. The heat required for evaporation must be supplied to the material to effect simultaneous heat and mass transfer processes (Berger and Pei, 1973).

1.5 Statement of the Problem

Several factors affect the performance of gari frying machine, these include:

i. The material of the frying trough

ii. Area and length of the trough

iii. Quantity of mash in the drying chamber

iv. Rate of heat supply

v. Heat capacity of the mash

vi. Time of frying, and

vii. Amount of moisture in the mash.

These facts constitute areas of study for effective design of gari fryer. This study is aimed at investigating these factors experimentally with a view to developing a model that will characterize the heat and mass transfer processes during gari frying operations.

1.6 Research Objective

The objectives of this work are:

1. To modify and evaluate the perfomance of an existing cassava mash dryer.
2. To establish the drying mechanisms of the cassava mash in the dryer.
3. To formulate a mathematical model characterizing heat and mass transfer process of drying cassava mash.

CHAPTER TWO

2.0 LITERATURE REVIEW

Preservation of food products using different local methods have been an age long phenomena. For instance, in the early times, grains were spread out in the sun after harvesting to reduce moisture. As a result of quick deterioration of cassava tubers, several equipment are in existence for cassava processing and drying. Cassava tubers are extremely perishable such that once they have been harvested, they start to deteriorate within two to three days (Hahn, 1995). The deterioration is caused by physiological changes and subsequently they rot and decay (IITA, 1990, Nweke, 1996). The rapid deterioration of the tuber has been a major problem for production, marketing, utilization and industrialization of cassava, thus several processes are identified to convert cassava into a form that can keep for a longer period. Such processes include drying, cooking, parboiling, cutting into chips and soaking (Kwatia, 1986)

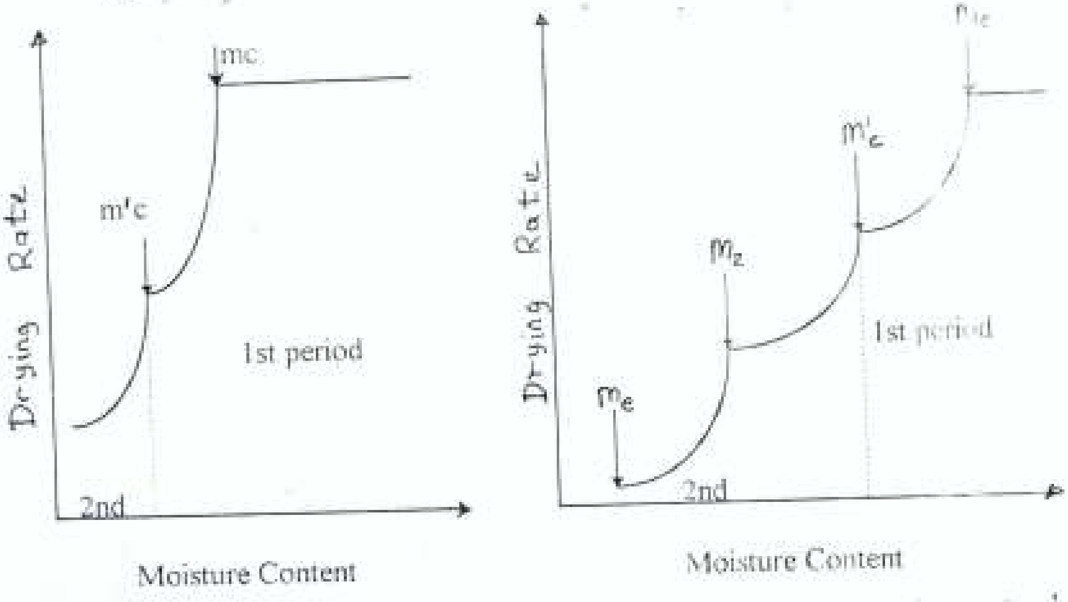
2.1 Drying

Drying a solid means the removal of some amounts of water or other liquid from the solid material to reduce the content or residual liquid to an acceptable low value. It is usually the final step in a series of processing and handling operations and the product from a dryer is often ready for final packaging. There are three major industrial methods of removing moisture from solid materials as reported by Jackson & Lamb, (1981).These are by subjecting it to a high velocity stream of heated, low humidity air (air drying), or by placing it on a heated surface and allowing evaporation of moisture into the surrounding atmosphere (contact drying), or by subjecting it to a low pressure and a heating source (vacuum drying or freeze drying), solar drying also occur here.

Generally in solid drying, there exists two major periods called the first period and the second period of drying (McCabe et al., 1986). The first period is characterized by the relative ease of moisture removal while in the second period moisture is bound, or held within the solid matrix. The moisture content at which the change from the first to second period occur is know as the critical moisture content (cmc). Two drying rates also exists during drying, the constant rate and the falling rate. Constant drying rate is a situation when moisture removal is constant, at a certain moisture content called critical moisture content, the rate of moisture removal begin to reduce , this is called falling rate drying. According to Jackson and Lamb (1981), solids are classified into three categories with their forms of drying. Non-Porous hygroscopic solids such as leather and wood, have two drying periods, (first and second). The first period exhibits a constant rate of drying, while the second period exhibits a falling rate of drying. A porous, non hygrosocpic solid such as pellets, exhibit a constant rate of drying and first falling rate of drying during the first period, while the second period features the second falling rate. A porous and hygroscopic solid which characterises most of the agricultural products exhibits the constant rate and falling rate during the first period, while in the second period, the falling rate period is attained while the solid reaches the equilibrium moisture content (emc). These are as shown in Figure 2.

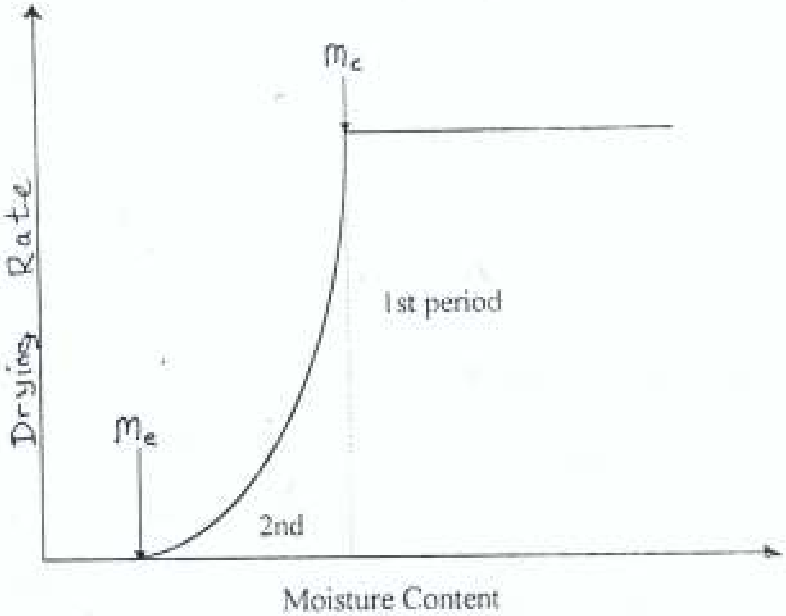
During drying of grains for example, the heated air conveys heat to the grains and takes moisture away from it. This is necessary to maintain quality, mininize losses and prepare the grains for storage and further processing. Drying could also inhibit biological deterioration, prevent mould growth, sprouting and grain discoloration (Pillaiyar, 1988). A controlled drying will also maintain better milling quality. During roasting of the cassava mash, moisture is removed and this gives a dry, free flowing granular product called gari. Heat treatment breaks down residual unreacted cyanide and drives off lingering hydrogen which gradually reduces the total amount of cyanide in cassava roots thus making consumption of gari safe (Williams, 1979).

Thin layer drying process refers to the drying process in which all grains are fully exposed to the drying air under constant drying parameters that is, at constant air temperature and humidity. Generally, up to 20 cm thickness of grain bed is taken as thin layer. All commercial



Porous Non-hygroscopic material

Porous Hygroscopic material



Non-porous Hygroscopic material

Figure 2. Drying Characteristics of Wet Solids

Source: Jackson and Lamb,(1981)

flow dryers are designed on thin layer drying principles (Hall, 1980).

Deep layer drying refers to any drying process done when the grain thickness is greater than 20 cm. A deep bed of grain could be divided into a finite number of thin layers to make calculation easier, it has been shown that small grains exposed in thin layers one kernel deep dry according to the following equation as proposed by Lewis, (1921).

$$\frac{dm}{dt} = -k(M - M_e) \qquad (3)$$

which simplified to

$$\frac{M - M_e}{M_o - M_e} = \exp(-kt) \qquad (4)$$

where

M_o = Initial moisture content, %

M_e = Equilibrium moisture content %

M = Moisture content after a time t %

k = Drying constant (Min^{-1})

t = Drying time (Min).

Lewis, 1921; Chhinnan (1980a, 1980b) have used this equation to describe drying of porous materials other than cereals as reported by Jayas and Sokhansanj (1989), Chhinna (1984) used it for pecan drying. This equation has been modified in several forms and used by many researchers in grain drying, Noomherm and Verma (1986) used the form:

$$MR = A\exp(-kt) \qquad (5)$$

where

A = constant which depends on the crop for single layer drying.

For shelled maize drying, Page (1949) used the equation

$$MR = \exp(-kt^n) \qquad (6)$$

and the constants k and n for gari were found to be 0.0567 and 1.4286 respectively where

MR = moisture ratio = $(M - M_e) / (M_o - M_e)$

n = constant which depend on the grain..

2.2. Mechanisms of Drying

If the initial moisture content of the solid is below the critical point, the constant rate period does not occur (Jackson & Lamb, 1981). McCabe et al.(1986) categorised solids into three forms: Crystalline, Porous and Non-porous. Crystalline particles contain liquid in their interior and drying occurs only at the surface of the solids, so that a bed of such particles can be considered a highly porous solid. Truly porous solids, such as catalyst and pellets contain liquid in interior channels while Non-porous solids include colloidal gels such as soap, glue, plastic clay, leather, wood and other polymetric materials. Gari can be considered as a hygroscopic and porous solid from the above consideration. The use of high temperature may reduce quality of grain for processing because stress cracks may develop in the kernels and in subsequent handling of the grain, there may be excessive breakage. During drying, evaporation takes place only from the grain surface, the internal moisture can evaporate only after it has diffused to the surface, therefore as diffusion is a slower process, a mixture gradient gradually develops in the kernel during rapid drying with the center being more wet and the surface more dry. This leads to stress which the grain can only release through crack propagation when a certain level of stress is reached (Wasserman et al., 1969).

Water or other liquids may be removed from solids mechanically by presses or centrifuges or thermally by vaporization. It is generally cheaper to remove water mechanically than thermally and thus it is advisable to reduce the moisture content as much as practicable before feeding the material to a heated dryer. The moisture content of a dried substance varies from product to product. Occasionally, the product contains no water, and is called bone dry, more commonly, the product does contain some water, dried table salt for example contains about 0.5% water, dried coal about 4% and dried casein about 8% (McCabe and Smith, 1976). Drying is then a relative term and means a reduction in moisture content from an initial value to some acceptable final value. Cassava has about 60% water content while final gari is between 10 - 15% (Odigboh and Ahmed, 1982).

2.3 Theory of Drying

The basic principle of frying gari is that of moisture removal from the fresh mash, repetitive pressing, scrapping and stirring over a hot surface until the moisture reaches an acceptable level when the gari could be stored. Heat is applied via the trough to the mash for the evaporation of its moisture this is accompanied by the gelatinization of the starch granules, toasting and eventually drying of the mash. Effectiveness of these processes depends on the mash initial moisture content, time, and drying temperature as well as the quantity of mash introduced into the fryer.

Gari frying = f (Mc, time, Temperature, mass)

Two major drying rates could be said to be responsible for the process of gari frying, these are the constant and the falling drying rates. The curves of drying rate with moisture content and time of drying were shown in figure 3.

2.4 Constant Rate Drying Period (CRP)

The constant drying rate occur at the beginning of the drying process, it is common with products that are very wet, moisture removal is at a constant rate, the free surface water and the water of saturation are removed at constant rate and this applies to gari drying (Kreith and Bohn, 1980).The evaporation rate at the water surface is expressed as

$$\frac{dm}{dt} = K_m A_m (H_m - H_a) \qquad \text{(McCabe and Smith, 1976)} \qquad (7)$$

Where

$\frac{dm}{dt}$ = drying rate, kg/min

k_m = mass transfer coefficient, kg/m^2 s

A_m = Drying surface area, m^2

H_a = absolute humidity of air,kg/kg

H_w = absolute humidity of water,kg/kg

Drying rate at constant period (R_c) is described as :

$$R_c = \frac{h}{s}(H_s - H_a) \tag{8}$$

$$= \frac{h}{\lambda}(T_a - T_s) \tag{9}$$

(Jackson and Lamb, 1981)

Where

h = Coefficient of heat transfer,W/m^{2}K

s = Humid heat,kJ/kgK

T_s = Surface temperature of the mash at equilibrium,(°C)

T_a = Air temperature at drying condition, (°C)

λ = latent heat of evaporation of water, kJ/kgK

H_s = Humidity at surface temperature, kg/kg

H_a = Humidity at air temperature, kg/kg

As the moisture content decreases, the constant - rate period ends at a definite moisture content, and during further drying the rate decreases, the point terminating the constant rate period is called critical point. This point marks the instance when the liquid water on the surface is insufficient to maintain a continuous film covering the entire drying area. In porous solids, the critical point is reached when the rate of moisture flow to the surface no longer equals the rate of evaporation called for by the wet bulb evaporative process. If the moisture content of the solid is below the critical point the constant rate period does not occur (McCabe et al., 1986).

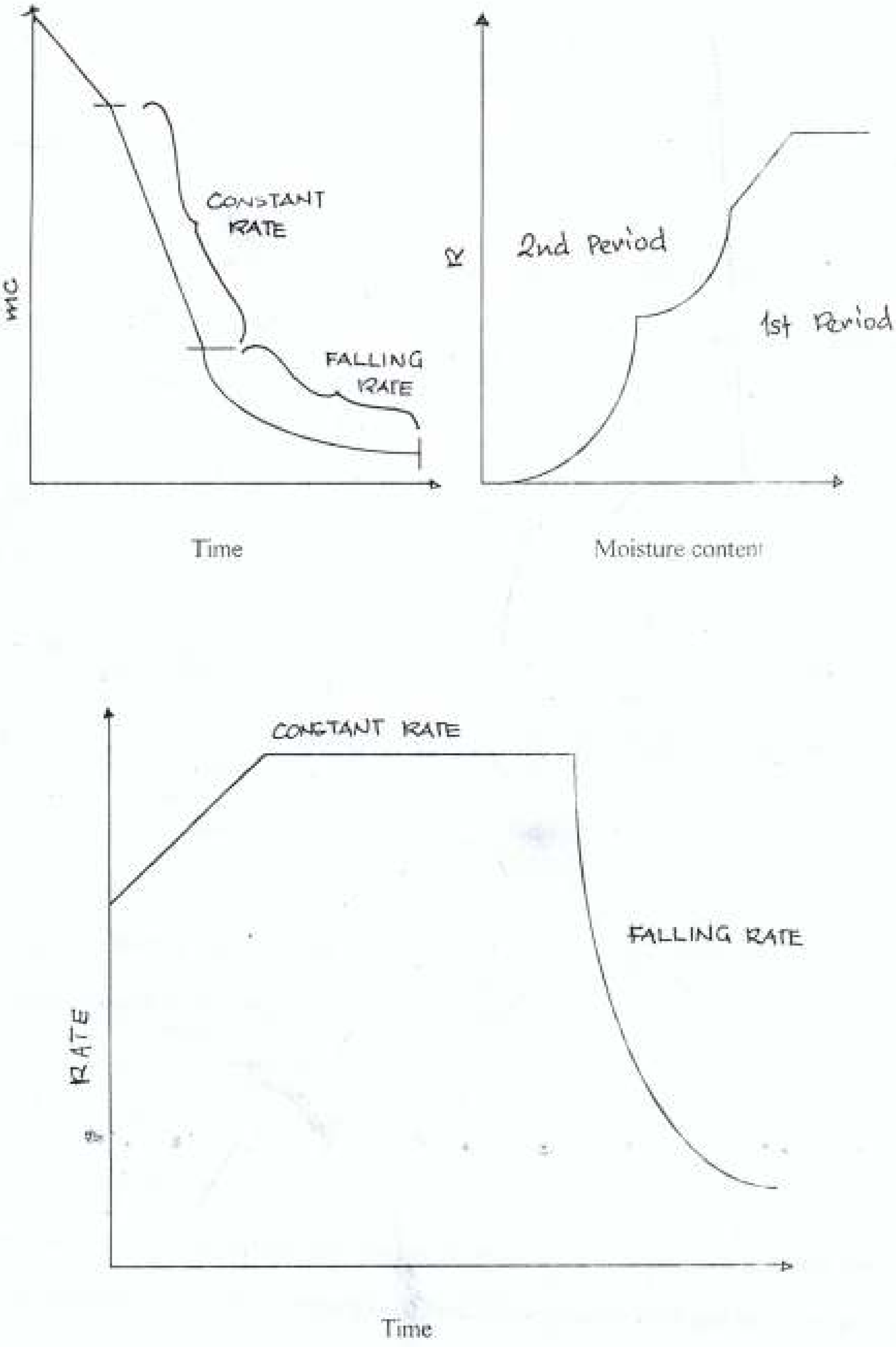


Figure 3 Drying Rate curves with Moisture Content and Time

Occasionally, there may be a second critical point and finally the solid dries to the equilibrium moisture content at a falling rate that is determined by diffusion or evaporation processes depending on the type of material being dried.

2.5 Falling Rate Period (FRP)

The FRP is the period when water in the pores of granulous materials is being dried up as described by Keey (1972), this immediately follows the constant period which can also be computed using the equation below:

$$F_2 = \frac{M_{ev}}{At} \qquad (10)$$

Considering the initial moisture content,

$$Mokg = Mo \left[\frac{Wo}{(Mo + 100)}\right] \qquad (11)$$

$$Mckg = (W_o - Mokg)\,\frac{M_c}{100} \qquad (12)$$

where,

Mokg = initial moisture content in kg

W_o = initial weight of the mash, kg

M_o = initial moisture content % db

Mckg = critical moisture content in kg

M_c = critical moisture content in % db.

These two periods (constant and falling rate drying periods) help in data generation for the calculation of the total drying time of gari frying both in the experimental work and the computer simulation as shown in table 5. For moisture evaporated (M_{ev}) during frying,

$$M_{ev} = Mokg - Mckg \qquad (13)$$

$$Vol = (Wo - Mokg)/\rho \qquad (14)$$

$$\text{Area} = \text{Vol}/L \qquad (15)$$

where,

Mev = moisture evaporated, kg

Vol = volume of the mash, m^3

ρ = density of the mash, kg/m^3

L = mash thickness, mm.

2.6 Drying Time

In the design of dryers, an important quantity is the time required for drying of the material under the conditions existing in the dryer. Time of frying designated t can be calculated for the first period of drying as:

$$t_{10} = \frac{M_{ev}}{F_1 A} \qquad (16)$$

$$t_{11} = \frac{(Mokg - M'_c)}{F_c . A} \qquad (17)$$

and for the second period as:

$$t_{21} = L\rho M_c' \left[(F_c - F_e)^{*} - F_c . M_c' A \right] \quad Ln \frac{[(F_c - F_e) m_2]}{[\ F_e m_2\ ]} \qquad (18)$$

and

$$t_{22} = \frac{[L\rho (M_2 - M_e)]}{[\ F_3 . A\ ]} - Ln \frac{[M_2 - M_3]}{[M_3 - M_e]} \qquad (19)$$

where,

t_{10} = time at first period, first stage, min

t_{11} = time at first period, second stage, min

A = drying area, m^2

F_1 = drying rate, kg/s

M_c^1 = critical moisture content %

t_{21} = time of second period, first stage, min

t_{22} = time of second period, second state, min

L = mash thickness, mm

ρ = mash density, kg/m³

F_c = drying rate at critical period, kg/s

F_e = drying rate at equilibrium, kg/s

M_2 = Moisture content at stage two, %

F_3 = drying rate at final moisture content, kg/s

M_3 = Final moisture content, %

Alternatively, the time of drying can also be obtained from the drying rate curve and can be expressed as shown below:

$$F = \frac{M_{ev}}{At} = \frac{M_s}{A}\frac{dm}{dt} \qquad (20)$$

where,

M_{ev} = moisture evaporated, kg

t = time of drying, min

dm/dt = rate of moisture removal, kg/s

Integrating between M_o and M_f (the initial moisture and final moisture contents) the total drying time will then be

$$(21) \qquad t_T = \frac{M_s}{A}\int_{m_f}^{m_o}\frac{(dm)}{F}$$

where,

t_T = total time of frying, min

M_s = mass of solid, kg

m_o = initial moisture content, %

m_f = final moisture content, %

For constant rate, time of frying t_c is computed as:

$$t_c = \frac{M_s}{A.F_c} (M_o - M_c) \qquad (22)$$

where,

t_c = time for constant rate period, min

m_c = moisture content at the end of crp, %

while the falling rate period occur during the time interval given as:

$$t_f = \frac{M_s}{A} \left(\frac{M_c - m_c^1}{F_c - F_c^1} \right) \text{Ln} \frac{F}{F_f} \qquad (23)$$

or

$$t_f = \frac{M_s}{A} \frac{m_c}{F_c} \text{Ln} \frac{m_f}{m_c} \qquad (24)$$

where

m_c^1 = moisture content at second critical period, %

F_c = drying rate at critical moisture content, kg/s

F_c^1 = drying rate at second critical moisture content, kg/s

F = drying rate, kg/s

F_f = drying rate at falling period, kg/s

m_f = Moisture content at falling rate period, %

If we have a constant initial moisture content (m_o), and a fixed final moisture content (m_c), we can assume a single straight line passing through the origin for the FRP, at the end of the process, thus, frying time will be the total sum of time used for the constant and the falling rate drying and will be expressed as:

$$t_T = t_c + t_f \qquad (25)$$

and using equations 22 and 24, the total time for drying a given quantity of cassava mash is:

$$t_T = \frac{m_s}{AF_c}\left[(M_o - M_c) + M_c \; Ln \; \frac{m_c}{m_f}\right] \qquad (26)$$

Drying rate at falling period is described by the expression below:

$$R_f = (R_c - R_e)\,\frac{(M'_c)^n}{(M_c)^n} + R_e \qquad (27)$$

(McCabe and Smith, 1976)

Where n = 0.5 for fibrous materials (Jackson & Lamb, 1981).

2.7 Classification of Dryers

Dryers in which the solid is directly exposed to a hot air are called "adiabatic dryers" while those dryers in which heat is transferred to the solid from an external medium such as a metal surface are called "non-adiabatic dryers" (McCabe et al., 1986). Some dryers are continuous and some operate batchwise, some agitate the solids while some are unagitated. Some of the dryers available are as discussed below:

Air dryers use hot air to evaporate moisture from the drying product. This air is supplied externally and heated at a low relative humidity, fan or blower blows the hot air over the wet (moist) solid and take moisture along with it as it moves along the lenght of the dryer. As the time elapses the moisture content reduces (Hall,1980). Adiabatic dryers are examples of this type. Contact drying occurs when a moist material is placed on a heated surface and heat flows by conduction to the free surface of the material. Some of this heat causes evaporation of water to occur and causes a rise in temperature of the material and some are lost by convection from the surface (Jackson & Lamb, 1981). If the contact medium is so hot and the mash is very wet, there will be outward movemenet of moisture to keep the surface moist, till an equilibrium will be achieved.

Solar drying which is one of the means of drying directly with the heat of the sun has not proved satisfactory for gari drying. This is because the harvested heat is too low, usually at a temperature below the boiling point of water. With solar drying , the product will be dried but it will not form good quality gari. Clark and Haridas (1982) once reported a collection of solar heated air at 56 - 58°C for paddy rice drying in India, but noted that this temperature is low for gari drying.

2.8 Gari Fryers

Historically, frying of gari starts from a shallow earthenware, aluminium or cast iron simple frying containers set on tripod stones and fuelled by burning firewood. Other forms of dryers consist of clayed water pot which are cut into two-halves and used as a fryer. An improvement on the local fryer is to cut an oil drum into two-halves longitudinally and set into a specially prepared fire place that is meant for the purpose. The burning firewood also supplies the heat required for the frying. Stirring is done with carved wood or calabash or broom (IITA, 1990). Several versions of small and medium scale fryers are in existence. The Rural Agro-Industrial Development scheme (RAIDS) Ibadan, Nigeria developed a fryer suitable for a small scale production of gari. This consists of a rectangular metal tray measuring 1.2 by 2.4m and 3mm thick to fry gari, with a side gate for discharging the fried gari. The gari is fried in batches and manual stirring is employed and the machine operates on a contact drying process as described by (IITA, 1990).

The Project Development Agency (PRODA), Enugu, Nigeria developed a commercial gari fryer which can be used by four to six women simultaneously. The fryer possesses a high thermal efficiency and comfort characteristics for its users.

The system consists of a frying part of large projected area (2.75 m^2) that forms the top part of a rectangular cabinet - like structure and four fire-place chambers lie immediately below the frying pan, each separated from its neighbour by baffles which deflect the hot gases to the bottom of the pan as reported by Kwatia (1986). The Brazillian type of gari fryer is a simple machine that consists of a semi-circular stainless steel plate. A specified amount of mash is metered into the circular plate and the eccentric paddles shift the mash circularly to dry the product with a side gate that ejects the fried gari. Odigboh and Ahmed,(1982) developed an equipment that can fry gari. This machine consists of spring loaded paddles that are carried on a long shaft which is mounted axially in such a way that the spatular-like paddle overlap. The trough is semi-circular in nature and the mash is metered through the hopper and stirred by the paddles along the length of the fryer. The fuel used is cooking gas. Large scale and mechanised gari fryers were developed and are in use, such include the one developed by the Fabrication Engineering company (FABRICO) Edo State, Nigeria. This machine fries gari on a continuous process, the trough is a semi-circular steel plate with rotating paddles which rotate and the mash is stirred and moved from one end of the plate to the other, this was reported by Kwatia, (1986). FIIRO And Newel Dunford Company developed a very complex gari processing machine jointly financed by the Nigerian Government through the Federal Institute for Industrial Research Oshodi, Lagos (FIIRO), and a British firm (Newel Dunford's Company). The unit is a complete process line which has about 83 workers at the plant. It is a modern and totally mechanised technology, with a bigger and effective dryer and also operates on a large scale basis. (FIIRO and NEWEL DUNFORD, 1974).

Gari is a staple food in Nigeria, and to satisfy the need of the people of Ondo state. The Agric Engineering Department Federal University of Technology, Akure took the challenge and produced the first version of its frying machine. In his work, Ohanwe, (1988) came out with the concept of a frying machine, Oshogbon (1989) further developed the work and tested the machine, Omolakin (1994) modified and tested the machine again while heat and mass balance tests are being carried out presently on the fryer in order to provide necessary informaton to produce an effcient gari fryer. Considering the above gari frying machines, three points are noted;

There is a container or trough for frying, there is a source of heat either, firewood, gas, hot air or electricity,and there is also a means of stirring (paddles) or slabs which could be of different material and shapes.

2.9 Mode of Heat Transfer

There are three major ways of heat transfer: conduction, convention and radiation (Nelkon and Parker, 1984). Conduction is the transfer of heat from a region of higher temperature to a region of lower temperature within a medium (Solid, liquid [illegible] gas), or between different material in physical contact, without appreciable movement of the molecules of the material (Jackson and Lamb, 1981). Convection occurs when there is a temperature difference between a fluid and a solid boundary that causes molecular motion and energy transfer during the fluid movement. Naturally, the molecular movement is due to density differences generated by temperature gradients. (Welty et al, 1976). Radiation is the heat energy that passes through a vacuum which does not need the existence of an intervening medium. The basic relationship for conduction heat transfer using Fourier equation is

$$Q = \frac{kA\Delta T}{L} \qquad (28)$$

once the steady state has been reached, the rate of heat flow can be represented as:

$$q = hA\Delta T \qquad (29)$$

where

Q = quantity of heat that flows, J

q = rate of heat flow, J/s

A = Area of heat flow, m^2

ΔT = Temperature gradient, K

L = Thickness of the material, mm

h = Heat transfer coefficient, W/m^2K

2.10 Heat, Mass and Moisture Transfer Processes

Heat is generally transferred when there is temperature gradient in an object. Drying of wet solid is a thermal process, thus making it possible to dry many materials by merely heating them above the boiling point of the liquid. Heat is applied to a dryer to accomplish the following:

1. To heat the feed (solid and liquid) to the vapourization temperature.
2. To vapourize the liquid.
3. To heat the solid to its final temperature.
4. To heat the vapour to its final temperature.

Mass transfer is found almost everywhere in nature, it refers to the motion of molecules or fluid elements caused by some term of potential or driving force which includes not only molecular diffusion, but also transport by convection and sometimes simple mixing (Kreith and Bohn, 1986). The drying of hygroscopic capillary porous solid removes liquid from the moist material by evaporation (Berger and Pei, 1973). Early studies on heat and mass transfer have been reported by Sherwood, (1931) and Newmann (1931) that moisture is transferred by diffusion, while Haines (1927) says its by capillary action. The second series was based on the assumption that during drying, some combination of capillary flow of liquid and diffusion of vapour controlled the internal moisture transfer (Krischer, 1942). Another approach is an attempt to establish a theoretical model by applying the methods of the thermodynamics of irreversible processes to the transport phenomena during the drying process (Luikov, 1966, Berger and Pei, 1973). Evidently, the presence of mass transfer raises or lowers the rate of heat conduction depending on the direction of mass transfer. Mass transfer of water occurs within the kernel as the water vapour escapes into the surrounding air

The initial moisture content of the mash is reduced by dewatering, the subsequent removal of moisture to the storage level is by thermal application. There are three types of water that exist in a bio-mass material according to Igbeka (1980). These are: Unbounded free water in interstitial pores, that is surface water, water molecules bounded by hydroxyl groups (OH-) and water molecules bounded by ionic groups. Meaning that whenever any material is being dried, these forms of waters are encountered and must be dried. The degree of difficulty involved in removal of water during dehydration of a product depend on the classification within which the water falls, it is easier to evaporate surface water than ionically bounded water from a material. Faborode et al. (1992) established that in gari frying, the unbounded free water are first removed during the first few minutes at the constant rate period. Moisture transfer in agricultural materials occurs in the following ways according to McCabe et al,(1986):

(a) Water vapour diffusion or evaporation,

(b) Flow due to shrinkage and pressure gradients,

(c) Diffusion of liquids,

(d) Liquid movement by capillary forces (capillary flow).

During grain drying, Chau et al, (1982) discovered that Fillet and Roe dries during the first several minutes at a faster rate followed by a falling rate period when the drying rate was governed by the rate of moisture migration within the product.

CHAPTER THREE

3.0 MATERIAL AND METHODS

This chapter describe the types of material used in the work and the methods of the experiments performed.

3.1 Material

The main material used in the execution of the project is the fermented sieved cassava mash which was obtained after a series of operation on the cassava root. This operations include peeling of the tubers, grating, dewatering, fermentation and sifting. The product (fermented sieved cassava mash) was now fried using the experimental gari fryer. The cassava mash was obtained from a local frying center in Akure LGA of Ondo State, Nigeria.

3.1.1. Equipment

The shematic diagram of FUTAAGE gari frying machine shown in Figure 4 consists of a 60 cm diameter, 120 cm long frying trough of 2 mm galvanized steel sheet which carries 16 paddles arranged in two sets on a 132 cm long shaft. The trough is folded into a semi-circle and mounted at an axial inclination that may be adjusted between 0° and 10° to the horizontal using two telescopic front legs. The conical hopper with a capacity of 6.75 kg (0.135 m^3) of wet cassava mash is located over the frying trough. A small metering device is located at the center of the hopper couple to a shaft through a 5 cm pulley to meter the mash into the trough. The drive mechanism of the machine consists of an 0.75 kW(1hp) single phase electric motor with 1420 rpm, transmitting power to a 43cm pulley through a V-belt.

A pulley, 8.5 cm diameter transmit the power to another 43 cm pulley, these two pulleys of diameter 43 cm act as speed reducer. Through a crank arrangement and a rack and pinion gear system, the power is transmistted to the shaft that carried the paddles. The frame support is made of 35 x 35 x 35 mm and 25 x 25 x 25 mm angle iron, 5cm diameter steel pipe were used

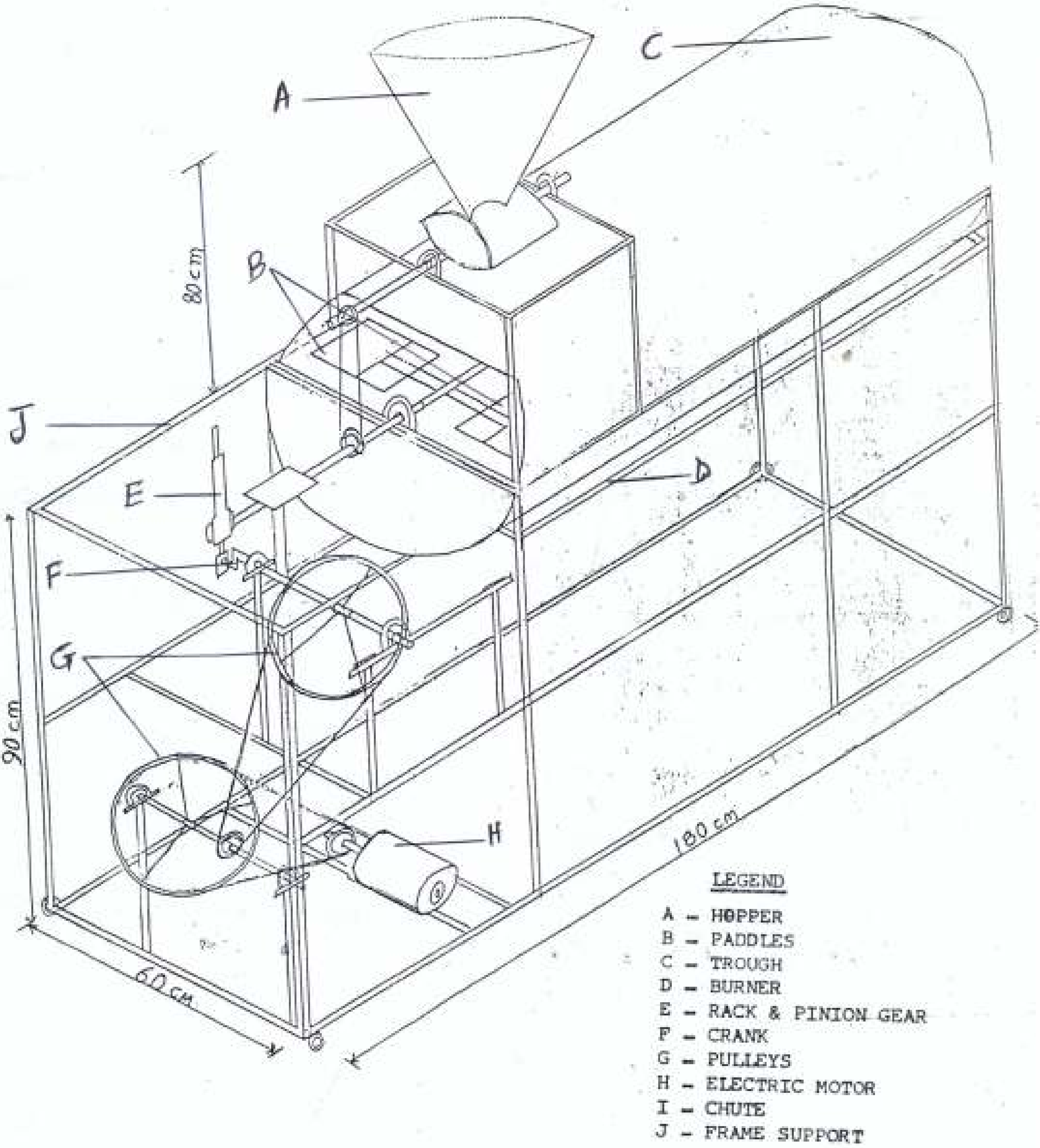


Figure 4: Schematic diagram of FUTAAGE Gari Fryer

for the front telescopic legs. The overall dimension of the dryer is 180 cm in length, 60 cm in breadth and 170 cm high. The burner is made with 12.5 mm internal diameter steel pipe which is 120 cm in length and 30 cm in breadth welded into a rectangular shape with 22 holes on each side. Compressed cooking gas was used for the fuel, while an 0.75 kW(1hp)single phase electric motor of 1420 rpm was used as the power source for the stirring device.

3.2. Experimental Procedure

Several of the properties of the gari mash that were measured are as described below:

3.2.1 Physical properties

The physical properties of the sieved cassava mash and the fried gari were considered and measured. The moisture content of the mash was determined by the method approved by the American society of Agricultural Engineers in ASAE standards (1989) whereby, a known mass of the mash is placed in an oven at 110 °C for 8 hours. The final weight was taken when the product has cooled down inside a desiccator, the moisture content was obtained in the dry and wet basis as:

$$Mc_{db} = \frac{\text{Weight of Water}}{\text{Weight of dry matter}} \times 100\% \qquad (30)$$

$$Mc_{wb} = \frac{\text{Weight of water}}{\text{Weight of wet mash.}} \times 100\% \qquad (31)$$

The conversion equations used for conversion of the moisture contents are:

$$\%\ Mc_{db} = \frac{(\%\ Mc_{wb})}{(100 - \%\ Mc_{wb})} \times 100 \qquad (32)$$

and

$$\%\ Mc_{wb} = \frac{(\%\ Mc_{db})}{(100 + \%\ Mc_{db})} \times 100 \qquad (33)$$

The bulk density of the wet mash and the fried gari was determined by filling a 50ml plastic container and its mass was determined as was proposed by Ukpabi and Ndimele, (1990).

$$\rho = m/v \qquad (34)$$

Where

ρ = the bulk density (kgm^{-3})

m = mass (kg)

v = volume (m^3)

This was done in triplicates and the average value was used.

An Endocott sieve shaker (Model EFL 2 mil)and a set of laboratory test sieves were used to determine the percentage aggregate sizes of the gari samples. The Finess Modulus(FM) equation (14) below was used for the particle size calculation.

$$Fm = d/\Sigma c = d/100\ \%$$

$$d_{av} = 0.002414\ (2.0)^{FM} \qquad (35)$$

Where

d = particle diameter, mm

c = total percentage of particles that pass through the sieve, %

d_{av} = average particle diameter, mm

Fm = Finess Modulus

The angle of repose of the product was determined using a circular platform (Fowler's method), a compass and a meter rule. The angle of natural slope of gari between the base and the slope of the cone formed on a free vertical fall of the gari sample to a horizontal plane was determined using equation (15) below and values of the angle of repose were as shown in table 3.

$$\theta = \tan^{-1}(y/x) \qquad (36)$$

where

θ = angle of repose(°)

y = height of the piled material(m)

x = half-length of the material base(m)

The tangent of an angle of internal friction at which the gari sample begin to roll (move) when tilted on a smooth surface this was also measured using three different surfaces (stainless steel, polished wood and plywood) with a compass. Equation (16) was used to calculate this and the values were shown in table 3.

$$\mu = \tan \theta \qquad (37)$$

Where

μ = Coefficient of friction

θ = angle of internal friction(°)

3.2.2 Thermal properties

Temperature variation along the length of the frying trough when the fryer was in operation was measured by Procter digital probe thermometer and steel thermometers. The Procter probe thermometer was used mainly to measure the temperature of the mash at specified spots(0, 30, 60 cm along the height of the fryer and 0, 60, and 120 cm mark along the lenght of the fryer). Figure 5 shows the diagram of the thermometer arrangement during the gari frying operation.

The heat capacity was determined by measuring the quantity of heat that was passed with the corresponding change in the temperature of the mash using equation (38) below.

$$c = \frac{Q}{\Delta T} \qquad (38)$$

Where

Q = Quantity of heat (J)

ΔT = Change in temperature (°C)

c = Heat capacity (J/K)

The specific heat capacity of the mash and the drying gari was determined by the calorimetry method. A known volume (mass) of the mash was heated at a specified temperature in an electric oven, after some time, it was taken out into a copper calorimeter that has been set up for the purpose. The content was poured into the calorimeter with water, it was covered and stirred until an equilibrium temperature was attained. Audu and Ikhu-Omoregbe, (1982) and Shukla et al. (1985) proposed an equation to calculated specific heat capacity as:

$$C_g = \frac{M_c C_c (T_t - T_c) - M_w C_w (T_t - T_w)}{M_g (T_g - T_t)} \qquad (39)$$

where

C_g = specific heat capacity of gari (mash) (J/kgK)

M_c = Mass of calorimeter (kg)

C_c = specific heat capacity of copper calorimeter (J/kgK)

T_t = Equilibrium temperature (°C)

T_t = Initial temperature of the calorimeter (°C)

M_w = Mass of water (kg)

C_w = Specific heat capacity of water (J/kgK)

T_w = Initial water temperature (°C)

M_g = Mass of the gari mash (kg)

T_g = Initial mash temperature (°C)

Typical values of specific heat capacity are as shown in table 4.

The thermal conductivity was determined for the gari mash using the flat plate method described in Carslaw and Jaeger, (1976). A cylindrical plate of known length and diameter was filled with gari sample. The length to diameter ratio of 2 was chosen (as in Carslaw and Jaeger, 1976). The cylinder was placed on a hot plate and the change in temperature with time was monitored. By using equation (40)

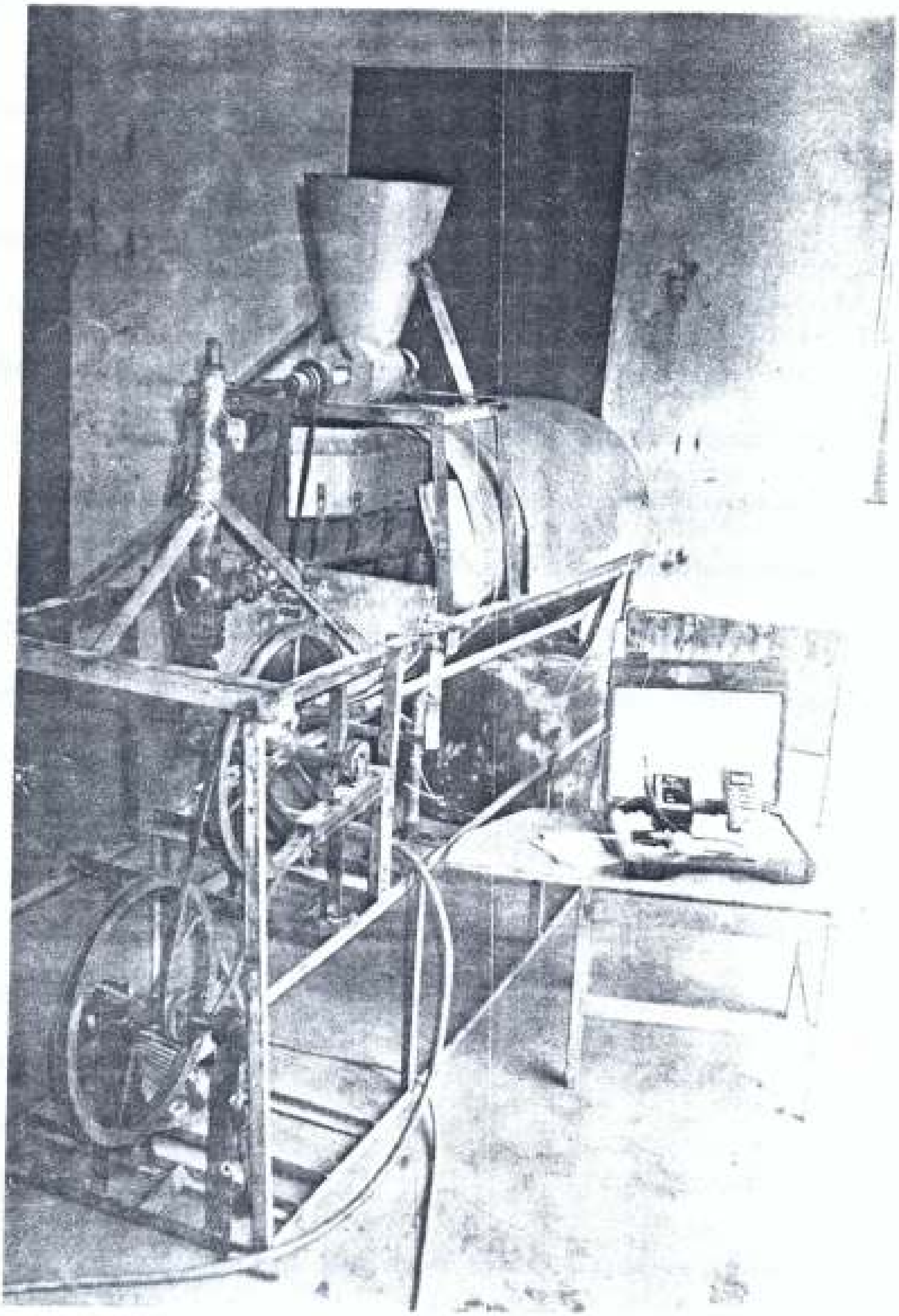


Figure 5: Arrangement of Thermocouples during the gari frying operation

$$T = \frac{Q}{4\pi k} \operatorname{Ln} t \qquad (40)$$

and plotting a graph of T against Ln t, the slope of the curve obtained was used to calculate k, and the values of these were shown in table 4.

Where

T = sample temperature, °C

Q = Quantity of heat, J

k = Thermal conductivity, W/mK

t = time, min

The molecular diffusivity of heat is a measure of the ratio of heat transmission and energy storage capacities (Kreith and Bohn, 1986). Thermal diffusivity is a quantity which measures the rate of temperature changes and indicate the speed at which temperature equilibrium will be reached, that is, how fast heat goes through a material. The thermal conductivity experiment was used for determining diffusivity since its a function of conductivity, specific heat capacity and bulk density of the material (Hall, 1980). These quantities are related by the expression:

$$\alpha = \frac{k}{\rho C} \qquad (41)$$

where

α = thermal diffusivity (m^2/s)

k = thermal conductivity (w/mK)

ρ = bulk density (kg/m^2)

C = Specific heat capacity kJ/kgK

Some values of thermal diffusivity of gari were shown in table 4. Other equipment used are stop watches, gas cylinder, weighing balance, electrical oven and petri dishes.

3.3 Performance Test

The machine was cleaned up, and the gas valve was turned on, the fire was lit and the trough was allowed to heat up for about 12 minutes until the temperature reached a constant state known as steady state. The wet mash of known moisture content was put into the hopper and the power was switched on, as soon as the power was on, the stop watch was also started. The paddles reciprocated at 50 reversals per minute while the mash was metered in and traverses the length of the trough. The rerciprocating motion of the paddle allows the simultaneous stirring, pressing and toasting of the mash while starch gelatinization occurs as it moves down towards the outlet. The frying was done at 5^0 machine angle of inclination and high rate of heat supply (high heat intensity). The high heat intensity was attained when the gas control valve was opened to the maximum at a flow rate of 83.3 g/min. The medium rate of heat supply (medium heat intensity) on the other hand is when the gas control valve is turned to the middle point and the flow rate is 73.3 g/min while low rate of heat intensity(low heat intensity) is when the value was turned to the minimum point and the gas flow rate is 60.2 g/min. These were callibrated and the marks were also put on the valve.

The first experiment performed was to determine the temperature of the dryer and the drying mash at intervals of 3 minutes up to the 21 minutes. The dryer was set up without the engine running and the gas value was turned on to warm up the trough. As soon as the steady state was reached, the engine was turned on and ground cassava mash was measured in. The temperature was monitored at 3 locations along the vertical axis and 3 along the horizontal axis. The mash inlet temperature T_{in} and outlet temperature T_{out} were also measured as the drying progressed.

The second set of experiment was conducted at the medium heat intensity. Each test was started from the steady state and the temperature variations were monitored at intervals during the frying process ,the gas flow rate was 73.3 g/min. The experiment was done in triplicates and the average values used.

The third set of experiment were conducted at a low heat intensity, after a long time the steady state temperature was reached and the frying started, the time of frying and the drying rates were measured.

The fourth set of experiments were done by varying the amount of mash introduced into the trough. The temperature distribution was observed and monitored as well as the time of frying required for the mash to reach the acceptable moisture content. These set of experiments were done in triplicates and the average values used.

The fifth series of experiments were done to monitor and measure the following parameters of the drying mash: The moisture content, the bulk density, specific heat capacity, drying rate and thermal conductivity, these were done in duplicates. From the above experiments, the efficiency of the machine was also determined to be 72.3%, using the formula below:

$$\text{Efficiency} = \frac{\text{Product output}}{\text{Material output}} \times 100\ \%$$

$$= \frac{\text{Mass of gari obtained}}{\text{Mass of mash introduced into the fryer}} \times 100\ \% \tag{42}$$

CHAPTER FOUR

4.0 MODELING AND TECHNICAL CONSIDERATIONS

A mathematical model to predict the mash temperature and time of frying based on the quantity of gas used for heating was developed for AFUTAGE gari fryer at high heat and inclination angle of 5^0. Basic equations were obtained from psychometric chart process by using the psychrometric curves assuming a standard atmospheric pressure of 1Bar as shown in Figure 6.

4.1 Theory of Psychrometric Equation

In many unit operations, drying involves dry air and water vapour, when a moist material is placed on a heated surface, heat flows by conduction to the free surface of the material. Some of this heat causes evaporation to occur, some is lost by convection from the surface and some causes the surface of the material to rise in temperature. While there is still sufficient moisture to keep the surface moist, an equilibrium temperature (T_s) will be achieved, the relationship of such expressed in a graphical term is termed psychrometric chart. For contact drying, assuming a negligible temperature gradient in the horizontal direction, the heat balance over the drier gave:

$$\frac{K_m}{L}(T_p - T_s) = h(T_s - T_a) + h(H_s - H_a)\frac{\lambda}{s} \qquad (43)$$

where,

K_m = thermal conductivity of moist mash, W/mK

L = thickness of the mash in the drier, mm

T_p = drier temperature (heated surface), K

T_s = Product surface temperature, K

h = heat transfer coefficient, W/m²K

T_a = Atmospheric temperature (dry bulb temperature), K

H_s = Absolute humidity of the surface at T_s, %

H_a = Absolute humidity of the air at T_a, %

λ = Latent heat of evaporation of water, kJ/kgK

s = Humid heat of air, kJ/kgK

$K_m(T_p - T_s)/L$ = Conduction term ≡ A (44)

$h(T_s - T_a)$ = Temperature term ≡ B (45)

$h(H_s - H_a)\ \lambda/s$ = Evaporation term ≡ C (46)

The initial drying rate (F_1) is **obtained** from the heat balance equation. Since H_s depend on T_s , the value of T_s has to be obtained by trial and error method from the relationship between the air temperature and pressure using the psychrometric chart whereby T_s is guessed. H_s and H_a are read off from the chart and the first calculation is done. Alternatively, the relationship of steam temperature and pressure from steam tables are used by relating the dryer temperature with partial pressure of water vapour in the air and the equation below is obtained:

$$P_w = 67.9499E\text{-}4 + 1.9532E\text{-}4T_p + 0.3383E\text{-}4\ T_p^2 - 2.9673E\text{-}7T_p^3 + 9.4457E\text{-}9T_p^4 \quad \text{....(47)}$$

and

$$H = \frac{18\ P_w}{29(P - P_w)} \qquad (48)$$

where,

T_P = temperature of the dryer, K

H = absolute humidity, %

P_w = partial pressure of water vapour in the air, Pa

P = total pressure (atmospheric), Pa

when P = 1 (for psychrometry), and when P_w is small, then from equation (48)

$$H = 18/29\ (P_w) \qquad (49)$$

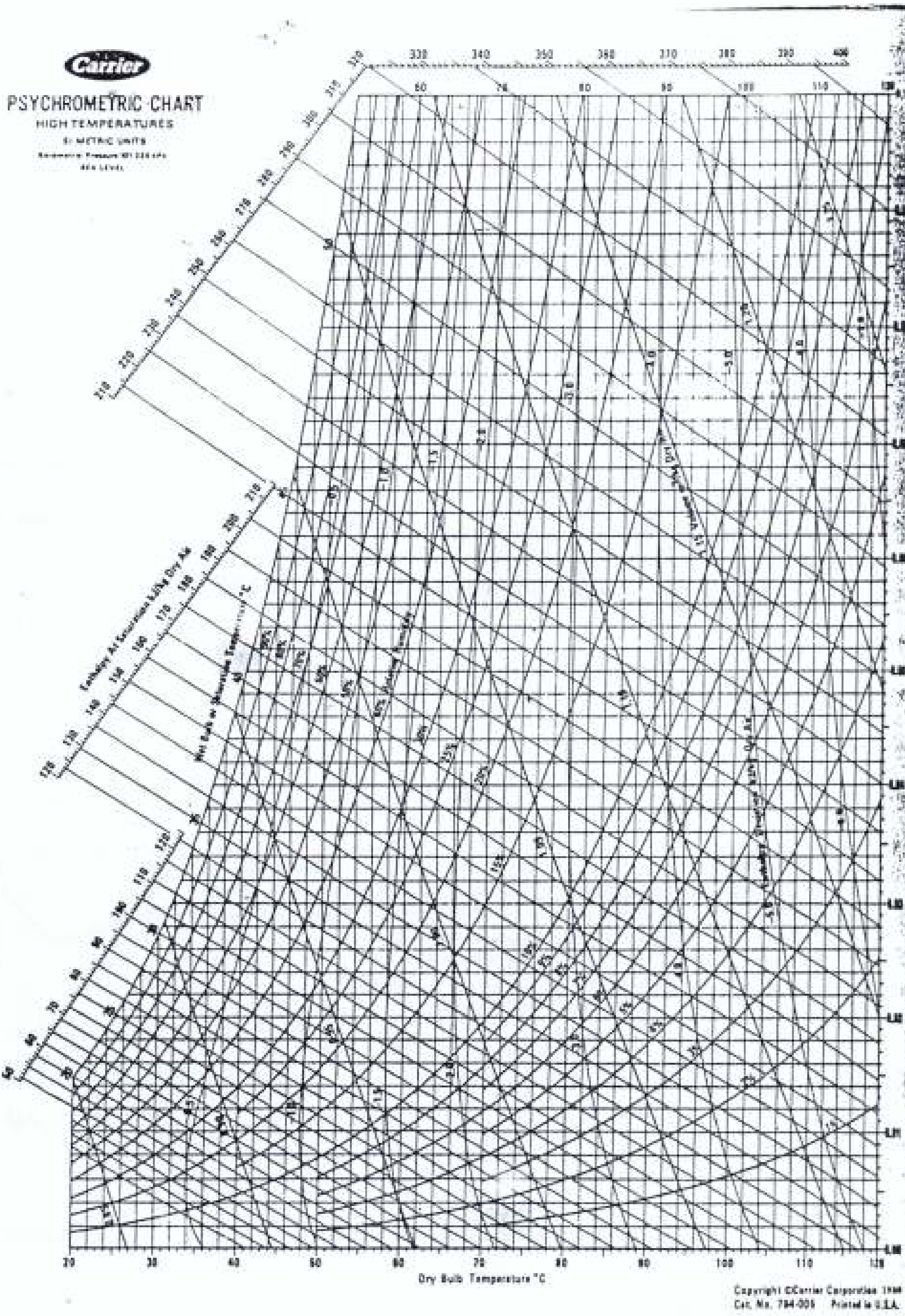


Fig. 6 PSYCHROMETRIC CHART FOR AIR AT 1 ATMOSPHERE
(source : McCabe and Smith , 1986)

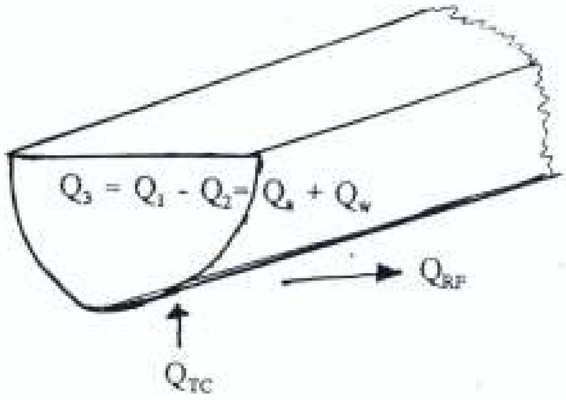
H_a is obtained from the chart while a first guess of T_s is made and terms A, B, and C, were calculated, the acceptable T_s is reached when this situation holds, that is, when

$$A = B+C. \tag{50}$$

(Jackson and Lamb,1981)

The model was built to do this iteration and pick the correct value of T_s. The process of drying using heated surface is dependent upon the loss of moisture from the granules by diffusion to produce the temperature difference necessary for the entry of heat energy into the grain from the surrounding air (Bennett and Myers, 1983). Drying of gari is therefore characterised by two drying periods, the constant rate and the falling rate periods. These periods assume some definite values which can be computed as drying progresses.

Since the temperature of the fryer (Tp) is fixed, the mash temperature and heat quantity can be evaluated as shown in the sketch of the fryer below, the values of which were obtained as shown in Appendix II.



The quantity of heat transferred to the fryer is:

$$Q_{TC} = KA\Delta T_p/L \tag{51}$$

While the heat retained by the fryer is:

$$Q_{RF} = M_p C_p \Delta T_p \tag{52}$$

As the frying progresses, the heat received by the cassava mash can be represented as:

$$Q_{CM} = M_M C_M \Delta T_M \tag{53}$$

This heat, Q_{CM} is used to absorb bond water in the mash and alslo used to heat the surrouding air within the trough . Hence, the heat absorbed by the water is:

$$Q_W = M_w \lambda \tag{54}$$

And the heat absorbed by the surrounding air is:

$$Q_a = M_a C_a \Delta T_a \tag{55}$$

Thus the overall heat absorbed is then:

$$Q_{CM} + Q_W + Q_a$$

Where,

Q_{TC} = quantity of heat conducted by the trough, J

Q_{RF} = quantity of heat retained by the fryer, J

Q_G = quantity of heat absorbed by the gari mash, J

Q_W = quantity of heat absorbed by water, J

Q_a = quantity of heat absorbed by the air, J

For the heat transfer,the quantity of heat transfer (Q) is given by:

$$Q = \frac{kA\Delta T}{L} \tag{56}$$

and the rate of heat flow is calculated as:

$$q = h\Delta T \tag{57}$$

whereas the coefficient of heat transfer h_c is calculated as:

$$h = 14.3\ G^{0.8} \tag{58}$$

(McCabe and smith, 1976)

When G equals 0.02 m/s

where

h = coefficient of heat transfer, W/m^2K

G = air mass velocity (m/s)

The Temperature history and the drying characteristics of the mash were shown in Appendices III and IV.

For the mass transfer, rate of mass transfer N, is given as:

$$N = k_m \, A \, \Delta \rho \qquad (59)$$

According to Sachdeva (1992), Sherwood number (S_h), Reynolds number (R_e) and Schmidt number (S_c) which are important in calculating mass transfer relations are described as below:

$$S_h = \frac{k_m \, L}{D_{eff}} = C \, R_e^{n} S_c^{0.33} \qquad (60)$$

$$R_e = \frac{Lu\rho}{\mu} \qquad (61)$$

and

$$S_c = \frac{\mu}{\rho \, D_{eff}} \qquad (62)$$

Sachdeva (1992) also gave the constant C to be 0.989 and n to be 0.33 since R_e is between 0 and 4. Then S_h is now related to R_e and S_c to calculate the coefficient of mass transfer k_m as:

$$S_h = 0.989 \, R_e^{0.33} \, S_c^{0.33} \qquad (63)$$

Recalling from equation (60), the coefficient of mass transfer k_m is given as:

$$k_m = \frac{S_h \, D_{eff}}{L} \qquad (64)$$

And according to Jackson and Lamb (1981), the quantity of mass transfer is given when the diffusion coefficient of water was calculated to be -0.0575m²/s as:

$$m = FAt = \frac{\delta m}{\delta t} At \qquad (65)$$

where,

D_{eff} =diffusion coefficient of water from the cassava mash, m^2/s

ρ =density of the mash, kg/m^3

μ =coefficient of friction (viscosity) of the mash

4.2 Computer Program

A FORTRAN computer program in Appendix I was used to generate values for the parameters chosen. The parameters include Total time (TT), saturation temperature (TS) and heat absorbed by mash (Q_g). The program was made of three subroutines called INFORM, PSYCHRO, and HTQTY. INFORM supplies all the information needed such as the initial moisture content, mash thickness, density and the fryer temperature. PSYCHRO supplies all the value needed for the computation of the humidities, while HTQTY assigns values for heat transfer and direction. The value of the saturation temperature was guessed first and the computer iteration begins until the correct value is attained which depend on the temperature of the through. The drying rates, moisture evaporated and drying time were then computed as shown on tables 11, 12, and 15. The model flowchart is shown in Figure 7, while the Statistical analysis and simulation of the model are shown in Appendices V and VI.

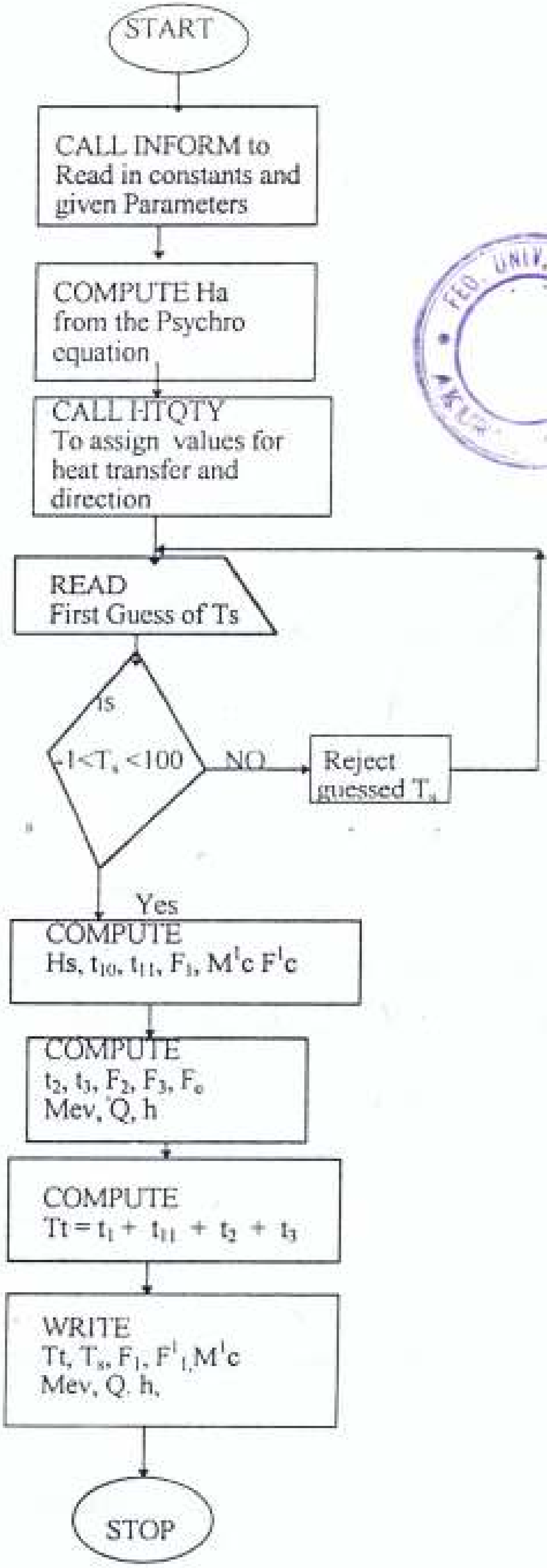


Figure 7 Flowchart of the model

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

This chapter presents the results of the experimental work and the results of the mahtematical modelling of heat and mass transfer during cassava mash drying.

5.1 Experimental Results

Several runs were carried out on the frying machine to determine the heat and mass transfer properties of the cassava mash. The steady state temperatures of the fryer was determined along the vertical direction for the three heat intensities as presented in Table 1. The maximum steady state temperature was 160 °C at high heat, 102 °C at medium heat and 75 °C at low heat intensity. Because of the shortest time of 12 minutes taken to reach the steady state, the high heat intensity with gas flow rate of 83.8 g/min was chosen, Figure 8 showed the graph of the steady state temperature at the three levels of heat intensities.

Three steady state temperatures of the frying trough were obtained at three levels of heat intensities. (high, medium and low); as shown in Figure 8, the steady state 160 °C at high heat was used for the modeling. This state was reached in twelve minutes. Figure 9 shows the increase in mash temperature with time of frying, while the changes in moisture content was shown in Figure 10. Observation of figures shows that as the temperature increases, the moisture content reduces.

5.1.1 Bulk density

Table 2 shows the variation of moisture content as the time of frying increases, this showed a decreasing trend as the time of frying increases. The mash temperature also increases with increase in frying time during the frying at different heat intensities. It was observed that only the high heat frying reaches the equilibrium moisture content (emc) of 12.5% at twenty-one minutes frying time.

Table 1. **Steady State Temperatures Of The Trough at Different Heat Intensities**

Trough Temperature(°C)

Time(min)	Heat Intensities		
	HIGH	MEDIUM	LOW
0	27	27	27
1	40	34	30
2	51	38	33
3	60	42	37
4	72	54	39
5	81	59	41
6	93	62	44
7	104	66	49
8	116	69	51
9	120	72	53
10	137	78	57
11	156	81	59
12	160	88	62
13	160	92	65
14	160	94	67
15	160	97	69
16	160	99	71
17	160	102	71
18	160	102	72
19	160	102	72
20	160	102	73
21	160	102	73
22	160	102	74
23	160	102	74
24	160	102	75
25	160	102	75
26	160	102	75

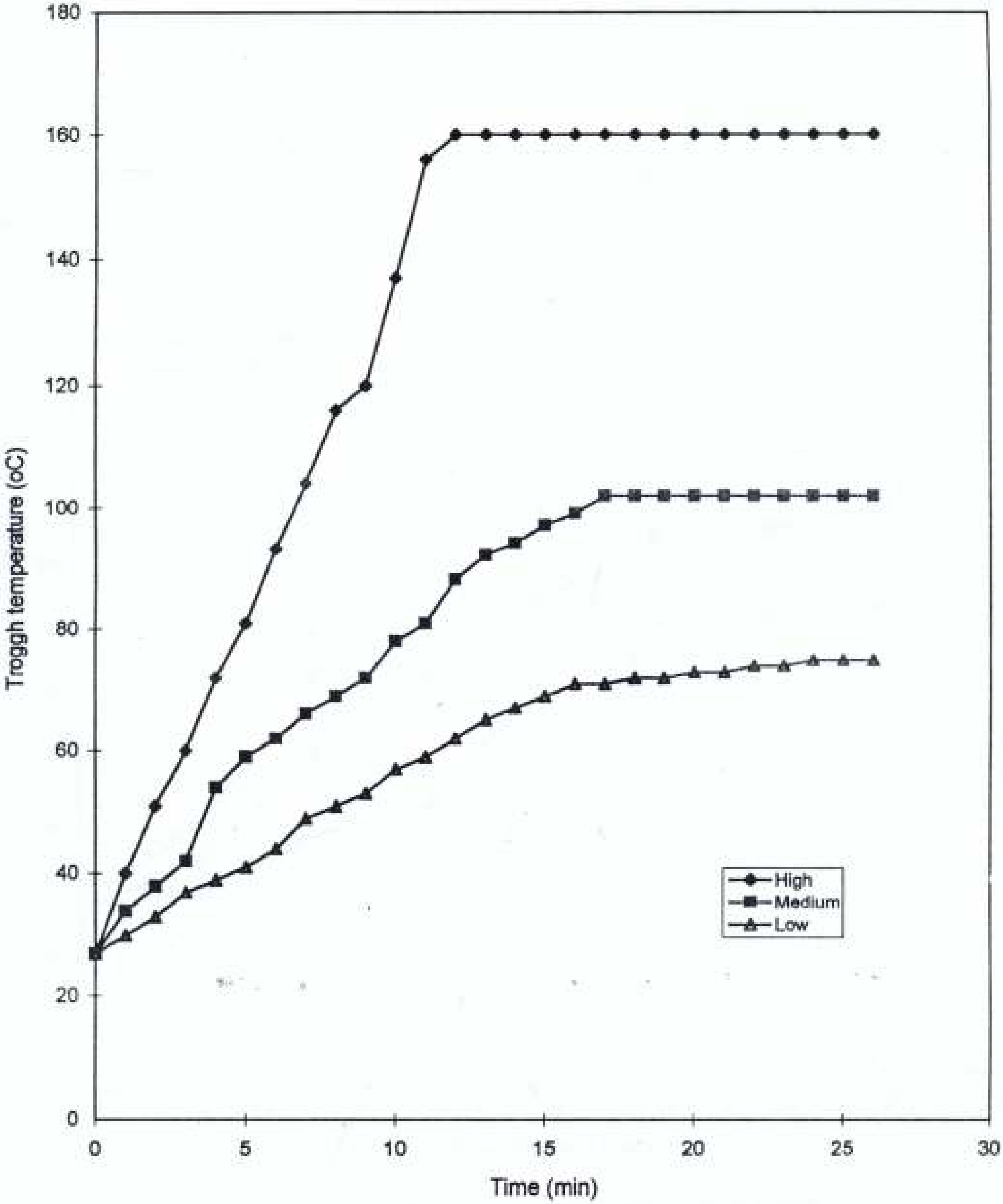


Figure 8. Graph of Trough steady state Temperature with Time

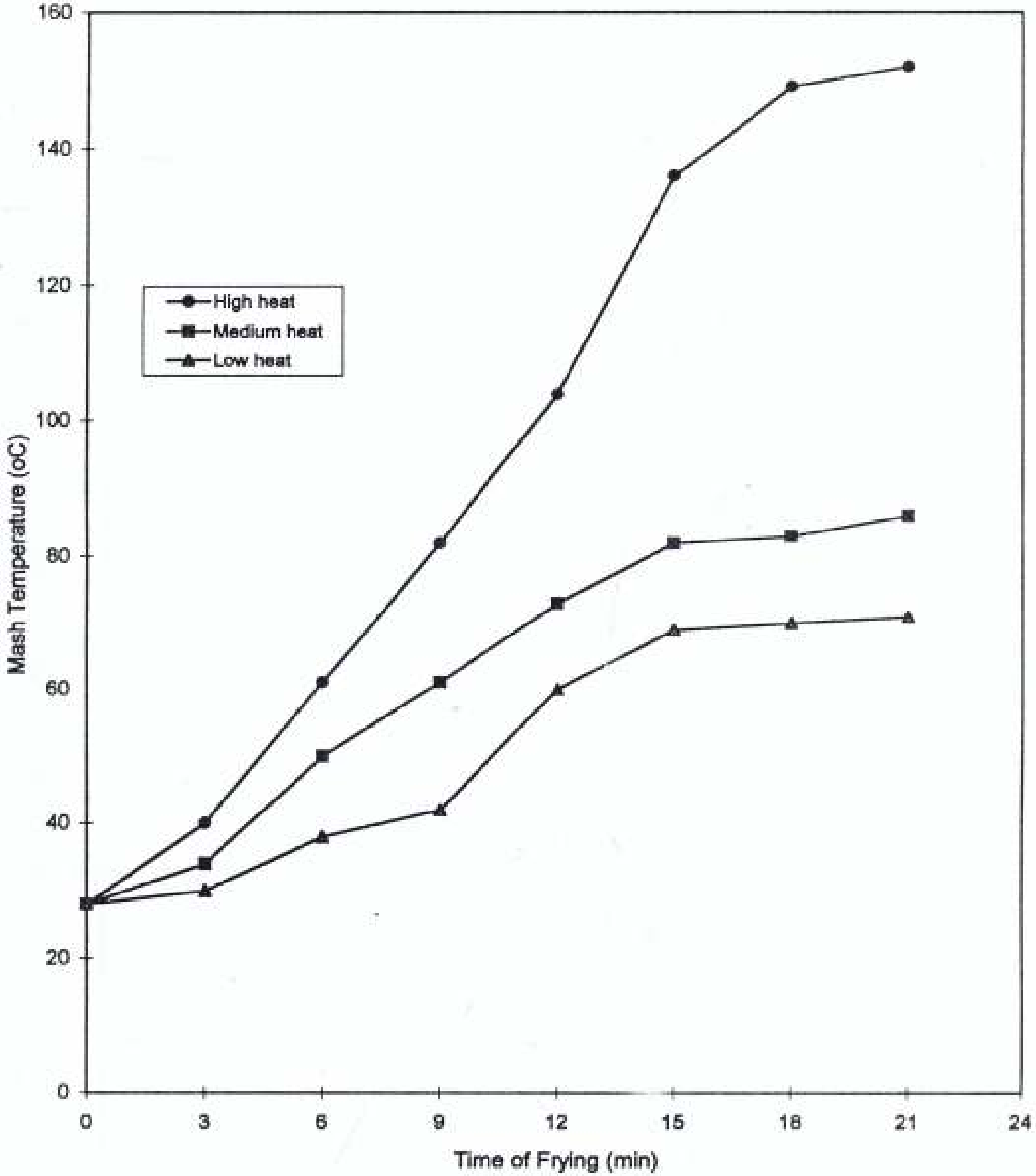


Figure 9. Graph of Mash Temperature with Time of Frying

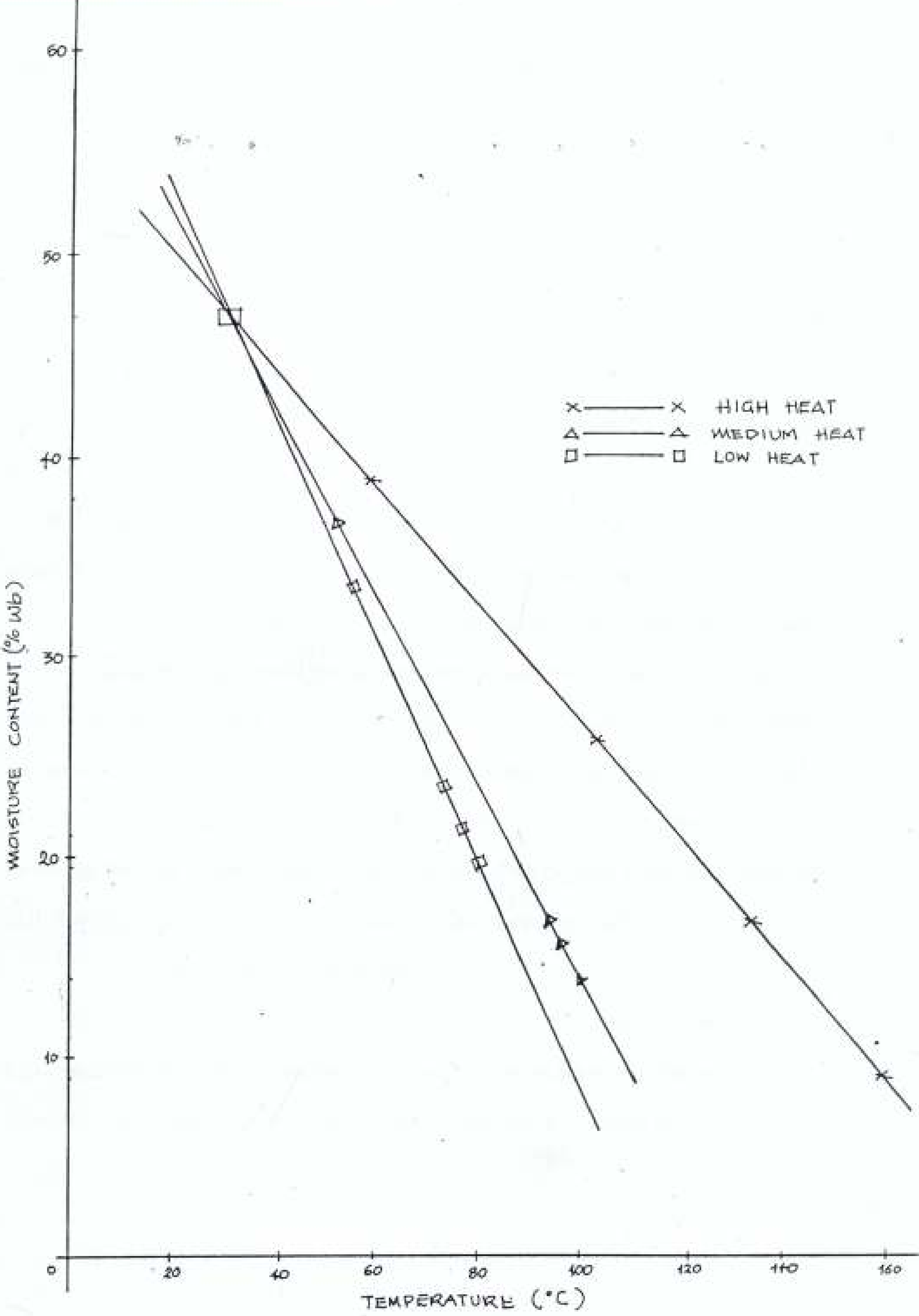


FIGURE 10 ; GRAPH OF MASH MOISTURE CONTENT AGAINST DRYING TEMPERATU

Figure 11 is the drying curve of cassava mash undergoing drying at 3 levels of heat intensities which shows that the moisture content reduces with iincreasiing time of frying. The equilibrium moisture content was reached in about 15 minutes when high heat was used at 5^{o} angle of inclination ol the machine. For the medium and low heat, the moisture content did not get to the emc when drying. This is because the heat used for the drying was lower than what is required to dry the mash. The drying curve in Figure 12 shows the value of the gradient of the curve for high heat drying which is the coefficient of mass transfer k_m obtained to be 1.67. As the mash traverses the length of the drying trough the moisture content history of the drying mash is expressed as:

$$MC = 47.5718 - 0.586645 * X + 0.00225826 * X^2 \qquad (66)$$

where X is the distance traverses by the mash along the lenght of the fryer.

It is noted from Tables 3 and 4 that the bulk density of the cassava mash decreases with decreasing moisture content during the drying process but the relationship is not linear. Fresh cassava mash is usually bulky and heavy, as the mash dries it loses moisture and become less heavy, but further drying of the mash tends to break all bonds between the mash particles thus reducing the pore spaces within the mash and consequently increasing the bulk density at lower moisture level (Faborode et al, 1992). This shows that bulk density is a function of moisture content which is expressed as:

$$\rho = \exp(-0.0136337\ MC)*10327.1 \qquad (67)$$

Heat was introduced to remove moisture from the cassava mash and as the time of frying increases, the moisture content decreases as shown in Figure 12. The specific heat capacity,C and thermal diffusivity,α decreases as the moisture content of

Table 2. **Change In Moisture Content with Time(Experimental)**

	HEAT INTENSITIES					
TIME	HIGH		MEDIUM		LOW	
		T		T		
0	(46.7)87.62	28	(46.7)87.62	28	(46.7)87.62	28
3	(38.5)62.60	40	(40.2)67.22	34	(42.1)72.71	30
6	(30.0)42.86	61	(35.6)55.28	50	(37.5) 60.0	38
9	(21.5)27.39	82	(25.4)34.05	61	(31.2) 45.35	42
12	(17.0)20.48	104	(21.1)26.74	73	(27.3)37.55	60
15	(12.5)14.29	136	(17.2)20.77	82	(22.1)28.37	69
18	(10.9)2.23	149	(15.8)18.76	83	(20.6)25.94	70
21	(9.2)10.13	152	(14.3)6.69	86	(19.4)24.07	71

LEGEND

( )	M/C in % wb.
T	Temperature,K

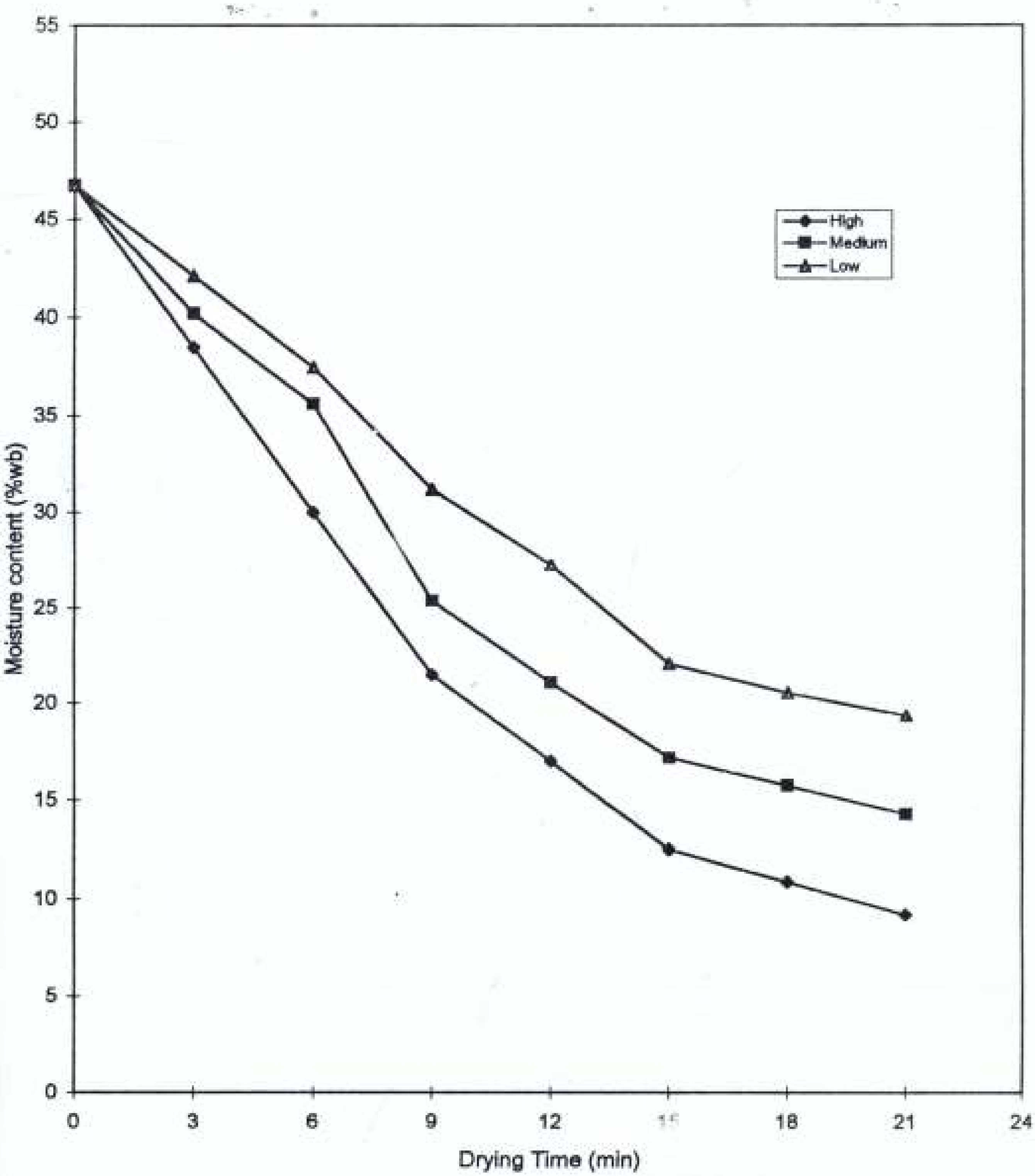


Figure 11. Drying Curve for Different Heat Intensities

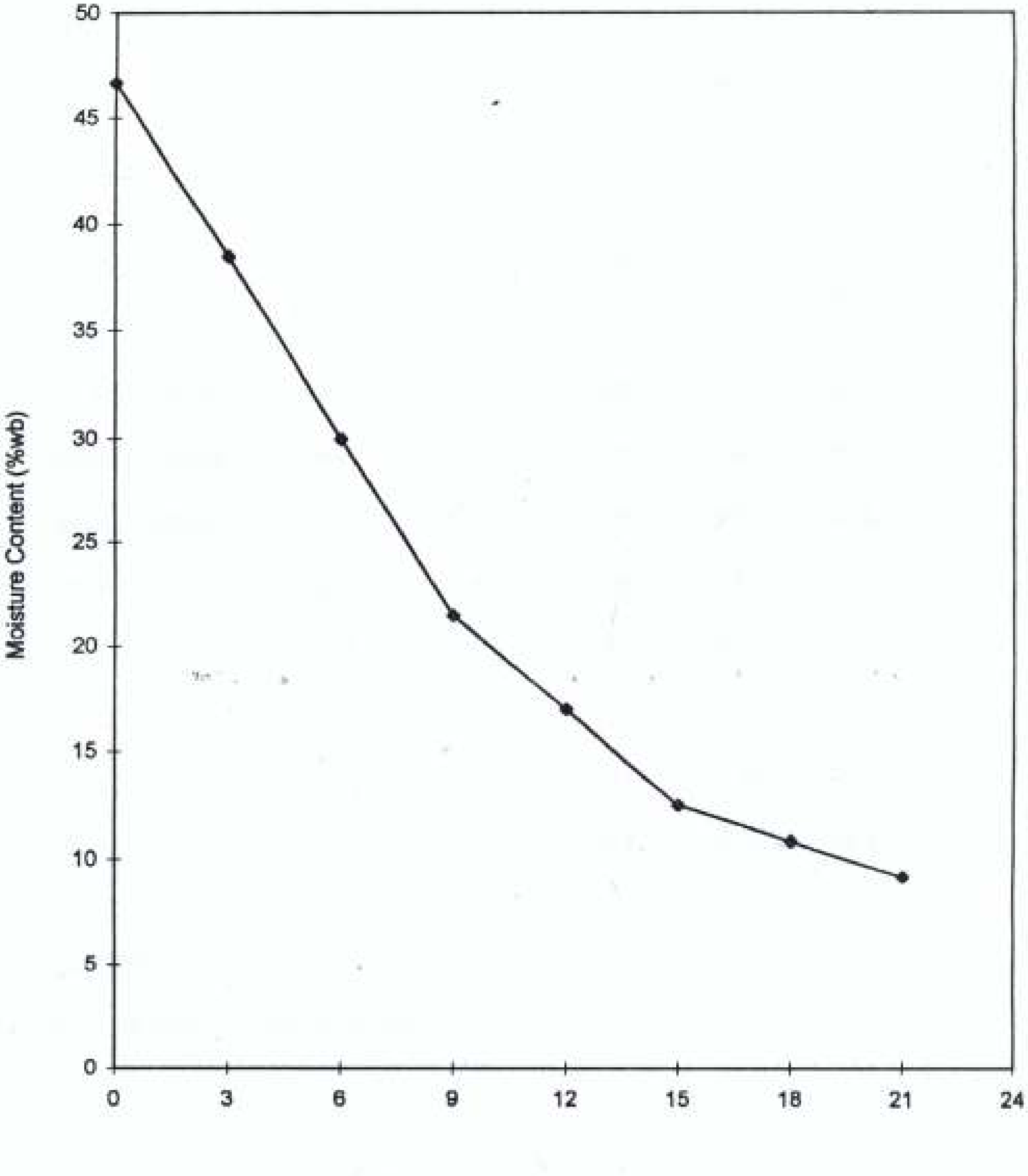


Figure 12. Graph of Moisture Content with Time of frying

Table 3. **Variation of the Bulk Density and Frictional Properties of Mash with Moisture Content during drying (Experimental)**

Moisture Content		Bulk Density	Coefficient of Friction			Emptying
(%)db	(%)wb	(kg/m³)	Galvanized steel sheet	Polished wood	Plywood	angle of repose
87.62	(46.7)	441.3	0.43	0.42	0.44	40.6
62.60	(38.5)	437.2	0.38	0.35	0.4	39.2
42.86	(30,0)	433.9	0.36	0.32	0.37	38.8
27.39	(21.5)	430.1	0.33	0.29	0.35	37.9
20.48	(17.0)	426.8	0.32	0.27	0.33	37.2
14.29	(12.5)	491.3	0.27	0.23	0.31	36.7
12.23	(10.9)	499.6	0.25	0.21	0.29	35.3
10.13	(9.2)	507.9	0.22	0.18	0.24	34.8

LEGEND

( ) Moisture Content in % wb

Table 4: **Change In Mash Properties During Frying (Experimental)**

TT	MC		ρ	R	k	C	α
(min)	(%)	(%)	kg/m^3	kg/m^2min	W/mK	kJ/kgK	$x10^{-6}m^2/s$
0	46.7	(87.62)	441.3	2.64	0.24	4.14	0.131
3	38.5	(62.60)	437.2	2.86	0.19	3.94	0.110
6	30.0	(42.86)	433.9	2.81	0.15	3.52	0.098
9	21.5	(27.39)	430.1	2.25	0.14	2.76	0.118
12	17.0	(20.48)	426.8	1.56	0.12	2.61	0.108
15	12.5	(14.29)	491.3	1.11	0.10	2.34	0.087
18	10.9	(12.23)	499.6	0.63	0.08	2.16	0.074
21	9.2	(10.13)	507.9	0.54	0.06	2.01	0.059

LEGEND

T T = Total drying time, min
Mc = Moisture Content, %
ρ = bulk density, kg/m^3
R = Rate of drying, kg/m^2s
k = thermal conductivity, W/mK
C = specific heat capacity, kJ/kgK
α = Thermal diffusivity, m^2/s
( ) = Moisture content in % db.

the mash reduces as seen in Table 4 showing that both specific heat and thermal diffusivity are functions of moisture content. At high heat intensity, the average measured value of heat transfer coefficient, h_c is 0.2826 while the predicted value from the model is 0.6254 both of which are less than 1.0 as shown in Table 11.

The time of frying the gari changes with some parameters as shown in Table 3. As the initial moisture content of the mash is reduced the drying time also reduces. Figure 11 shows the drying curve using high, medium and low heat and the final moisture contents. Observation of the figure shows that only the high heat reaches the equilibrium moisture content (emc) of 12.5(% wb) after 15 minute of drying when the initial moisture is kept constant at 47% wb. Figure 12 shows a decreasing relationship as the time is nearly held constant until the twenty-first minute and 13% Mc when there is a sharp time increase to 23.7 minutes with only 0.5% decrease in moisture content as also shown in table 8. as the initial moisture content increases so does the time of frying, this was supported by Faborode et al, (1992).

It was observed in Table 2 that the moisture content of the mash changed as a result of temperature and time change. As the time of frying increases, the temperature also increases until a steady state (or saturation temperature) is reached. The relationship between the mash temperature and the frying time is shown in Figure 9. The frying temperature was also monitored with the frying time. The drying time showed a decreasing trend when the temperature increases as shown in Figure 9.

As the initial moisture content was reducing, so does the frying time, the bulk density reduces also as a function of moisture content until the drying reaches the equilibrium moisture content (emc), after which it began to increase as shown in Tables 3 and 4. When 160 °C was used as the steady state temperature, it was observed that as the initial moisture content reduces the time of frying also reduces as shown in Table 7..

Further increase in temperature causes a drastic reduction in the drying time as shown in Figure 10. The coefficient of friction, angle of sliding friction, the specific heat, thermal conductivity and the drying rates all showed a decreasing trend as the drying progressed with corresponding decrease in moisture content.

Drying curves for three runs were presented for the low, medium and high heat intensities, and after 20 minutes drying, the frying with high heat intensity reached the equilibrium moisture content stage as shown in Figure 11. During this process, the heat was used to evaporate moisture from the product which resulted in mass transfer of water occurring within the grains as well as on its surface, and the coefficient of mass transfer obtained by determining the slope of the curve equals 1.67. As the initial moisture content (M_o) increases, the moisture evaporated (Mev) also increases showing that as the mass of the mash increases so is the amount of water evaporated as shown by the model and the experimental data.

The thermal conductivity of the mash decreases as the moisture content reduces (Figure 13). Also, as the temperature increases, much water is evaporated showing that thermal conductivity (k) is a function of moisture content of the material (Table 4). The equation which relates moisture content to thermal conductivity is given as:

$$k = 0.0741056 + 0.0204109 * MC - 0.0065843 * MC^2 + 7.84346E\text{-}06 * MC^3 \qquad (68)$$

Specific heat capacity of the mash decreases as the moisture content decreases as shown in Table 4. This revealed that the higher the moisture, the higher the specific heat capacity and the lower the moisture content the lower the specific heat capacity.The equation that can be used to predict specific heat is:

$$C = 1.20488 + 0.0937196 * MC - 0.000637805 * MC^2 \qquad (69)$$

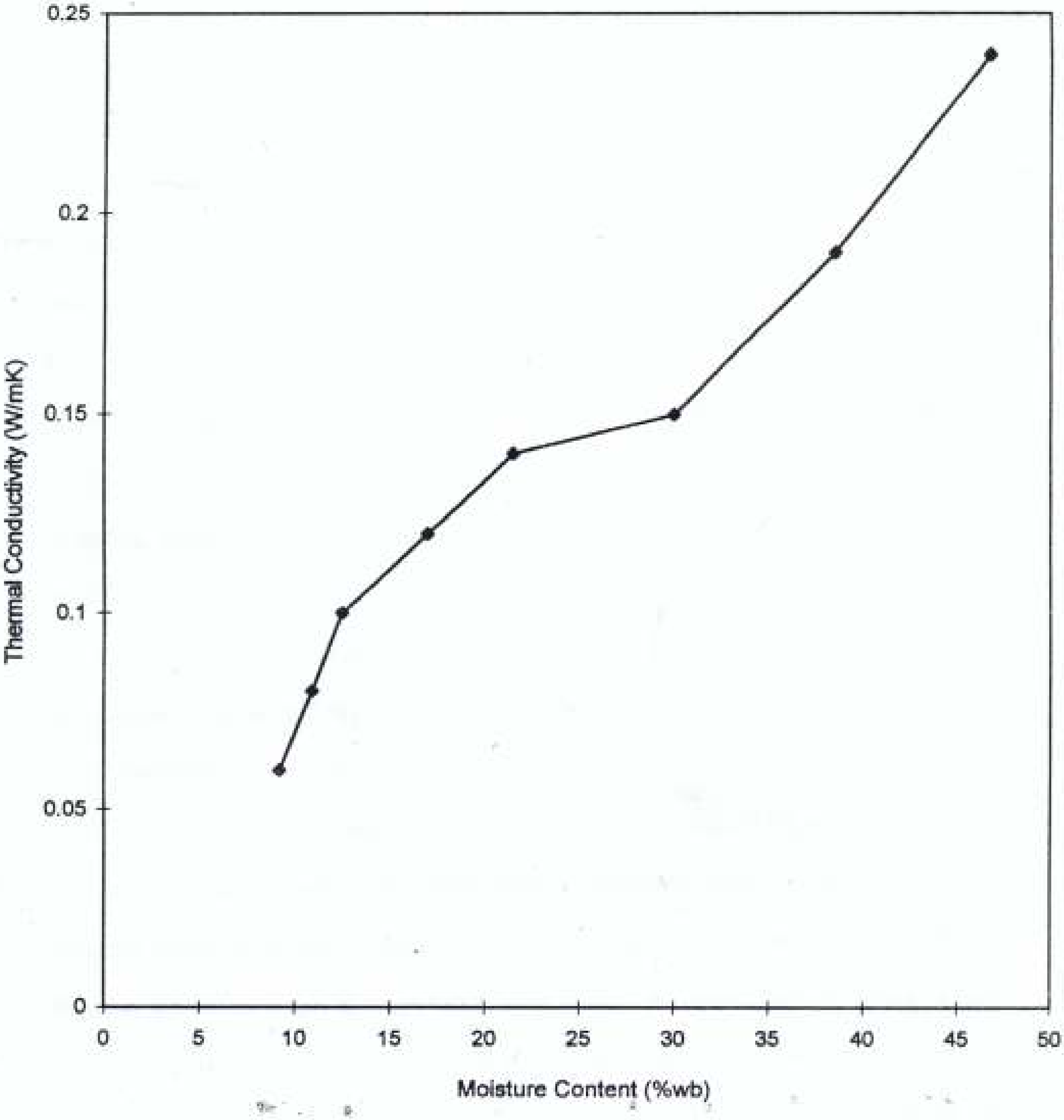


Figure 13. Graph of Thermal Conductivity against Moisture Content

5.1.2. Drying rate

The drying rate for the high heat intensity at machine inclination angle of 5° ranges between 0.5 and 2.9 kg/min during the drying period. A constant period and two falling rate periods were exhibited. The drying constant period occurs at 40 and 30% moisture content. The first falling rate occurs between moisture content 30 and 20%, while the last falling rate (diffusion period) was between 20 and 10% moisture content as shown in Figure 14. When the drying rate was compared with drying time, 3 periods were identified as shown in Figure 15. These are warming up period occuring between the first 3 minutes of drying, the constant period follows till the 8 minute, thereafter the falling rate continues to the end of the drying. The drying rate falls as the time of frying inreases, since the moisture content also decreases with time, this causes a reduction in the size of the grains as it begins to shrink and dry patches emerged on the grains surface.

5.1.3 Coefficient of sliding friction

The coefficient of sliding friction was found to decrease as the moisture content was decreased on all the three structural surfaces considered shown in Table 3. The values obtained for plywood was the highest for all the moisture levels considered, the difference between the values obtained for polished wood surface and galvanized steel sheet was not significant thus, better material flow, less friction and power loss would be encountered on the galvanized steel surface thus making it easier for the cassava mash to flow freely into the frying trough of the machine as the hopper was made of galvanized steel sheet.

5.1.4. Emptying angle of repose

The emptying angle of repose was found to vary between 40.6° and 34.8° from 46.7% moisture content to 9.2% wet basis which compared well with Faborode et al, (1992) values of 41.8° and 35.3° from 63.4 to 8.2% $Mc_{(wb)}$.

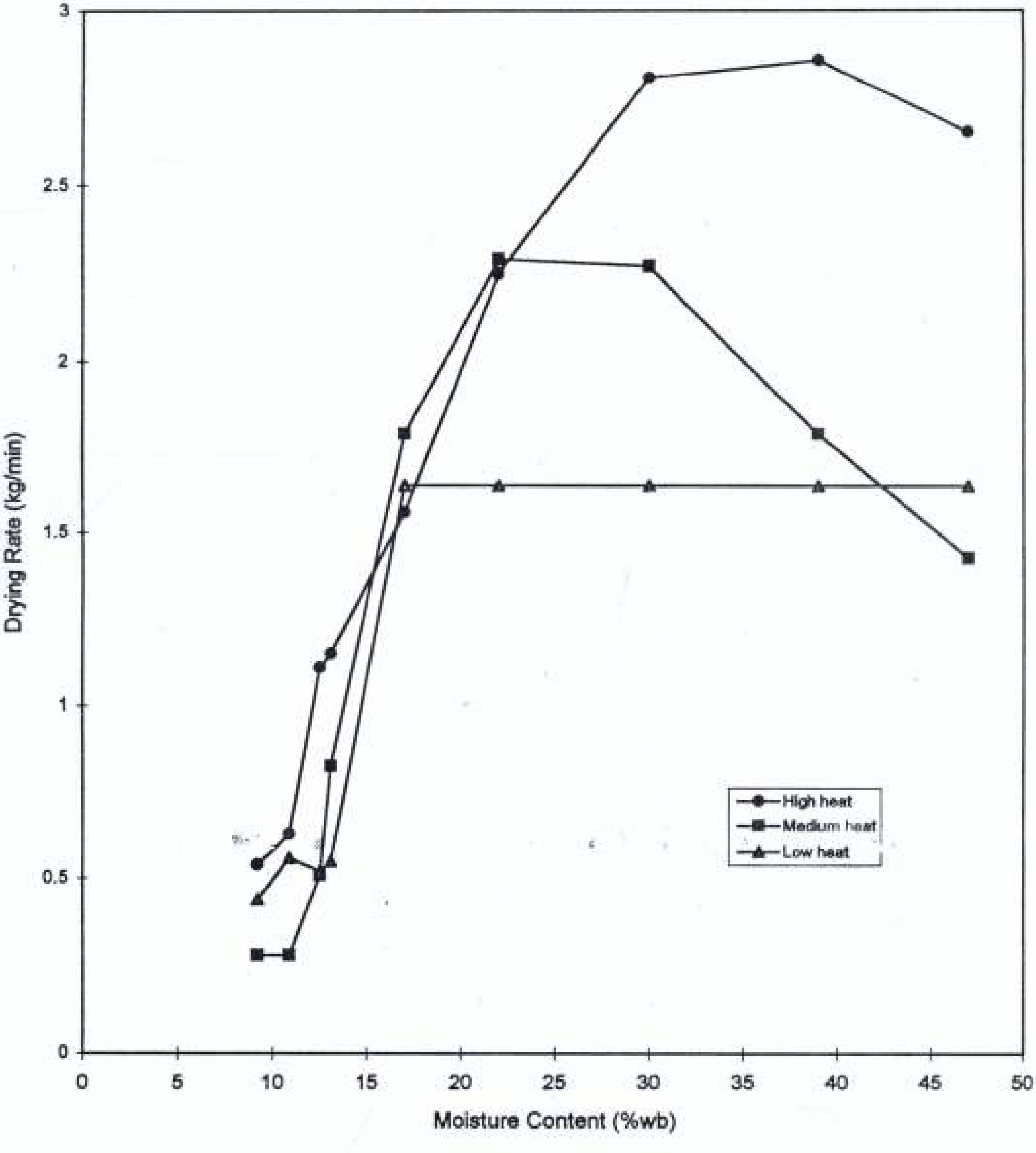


Figure 14. Mash Drying Rate with Moisture Content

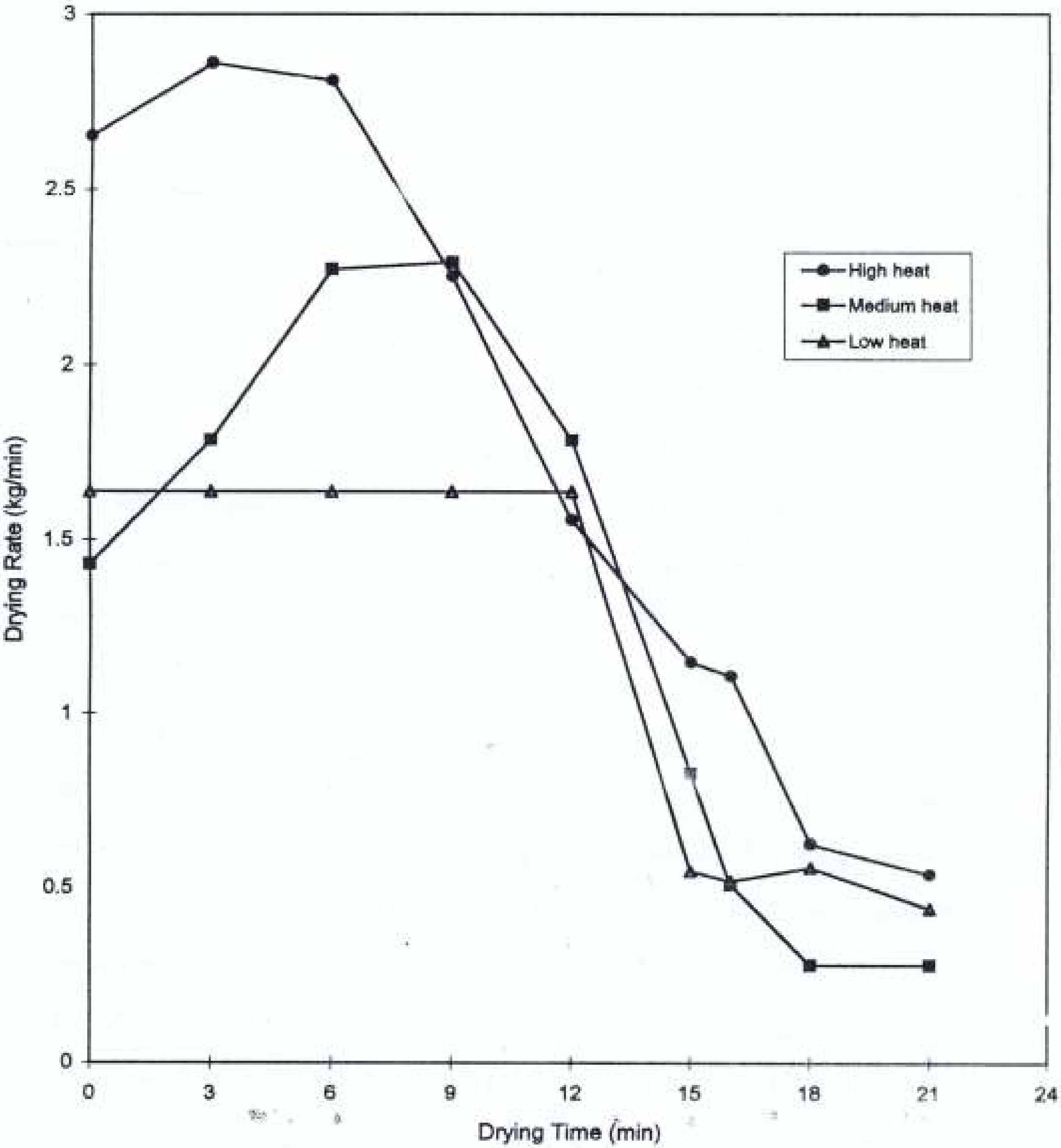


Figure 15. Mash Drying Rate with Drying Time

This was used in the design of the machines' hopper for easy emptying of the cassava mash into the frying trough. At higher moisture content, the internal friction of a material is usually higher, causing the material to stick together, and leading to high values of angle of repose. Hence in cassava processing machinery the wetter materials will require higher slopes to be able to flow freely, as against lower slopes for the drier products.

5.2 Results of the Model

The model was built based on the experimental results and a computer program written in FORTRAN language shown in appendix I was used to solve the model equation. The flowchart of the model is shown in Figure 7.

5.2.1 Effects of trough temperature and mash thickness on time of frying

The model was tested with a wide range of temperature, ranging from 100° -200 °C and the corresponding frying time monitored as shown in Table 5. The drying curve is also shown in Figure 16. It was observed that as the temperature of the trough increases, the time of frying reduces from 91.03 to 12.95 minutes indicating that it takes a lesser time to dry the mash to an acceptable moisture content. The 160 °C temperature was chosen for the model as this was the steady state temperature for the experimental work, and the thickness of the mash varied between Imm to 10mm while the thickness 4mm was chosen which was the clearance between the paddles and the fryer's trough. This gives a drying time of 20.70 minutes, a time very close to the experimental drying time of 22 minutes as shown in Table 6. It is also noted that a small change in the thickness of the mash greatly affect the total drying time as 1mm mash depth dries in 1.61 minute while 10mm depth mash dried in 122.06 minutes (2hr.2min.06sec).

Table 5. **Variation Of Total Drying Time (TT) With Fryer Temperature (TP)**

TP	T_1	T_{11}	T_2	T_3	TT	T_S
100	33.42	53.56	4.26	0	91.03	84.70
110	23.25	37.26	2.73	0	63.09	88.20
120	17.16	27.51	1.90	0	46.46	90.60
130	13.33	21.36	1.43	0	36.03	92.30
140	10.76	17.24	1.12	0	29.05	93.60
150	8.97	14.38	0.92	0	24.22	94.45
160*	7.67	12.30	0.78	0	20.70*	95.13
170	6.59	10.72	0.67	0	18.03	95.70
180	5.92	9.49	0.59	0	15.97	96.10
190	5.30	8.49	0.53	0	14.28	96.40
200	4.81	7.70	0.47	0	12.95	96.70

LEGEND

WTO - Initial mash weight = 6kg

Mo = Initial moisture content = 87.6 (46.7),%

L = Mash thickness 0.004m

TP - Trough temperature (°C)

TT - Total drying time (min)

Ts - Saturation temperature (°C)

* - Parameter used for the model

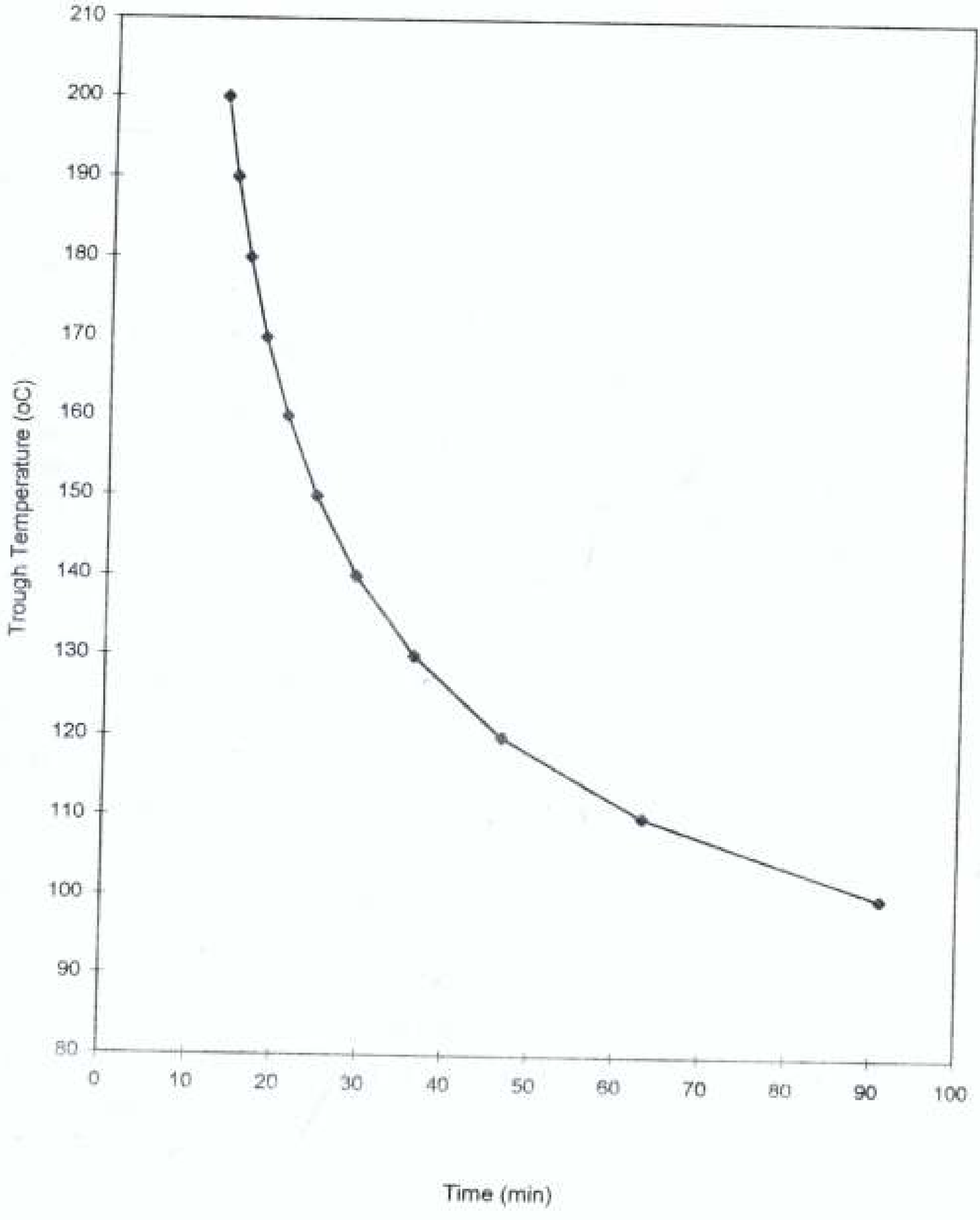


Figure 16. Graph of Temperature Variation with Drying Time

Table 6. **Variation Of Mash Thickness (L) With Saturation Temperature (Ts)**

L	T_1	T_{11}	T_2	T_3	TT	Ts_1	Ts_2
0.001	0.6	0.96	0.06	0	1.61	98.27	94.27
0.002	1.97	3.16	0.20	0	5.31	97.21	91.71
0.003	4.38	7.01	0.44	0	11.80	96.13	88.93
0.004*	7.67	12.30	0.78	0	20.70*	95.13	86.83
0.005	11.85	19.00	1.21	0	31.98	94.19	84.59
0.006	16.87	27.04	1.73	0	45.54	93.31	82.81
0.007	22.76	36.48	2.34	0	61.44	92.47	81.27
0.008	29.45	47.21	3.04	0	79.52	91.68	79.88
0.009	36.95	59.22	3.84	0	99.75	90.93	78.53
0.01	45.21	72.46	4.69	0	122.06	90.22	77.32

LEGEND

TP = Trough temperature = 160oC
TT = Total drying time = 20.7 min
WTO = Initial mash weight = 6kg
Mo = Initial moisture content = 87.6 (46.7),%
Ts_1 = saturation temperature at stage 1, °C
Ts_2 = saturation temperature at stage 2, °C
L = Mash thickness inside the trough, m
T_1 = Drying time at stage one, min
T_{11} = Drying time at stage one second period, min
T_2 = Drying time at stage two, min
T_3 = Drying time at stage two second period, min
* = Parameter used for the model

5.2.2 Effects of initial moisture content on time of drying

Several moisture contents were tested on the model and the corresponding drying time was monitored. Table 7 shows a range of initial moisture contents of 40% to 50% (wb) and the drying times were shown ranging between 13.35 and 25.05 minutes. The initial moisture content (M_o) was held constant at 47% as this was used during the experimental work and final moisture content, (M_f) was monitored. Figure 17 showed the drying trend with different initial moisture content. On starting with a different initial moisture content, and allowing the mash to dry to a certain level,if the machine is stopped this can allow the processor to obtain a constant final moisture content. The time of drying can then be measured which showed an increasing trend as the initial moisture content increases and also dereases as the moisture content decreased. These were shown in table 8 and in figure 18. Comparing the model and the experimental work based on the initial moisture content and the drying time, figure 19 showed the similarities between the two works that as the initial moisture content increases, the time of frying also increased.

5.2.3 Effects of volume and initial moisture content of mash on amount of Moisture evaporated

Table 9a showed the amount of moisture evaporated in the experimental and the model testing. The initial moisture content was varied and and the amount of moisture evaporated was measured the result showed that as the initial moisture content inreases also the amount of moisture evaporated increaases as shown in Figure 20. The coefficient of correlation (R^2) is 0.91. When the initial mash weight (volume) was varied there was an increase in the amount of moisture evaporated as the volume of mash increased as shown in Table 9b. This indicated that as the quantity of mash increases, the volume of water to be evaporated also increases. Comparing the quantity of moisture evaporated for both the model and the experimental work, the similarity is shown in figure 21 where the curve

Table 7 **Variation of Initial Moisture Content(M_0) With Total Drying Time(TT**

M_0	T_1	T_{11}	T_2	T_3	TT
100 (50)	9.85	14.47	0.78	0	25.05
96.08 (49)	9.16	13.79	0.78	0	23.68
92.31 (48)	8.50	13.12	0.78	0	22.35
*88. 68 (47)	7.86	12.49	0.78*	0	21.08
85.19 (46)	7.25	11.87	0.78	0	19.85
81.82 (45)	6.66	11.28	0.78	0	18.67
78.57 (44)	6.09	10.71	0.78	0	17.53
75.44 (43)	5.53	10.16	0.78	0	16.43
72.41 (42)	5.01	9.63	0.78	0	15.37
69.49 (41)	4.49	9.11	0.78	0	14.34
66.67 (40)	4.00	8.62	0.78	0	13.35

LEGEND

TP = Trough temperature = 160°C

WTO = Initial mash weight = 6kg

L = Mash thickness = 0.004m

Mo = Initial mash Moisture Content %

TT = Total drying time (min)

( ) = Moisture Content in % wb.

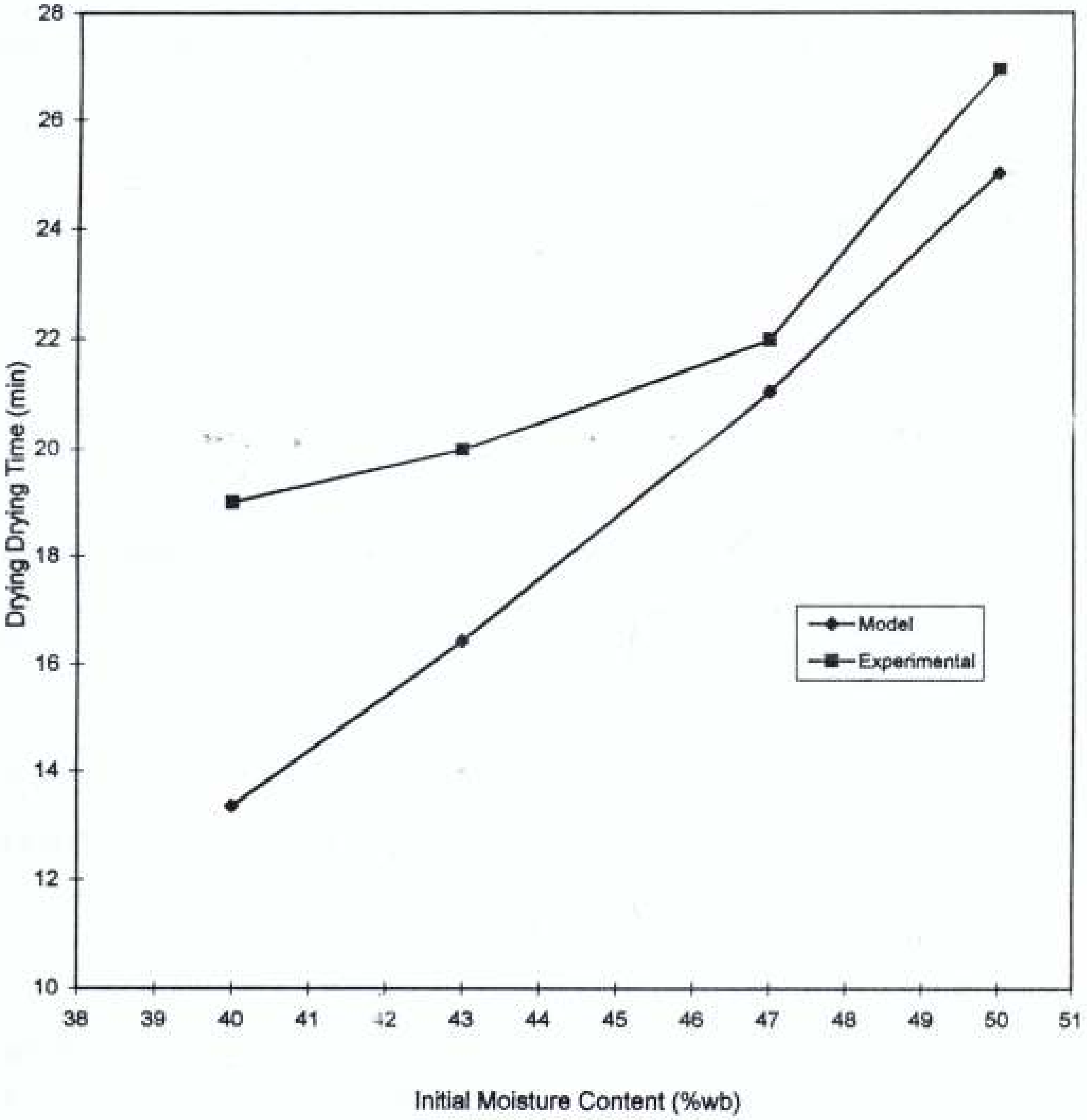


Figure 17. Variation of Mash Initial Moisture Content with Time of Drying

Table 8a. **Variation of Final Moisture Content(M_F) With Total Drying Time(TT)**

M_o	M_F	M_e	T_1	T_{11}	T_2	T_3	TT
88.68(47)	20.0(17)	14.3(12.5)	7.86	12.49	0.78	0.19	20.71
88.68(47)	19.2(16)	14.3(12.5)	7.86	12.49	0.78	0.18	20.95
88.68(47)	17.6(15)	14.3(12.5)	7.86	12.49	0.78	0.15	20.97
88.68(47)	16.5(14)	14.3(12.5)	7.86	12.49	0.78	0.13	21.00
88.68(47) *	15.0(13)	14.3(12.5)	7.86	12.49	0.78	0.05	21.08
88.68(47)	14.3(12.5)	14.3(12.5)	7.86	12.49	0.78	2.53	23.66

Table 8b. **Variation of Initial Mash (M_O) With Total Drying Time (TT)**

Mo	M_F	TT	
		Model	Experimental
100.00(50)	15 (13.09)	25.05	27
88.63 (47)	15 (13.09)	21.08	22
75.44 (43)	15 (13.09)	16.43	20
66.67 (40)	15 (13.09)	13.35	19

LEGEND

TP = Trough temperature = 160°C

L = Mash thickness = 0.00km

WTO = Initial mash weight = 6kg

Mo = Initial Mash Moisture Content = 88.68 (47)

Me = Equilibrium moisture content

Mf = Final moisture content

TT = Total drying time (min)

( ) = Moisture Content in % wb

* = Parameters chosen for the model

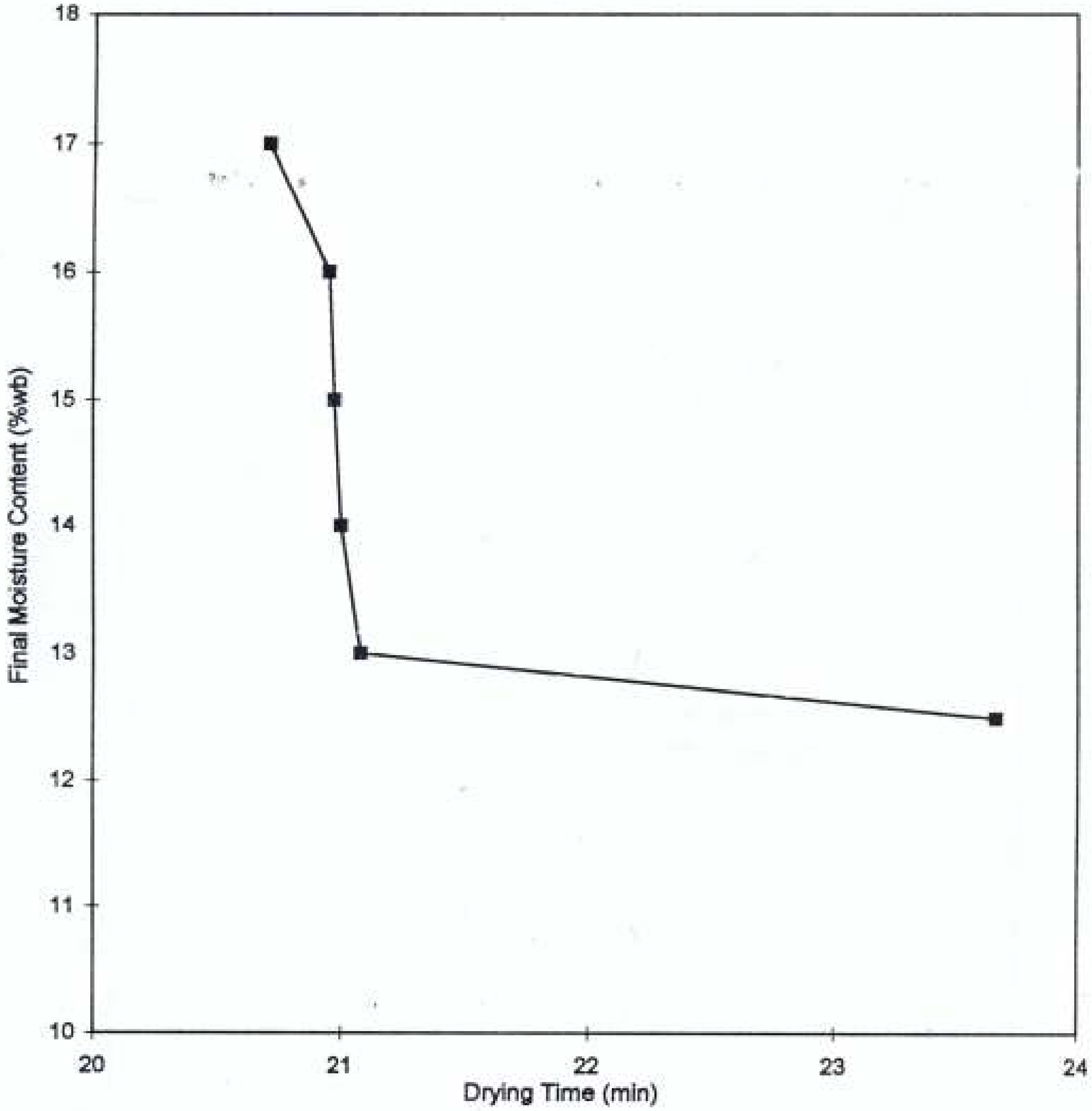


Figure 18. Variation of Mash Final Moisture Content with Time of Drying

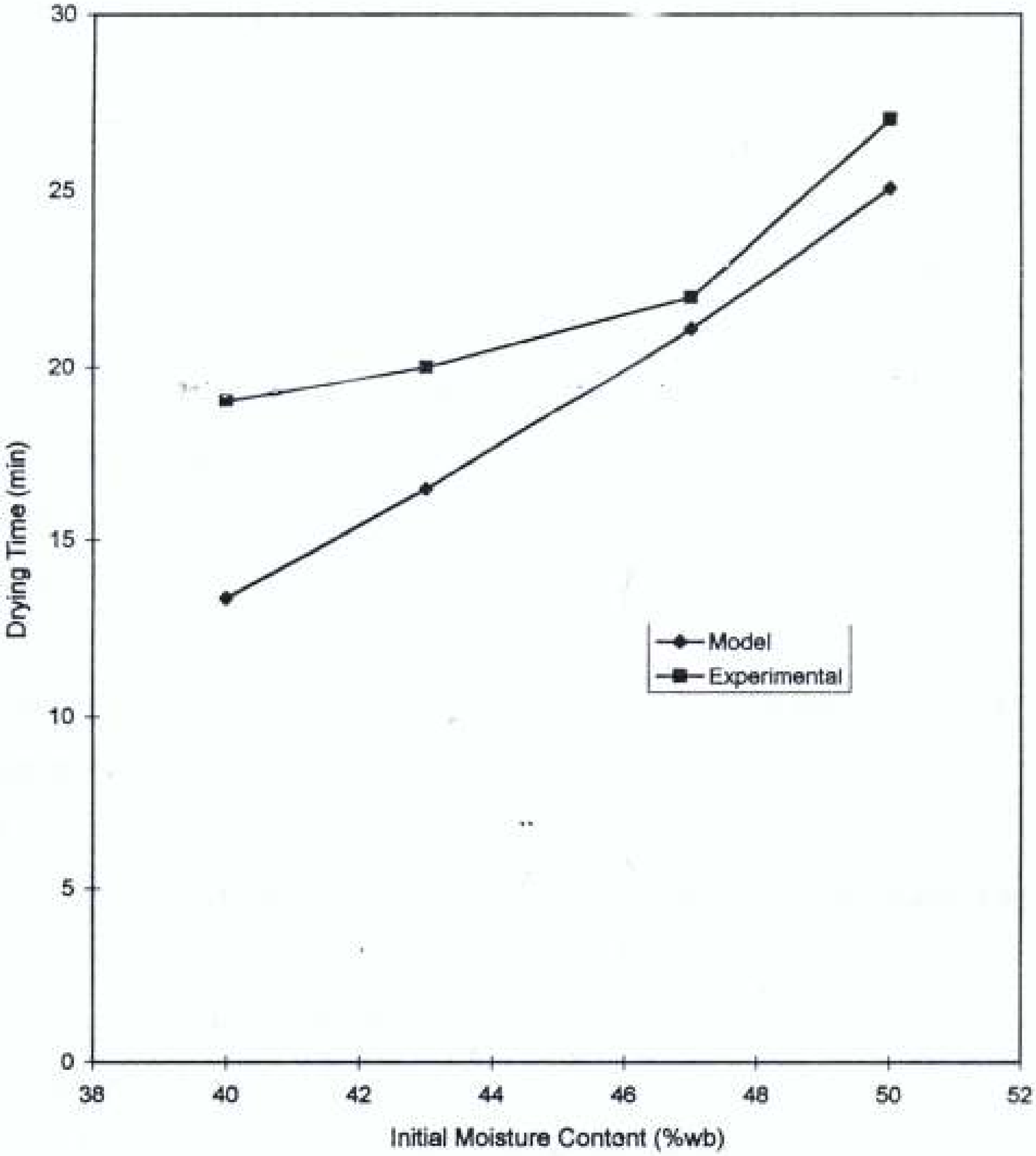


Figure 19. Change in Drying Time with Initial Moisture Content

showed that as the initial moisture content increases, the amount of moisture evaporated also increased.

5.2.4 Effects of drying rates on moisture content and drying time

After the warming up stage, it was observed that the drying rate remained constant until the critical moisture content was reached when the falling rate sets in until the final moisture content was reached. The effect of this on the drying time is that if the machine is allowed to reach the steady state before frying commenced, the warming up stage and the constant period stage time are reduced during the frying. But if the frying starts as soon as the machine is put on, then a lot of time will be used warming up the fryer and the mash before drying will really commences. The experimental frying was done at the 160°C steady state temperature and the drying rate was calculated to be between 0.5 and 2.9kg/min for the experiment while the modeling drying rate was predicted to be between 0.1 to 1.7kg/min as shown in table 10.

Figures 22 and 23 showed the drying rates with moisture content and time for the model and the experimental work.

5.3 Performance Evaluation of the Model

The results of the model was compared with the experimental results on nine of the parameters measured and a correlation of 0.99 was obtained, as shown in table 11. A performance efficiency of 72.3 % was also obtained for the gari frying machine.

5.4 Statistical Analysis of the Model

Based on the data obtained from the model, two regression equations were obtained as shown in Appendix VI. The first one was obtained when the time of frying (TT) was taken as the independent variable while dependent variables are mash weight (W_{To}), trough temperature (TP), mash thickness (L), mash initial moisture content (M_o) and mash final moisture content (M_f). The equation is expressed as:

Table 9a. **Moisture Evaporated (Mev) with Different Mash Initial Moisture Content (Mo)**

$^*M_o$	M_f	Moisture Evaporated (Mev)		R^2
		Model	Actual	
100 (50)	15(13.09)	0.1683	0.3332	0.91
88.68 (47)	15(13.09)	0.1423	0.1992	
75.44 (43)	15(13.09)	0.1079	0.1501	
66.67 (40)	15(13.09)	0.0820	0.1025	

Table 9b **Moisture Evaporated(Mev) With Different Mash Initial Weight(WTO**

WTO	MOISTURE EVAPORATED		R^2
	Model	Actual	
6	0.1423	0 .1992	0.99
4.5	0.1068	0.1682	
3	0.0831	0.1255	
1.5	0.0356	0.0594	

LEGEND

*WTO = Mash initial weight = 6kg

M_o = Mash initial Moisture Content = 88.68 (47)

( ) = Moisture Content in % wb

Mev = Moisture evaporated (kg)

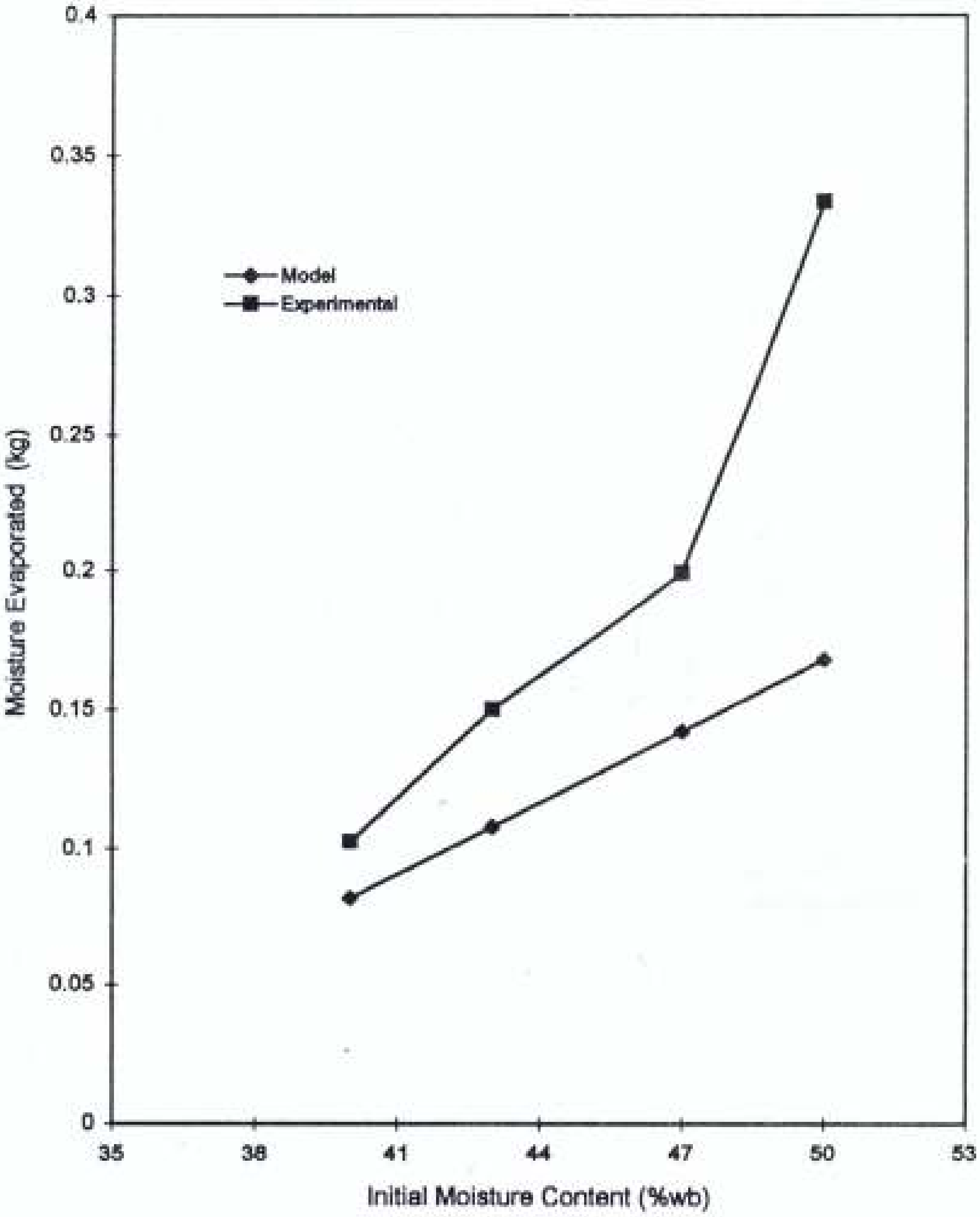


Figure 20. Moisture Evaporated with Mash Initial Moisture Content

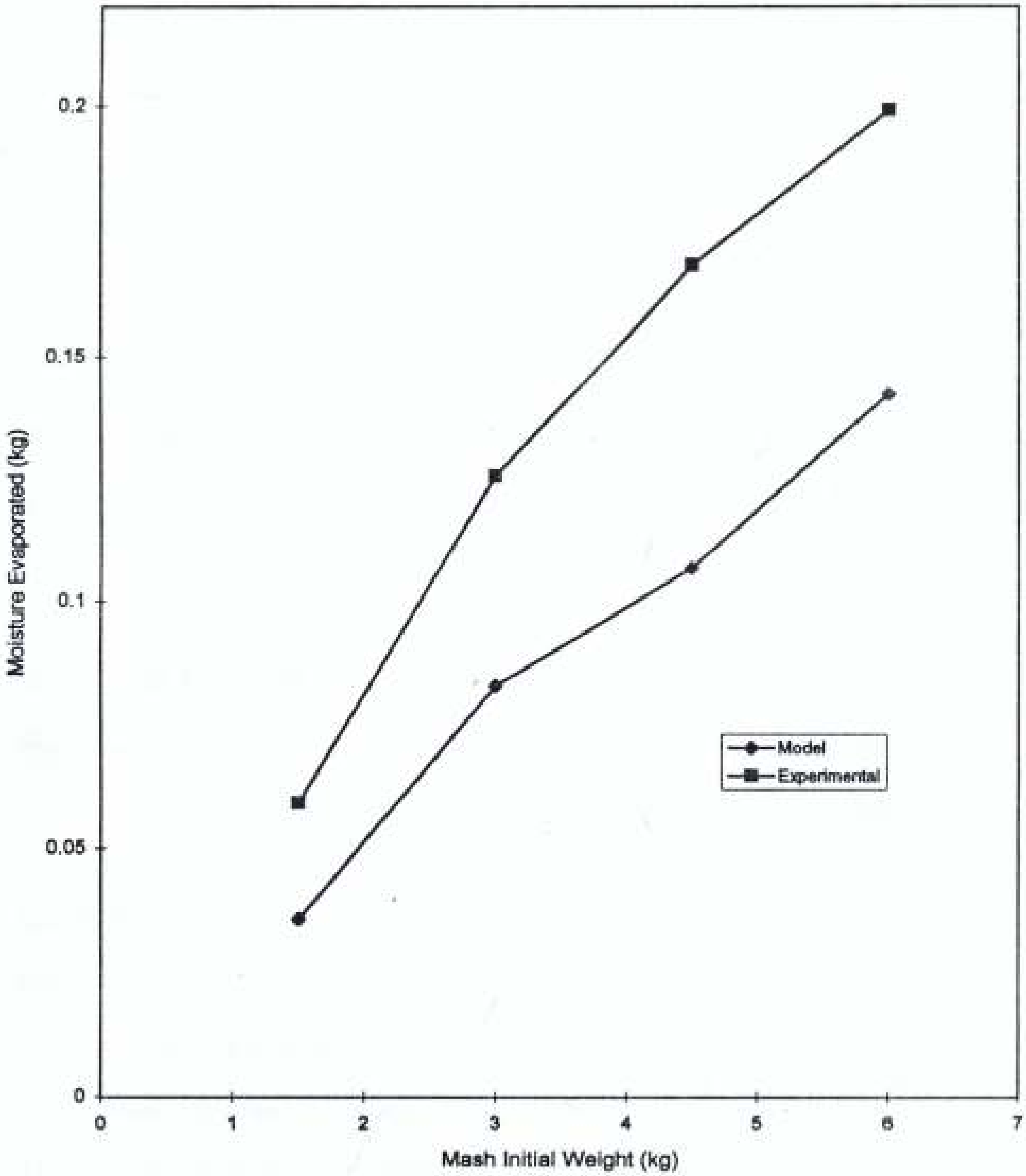


Figure 21. Moisture evaporated with Mash Initial Weight

Table 10. **Drying Rate With Moisture Content**

	M/C	Time(min)	Drying Rates(kg/min)			
	(%wb)		Model	Experimental		
				High	Medium	Low
M_o	47	0	1.68	2.65	1.43	1.64
	39	3	1.68	2.86	1.79	1.64
M_c	30	6	1.68	2.81	2.27	1.64
	22	9	1.53	2.25	2.29	1.64
	17	12	1.44	1.56	1.79	1.60
M_{f1}	13.1	15	0.84	1.15	0.83	0.55
M_e	12.5	17	0.05	1.11	0.65	0.54
M_{f2}	10.9	18	0.02	0.63	0.28	0.56
	9.2	21	0.44	0.54	0.26	0.44

LEGEND

M/C = Moisture content % wb

WTO = Mash initial weight = 6kg

L = Mash thickness = 0.004m

TP = Trough temperature = 160°C

M_c = Critical moisture content (%wb)

M_f = Final moisture content (%wb)

M_e = Equilibrium moisture content (%wb)

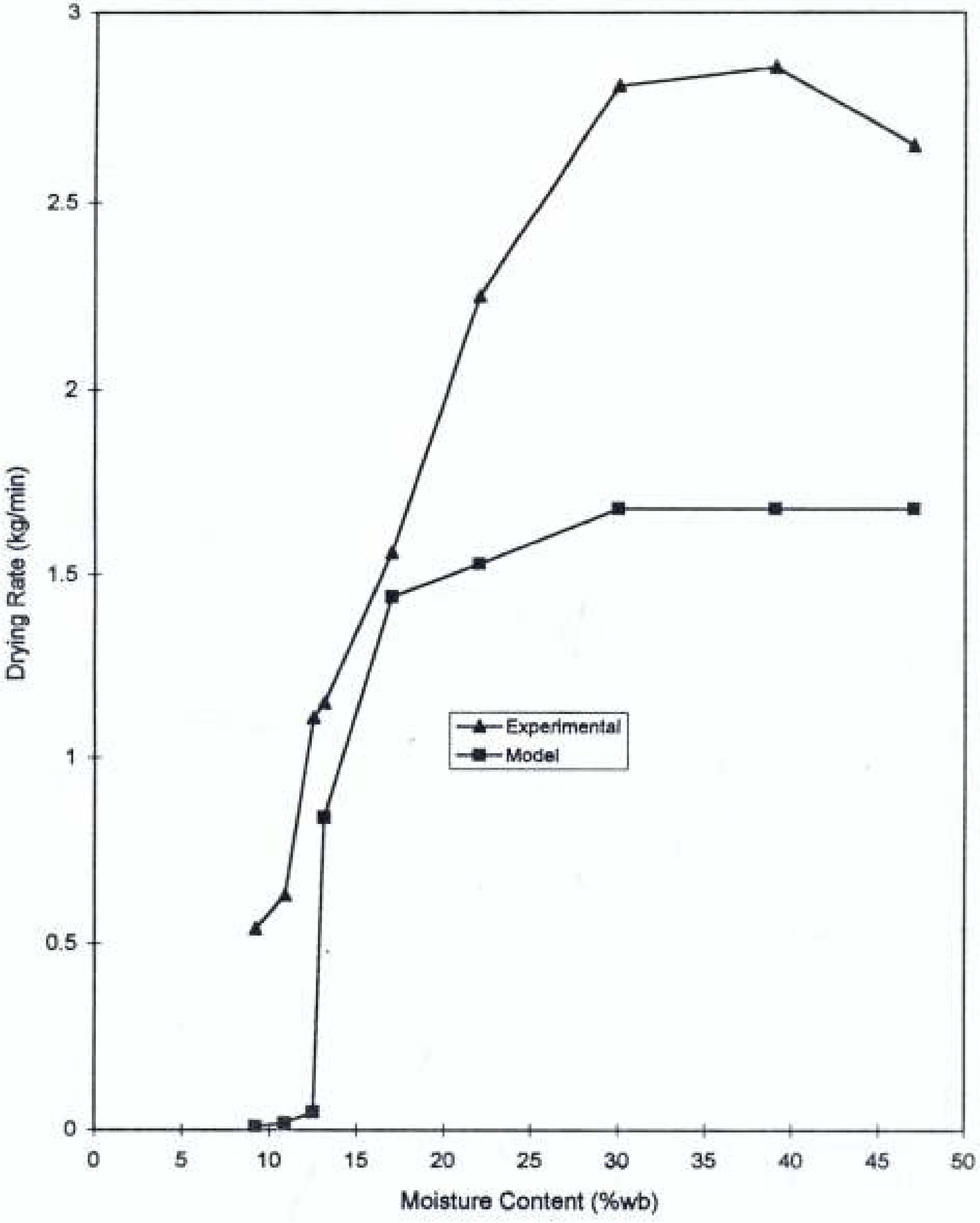


Figure 22. Drying Rate with Mash Moisture Content

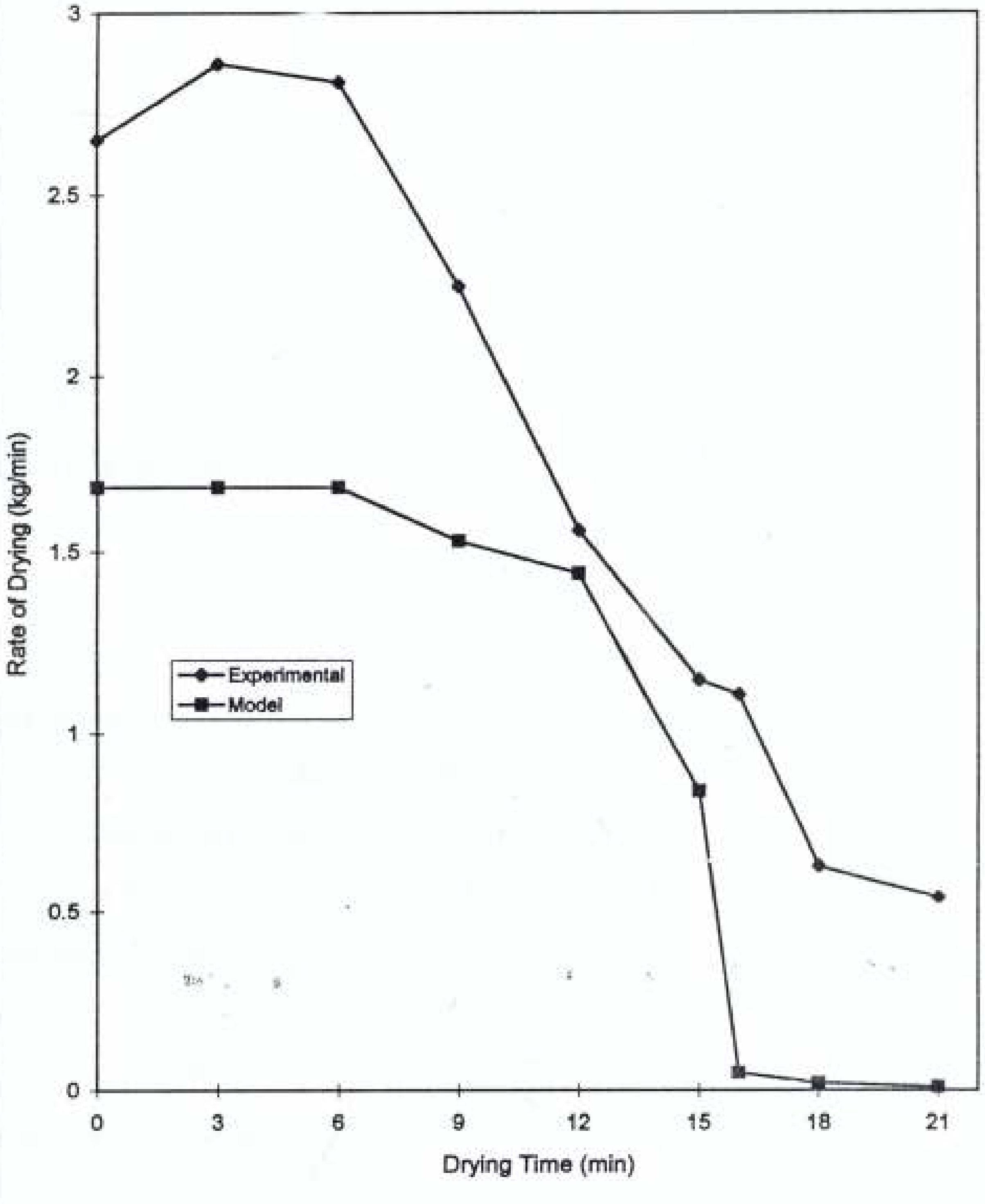


Figure 23. Drying Rate with Drying Time

$$TT = F(W_{To}, TP, L, M_o, M_f) \quad (70)$$

$$TT = -172.009 + 51.09766W_{To} - 0.67769TP - 16338.2L + 1.697693M_o - 1.25942M_f \quad (71)$$

This showed that when the final moisture content is known, you can predict the time of frying or the time to stop the machine. The analysis of variance, ANOVA as shown in Appendix VI with $R^2 = 0.81$ was performed. The ANOVA shows that F value of 17.57065 is greater than F significant of 1.03E-06 meaning that the relationship is significant and the equation is a good predictor of the frying process with L,the mash thickness as the most sensitive among the parameters having the greatest coefficient.

Table 11. **Performance Evaluation of The Model**

	MODEL	EXPERIMENTAL
Total drying time (TT)	21	22
Constant Period drying rate(kg/s)	2.65	1.68
Falling period drying rate(kg/s)	1.15	1.47
Quantity of Heat transferred (Q/kJ)	1895.824	1591.920
Mass transfer m(kg)	0.1423	0.1992
Heat transfer coefficient h_c (W/m^2K)	0.6254	0.2826
Mass transfer coefficient (k_m)	0.002846	1.67
Rate of heat transfer q(J)	495.32	223.92
Rate of mass transfer N(kg/s)	0.4287	0.3332
Machine Efficiency		72.3%
Correlation cofficient (R^2)		0.99

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

This chapter is divided into three sections, the summary of the work, the conclusion and the recommendation for further work.

6.1 Conclusion

From the result of the experiments performed with the dryer as shown in Tables 1 to 11 and Figures 1 to 20, it was shown that the machine can be a functional one with a performance efficiency of 70.3% which could be useful to the local processors and co-operative societies as well as the medium scale producers. The physical characteristics of the gari produced compared well with the local ones in the market in terms of colour, texture and swelling capacity as well as the final moisture content for a good storage. A good frying was obtained at high heat intensity with q, the rate of heat transfer at 223.82 J/s and h_c, the heat transfer coefficient at 0.2826 W/m²K and an average drying time of 22 minutes to give a final moisture content of 13.2 %wb, a value which is within the range of 9 to 15 %wb as proposed by Odigboh and Ahmed, (1982).

The statistical analysis of the data revealed a strong correlation between the time of frying, the initial moisture content, trough temperature, the thickness of mass, the initial weight and the final moisture content for the high heat frying with $R^2 = 0.81$. The ANOVA table in Appendix VI also support this in that F tabulated (17.57) is greater than F significance(1.03E-06).

From the model, a strong correlation is shown between the drying time and the initial moisture content, temperature and final moisture content than the final moisture content and the temperature, this is supported by Bennet and Myers, (1983). The model output result approximate that of the experimental results thus, the heat and mass transfer model developed can be used to predict the drying time of cassava mash.

6.2 Recommendation

For the perfection of the machine and subsequent usage, the followings are recommended

(i) A data bank should be created from other tests performed on the machine and should be made available to the department for for further work on the machine.

(ii) The inclination angle of the machine should be fixed at 5° and the initial moisture content of the mash should be between 44 - 47 %wb in order not to prolong the drying time and reduce the quality of the dried product.

(iii) A gasoline engine of 0.75 kW could be used to power the machine where there is no electricity, while biogas could be the source of fuel as cooking gas may not be available .

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APPENDIX I

THE COMPUTER PROGRAM

PROGRAM JB01

THIS PROGRAM OBTAIN EVERY DRYING INFORMATION NEEDED AND COMPUTES THE DRYING RATE AND THE DRYING TIME DURING GARI FRYING

```
      PROGRAM JB01
      REAL L,KM,LAMD,MOKG,MCKG,MC,MO,MEV,KD,ME,MC1P,M3
      REAL M2
      CHARACTER NATURE*1
      OPEN(UNIT = 1, FILE='JBPRJ2.OUT',ACCESS = 'SEQUENTIAL')
C
C   OBTAIN THE NECCESSARY INFORMATION AND CONSTANTS FOR MODEL
C
      CALL INFORM(L,RHO,G,TP,TA,ARH,WTO,MO,ME,MC,M3,NATURE,
     +                      LAMD,S,KM,BI,KD,H,SRH)

      CALL PSYCRO(TA,ARH,HA)
      CALL HTQTY(Q1,Q2,Q3,QG,QW)

C
C   FIRST PERIOD COMPUTATION (F1)
C

   55 WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'ENTER FIRST GUESS OF TS'
C     READ(*,*) TS
      TS = 30

      IF(TS.LT.0) WRITE(*,100)
      IF(TS.GT.99) WRITE(*,200)
      IF(TS .GT. 99 .OR.TS .LT. 0) GO TO 55

      WRITE(1,*) 'YOUR INITIAL GUESS OF TS =', TS
  100 FORMAT(///'SORRY! TS SHOULD NOT BE LESS THAN 0 DEGREE')
  200 FORMAT(///'SORRY! TS.SHOULD NOT BE MORE THAN 99 DEGREE')
  3   CONTINUE
      CALL PSYCRO(TS,SRH,HS)

      A = KM*(TP-TS)/L
      B = H*(TS-TA)
      C = H*(HS-HA)*LAMD/S
      RES = A-(B+C)
C     WRITE(*,*)'A = ', A
C     WRITE(*,*)'B = ', B
C     WRITE(*,*)'C = ', C
C     WRITE(*,*)'RES = ',RES
      IF(ABS(RES).LT.10) GO TO 2
      IF(RES.GT.10) TS = TS + 0.01
      IF(RES.LT.-10) TS = TS - 0.01
      GO TO 3
    2 CONTINUE
      WRITE(*,*)
      WRITE(*,*)
```

```
      WRITE(1,*) 'THE CORRECT TS AT STAGE 1 = ',TS
      WRITE(*,*) 'THE CORRECT TS AT STAGE 1 = ',TS
      TS1 = TS
      WRITE(*,*)TS1
      F1 = H*(HS-HA)/S
C     WRITE(*,*)
C     WRITE(*,*)' F1 = ',F1

      MOKG =  WTO*(MO/(MO+100))
C     WRITE(*,*)' MOKG =',MOKG

      MCKG =  (WTO-MOKG)*(MC/100)
C     WRITE(*,*) 'MCKG = ', MCKG

      MEV = MOKG-MCKG
      MEV=MEV/10
      WRITE(*,*)  'MEV   = ' , MEV
      WRITE(1,*) 'MEV    = ' , MEV
      VOL = (WTO - MOKG)/RHO
      SAREA = VOL/L
C     WRITE(*,*) 'SAREA =',SAREA

      DRT1 = MEV/(F1*SAREA)
      DRT1 = DRT1/60.0
      DRT1=DRT1*10
C     WRITE(*,*)' DRT1 =', DRT1

      T1 = DRT1
      WRITE(*,*)
C     WRITE(*,*)'THE TIME FOR THE FIRST STAGE =',T1

C
C  2ND STAGE COMPUTATION (F2)
C

   33 CONTINUE
      CALL PSYCRO(TS,SRH,HS)
      A = KD*(TP-TS)/L
      B = H*(TS-TA)
      C = H*(HS-HA)*LAMD/S
      RES = A-(B+C)
C     WRITE(*,*)'A = ', A
C     WRITE(*,*)'B = ', B
C     WRITE(*,*)'C = ', C
C     WRITE(*,*)'RES = ',RES
      IF(ABS(RES).LT.10) GO TO 22
      IF(RES.GT.10) TS = TS + 0.1
      IF(RES.LT.-10) TS = TS - 0.1
      GO TO 33
   22 CONTINUE
      WRITE(*,*)
      WRITE(*,*)
      WRITE(1,*) 'THE CORRECT TS AT STAGE 2 = ',TS
      WRITE(*,*) 'THE CORRECT TS AT STAGE 2 = ',TS
```

```
      TS2=TS
C     WRITE(*,*)'TS2=',TS
C
C  TO COMPUTE FE OF EVAPORATION
C
C     TP = 80
      CALL PSYCRO(TP,SRH,HP)

      FED = H*(HP-HA)/(S*(1+BI))
      FEE = H*(HS-HA)/S

      IF( FED .LT. 0 .OR. FEE .LT. 0) GO TO 16
      IF( FED .LE. FEE) FE = FED
      IF( FEE .LE. FED) FE = FEE
      GO TO 17

   16 IF( FED .LT. 0 .AND. FEE .GT. 0) FE = FEE

      IF( FEE .LT. 0 .AND. FED .GT. 0) FE = FED

      IF( FEE .LT. 0 .AND. FED .LT. 0)  FE = 0
   17 CONTINUE
C      WRITE(*,*)'********', FED,FEE,FE

      CC = MC/100.0
      IF(NATURE.NE.'H') GO TO 41
      FC = F1
      C1P = 0.4 * CC
      MC1P  = C1P * (WTO-MOKG)
      T11 = (MOKG-MC1P)/(FC*SAREA)
      T11 = T11/60.0
C     WRITE(*,*) 'TIME AT 2ND CRITICAL POINT = ',T11
      GOTO 42

   41 CONTINUE

      FC = F1
      C1P = CC
   42 CONTINUE

      FSS = FE/(FC-FE)

      C2 = CC/3.0
C     WRITE(*,*)' C2 = ', C2
C
C FIBROUS OPTION
C
      IF(NATURE .NE. 'F') GO TO 43

      T11 = 0
      FN = 0.5
      TH1 = 2*L*RHO*(CC **0.5)*FSS/FE
      TH2 = CC **0.5 - C2**0.5
      TH3 = FSS * CC **0.5
```

```
      TH4 = CC **0.5 + FSS*CC **0.5
      TH5 =  C2**0.5 + FSS*CC **0.5
      THETA2 = TH1 * (TH2 - TH3 * ALOG(TH4/TH5))
      GO TO 44
   43 CONTINUE
C
C  HYGROSCOPIC OPTION
C
      FN = 1
      TH1 = L*RHO*C1P
      TH2 = FC - FE
      TH3 = FC * C1P
      TH4 = (FC-FE)*C2
      TH5 =  FE*C2

      THETA2 = (TH1/TH2) * ALOG (TH3/(TH4+TH5))

      CONTINUE


   44 F2 = (FC-FE)*(C2/C1P)**FN + FE
      RMIN = 60.0
      THETA2 = THETA2/RMIN
      T2 = THETA2

C     WRITE(*,*) THETA2,F2

C
C COMPUTATION OF F3
C
      CE = ME/100.0
      C3 = M3/100.0
      F3 = F2

      TH1 = L*RHO*(C2 - CE)/F3
      TH2 = C2-CE
      TH3 = C3-CE

C     WRITE(*,*)'CE=',CE
C     WRITE(*,*)'C2=',C2
C     WRITE(*,*)'C3=',C3

C     WRITE(*,*)'TH1=',TH1
C     WRITE(*,*)'TH2=',TH2
C     WRITE(*,*)'TH3=',TH3

      IF(TH2.EQ.0) TH2 = 10E-20
      IF(TH3.EQ.0) TH3 = 10E-20

      THETA3 = TH1*ALOG(TH2/TH3)
      THETA3 = THETA3/RMIN
      T3 = THETA3

C     WRITE(*,*) THETA3, F3
```

```
      TT =  T1 + T11 + T2 + T3
      WRITE(*,*)'Q1=',Q1
      WRITE(*,*)'Q2=',Q2
      WRITE(*,*)'Q3=',Q3
      WRITE(*,*)'QW=',QW
      WRITE(*,*)'QG=',QG

C     WRITE(*,*)' TP = ', TP
C     WRITE(*,*)' H = ', H
C     WRITE(*,*)' L = ', L
C     WRITE(*,*)' WTO= ', WTO
      WRITE(*,*)' MO = ', MO
      WRITE(*,*)' MEV = ', MEV
C     WRITE(*,*)' T1 = ', T1
C     WRITE(*,*)' T11 = ', T11
C     WRITE(*,*)' T2 = ', T2
C     WRITE(*,*)' T3   =   ', T3
C     WRITE(*,*)' TT = ', TT

      WRITE(*,*)' FC = ', FC
C     WRITE(*,*)' F1 = ', F1
C     WRITE(*,*)' F2 = ', F2
      WRITE(*,*)' F3 = ', F3
      WRITE(*,*)' FE = ', FE
      WRITE(*,*)' MC = ', MC
      WRITE(*,*)' M3 = ', M3
      WRITE(*,*)' ME = ', ME
      WRITE(*,*)'TS1=',TS1
      WRITE(*,*)'TS2=',TS2
      WRITE(1,*)
      WRITE(1,*)' FC = ', FC
      WRITE(1,*)' F1 = ', F1
      WRITE(1,*)' F2 = ', F2
      WRITE(1,*)' FSS = ', FSS
      WRITE(1,*)' F3 = ', F3
      WRITE(1,*)' FE = ', FE
      WRITE(1,*)
      WRITE(1,*)' MC = ', MC
C     WRITE(1,*)' M2 = ', M2
      WRITE(1,*)' M3 = ', M3
      WRITE(1,*)' ME = ', ME

C     WRITE(1,*)' CC = ', CC
      WRITE(1,*)' C1P = ', C1P
C     WRITE(1,*)' C2 = ', C2
C     WRITE(1,*)' C3 = ', C3
C     WRITE(1,*)' CE = ', CE
      WRITE(1,*)
      WRITE(1,*)' T1   =   ',T1
      WRITE(1,*)' T11   =   ', T11
      WRITE(1,*)' T2   =   ', T2
      WRITE(1,*)' T3   =   ', T3
      WRITE(1,*)
      WRITE(1,*) 'THE TOTAL DRYING TIME =', TT
```

```
      STOP
      END
     *
      SUBROUTINE INFORM(L,RHO,G,TP,TA,ARH,WTO,MO,ME,MC,M3,NATURE,
     +                   LAMD,S,KM,BI,KD,H,SRH)

      REAL L,KM,LAMD,MOKG,MCKG,MC,MO,MEV,KD,ME,M3
      CHARACTER NATURE*1
C     WRITE(*,*)'INPUT THE THICKNESS'
C     READ(*,*) L
      L = 0.004
C     WRITE(*,100)
C     WRITE(*,*)'INPUT THE DENSITY OF THE MASH'
C     READ(*,*) RHO
      RHO = 441.3

C     WRITE(*,*)'INPUT THE MASS VELOCITY OF AIR'
C     READ(*,*) G
      G = 0.02
      H = 14.3*G**0.8

      WRITE(*,100)
      WRITE(*,*)'INPUT THE STEADY STATE TEMPERATURE OF THE FRYER'
C     READ(*,*) TP
      TP = 160

      WRITE(*,100)
C     WRITE(*,*)'INPUT ATMOSPHERIC TEMPERATURE ABOVE THE FRYER'
C     READ(*,*) TA
      TA = 40

      WRITE(*,100)
C     WRITE(*,*)'INPUT ATMOSPHERIC RELATIVE HUMIDITY ABOVE THE
FRYER'
C     READ(*,*) ARH
      ARH = 50

      WRITE(*,100)
C     WRITE(*,*)'WHAT IS THE INITIAL WEIGHT OF THE MASH (KG)'
C     READ(*,*) WTO
      WTO = 4.5

      WRITE(*,100)
   11 CONTINUE
C     WRITE(*,*)'INITIAL MOISTURE CONTENT OF THE MASH (% DRY
BASIS)'
C     READ(*,*) MO
      MO = 88.68

C     WRITE(*,*)'EQUILIBRIUM MOISTURE CONTENT (% DRY BASIS)'
C     READ(*,*) ME
      ME = 14.3

C     WRITE(*,*)'CRITICAL MOISTURE CONTENT (% DRY BASIS)'
```

```
C     READ(*,*) MC
      MC = 43.9

C NOTE THAT MC MUST BE MUCH MORE GREATER THAN ME!!!!

      WRITE(*,100)
C     WRITE(*,*)'FINAL MOISTURE CONTENT (% DRY BASIS)'
C     READ(*,*) M3
      M3 = 15.0

      IF(M3.GE.ME) GO TO 12

      WRITE(*,100)
      WRITE(*,112)
      WRITE(*,113) ME

  112 FORMAT('SORRY! THE FINAL MOSTURE CONTENT MUST NOT')
  113 FORMAT('BE LESS THAN THE EQUILIBRIUM CONTENT =',F5.1)

      WRITE(*,*)
      GO TO 11
   12 CONTINUE

      WRITE(*,100)
      WRITE(*,*) 'TREAT THE GAARI AS FIBER OR HYGROSCOPIC? [F/H]'
      WRITE(*,*) 'Enter F for Fiber and H for Hygroscopic'
C     READ(*,'(A)') NATURE
      NATURE = 'H'

      WRITE(*,100)
      IF(NATURE.NE.'F'.AND. NATURE.NE.'H') GO TO 12
      IF(NATURE.EQ.'F') WRITE(1,10)

      IF(NATURE.EQ.'H') WRITE(1,15)
      WRITE(1,20)
   10 FORMAT('THIS IS THE RESULT FOR FIBROUS OPTION')
   15 FORMAT('THIS IS THE RESULT FOR HYGROSCOPIC OPTION')
   20 FORMAT('=====================================')
      LAMD = 2.3E6
      S = 1300
      KM = 0.24
      BI = 35
      KD = 0.06
      H = 14.3*G**0.8
      SRH = 100

  100 FORMAT(//////////)
      RETURN
      END

     *
      SUBROUTINE PSYCRO(TP,RH,
      A0 =  0.00679499
      A1 = 0.000195316
```

```
      A2  =  3.38269E-005
      A3  =  -2.96726E-007
      A4  =  9.4457E-009
C     WRITE(*,*)'ENTER TEMPERATURE AND RELATIVE HUMIDITY'
C     READ(*,*) TP,RH
      PW  =  A0 + A1*TP + A2*TP**2 + A3*TP**3 + A4*TP**4
      HS  =  (18*PW)/(29*(1-PW))
      H  =(RH * HS) / 100
C     WRITE(*,*) TP, PW, H
      RETURN
       END
      *
      SUBROUTINE HTQTY (Q1, Q2, Q3, QG, QW)
      QGV  =  1676
      HV  =  50058553.0
      K  =  45.3522
      A  =  2.2619
      DTF  =  132.0
      RL  =  0.002
      MF  =  20.0
      CF  =  450.0
      MM  =  6.0
      CM  =  4140.0
      DTM  =  67.0
      MW  =  0.0987
      LAMDA  =  2087000.0
      MA  =  0.3786
      CA  =  1005.0

C     VC  =  PI*R**2  =  0.3394
C     VG  =  M/RHO  =  6/441.3  =  0.01360
C      VA  =  VC - VG = 0.3394-0.0136 = 0.3258
C       MA  =  RHO A*VA = 1.1650*0.3258 = 0.3796

      QTC  =  (K*A*DTF)/RL
      QRF  =  MF*CF*DTF
      QG  =  MM*CM*DTM
      QW  =  MW*LAMDA
      QW  = 0.987*LAMDA
      QA  =  MA*CA*DTM
      QA  =  0.3796*CA*DTM

      HEAT ABSORBED BY THE GARI EQUALS
      Q  =  QG+QW+QA

      WRITE(*,*)  QTC, QRF
      WRITE(*,*)  QG, QW, QA
      WRITE(*,*)  Q

      RETURN

      END
```

APPENDIX II **Values of Quantity of Heat Transferred during gari frying (J)**

	HIGH	MEDIUM	LOW
Q_{TC}	6770421.32	3795539.22	2410680.32
Q_{RF}	1188000.00	666,000	423000
Q_G	1664280	1415880	1018480
Q_W	205,986.90	211204.4	412808.60
Q_A	25557.47	21745.39	15641.42
$Q_{TM} = Q_G + Q_W + Q_A$	1985824.37	1648829.79	1446890.02
G	0.02	0.018	0.015
$h_c = 14.3\ G^{0.8}$	0.6254	0.5148	0.4968
Pred. h_c	0.6254	0.5148	0.4968
Exptal. h_c	0.2826	0.4545	0.5455
Pred q	495.32	255.21	140.10
Exptal. q	223.82	201.80	153.83
Pred k_m	0.002846	-	-
Exptal. K_m	1.67	-	-
Mev pr	0.1423	-	-
Exptal. Mev	0.1992	-	-

LEGEND.

Q_{TC} = Quantity of heat conducted by the trough (J)

Q_{RF} = Quantity of heat retained by the fryer (J)

Q_A = Quantity of heat absorbed by the gari mash (J)

Q_w = Quantity of heat absorbed by water (J)

Q_A = Quantity of heat absorbed by air (J)

Q_{TM} = Quantity of heat transferred to the mash (J)

Q_{AC} = Quantity of heat retained by air gari at end of frying (J)

G = Mass velocity of air m^2/s

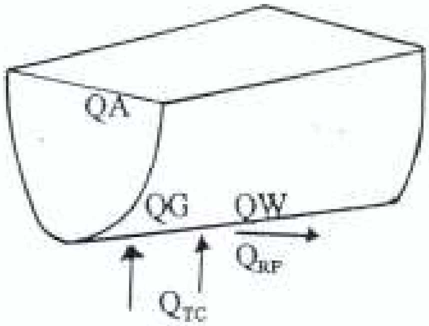
h_c = Coefficient of heat transferred, W/m^2K

q = Rate of heat transferred J/s

k_m = Coefficient of mass transferred

Mev = Moisture evaporated (kg)

APPENDIX II CONTD.



Q_{TC} = KADT/L K = 45. 3522 W/mK

A = 2.2619 m^2

DT= 160 - 28 = 132

L = 0.002 m

Q_{RF} = MCDT M = 20kg

C = 450 J

DT = 132K

Q_G = MCDT M = 6 kg

C = 4140J

DT = 95-28 = 67K

Q_W = Mλ M = 0.0987kg

λ = 2,08,7,000J/kgK

Q_A = MCDT Vc = $\pi r^2 L$ = 0.3394m^3

Vg = m/ρ =6/441.3 = 0.01360m^3

Va = Vc - Vg = 0.3394 - 0.01360 = 0.3258m^3

Ma = ρaVa = 1.1650 x 0.3258 = 0.3796kg

M = 0.3796kg

C = 1005J/kgK

DT = 95-28 =27K

Q_{CH4} = 50,0055J

T_x = Temperature at Spot x = 0, 30, 60

$T_y = \frac{T_x\,(k)}{Y}$ y = 0, 60, 120

Tn = $\sqrt{T_x^2 + T_Y^2}$

q = $\frac{T_Y}{Tx}$

Direction = $\tan^{-1}\theta$

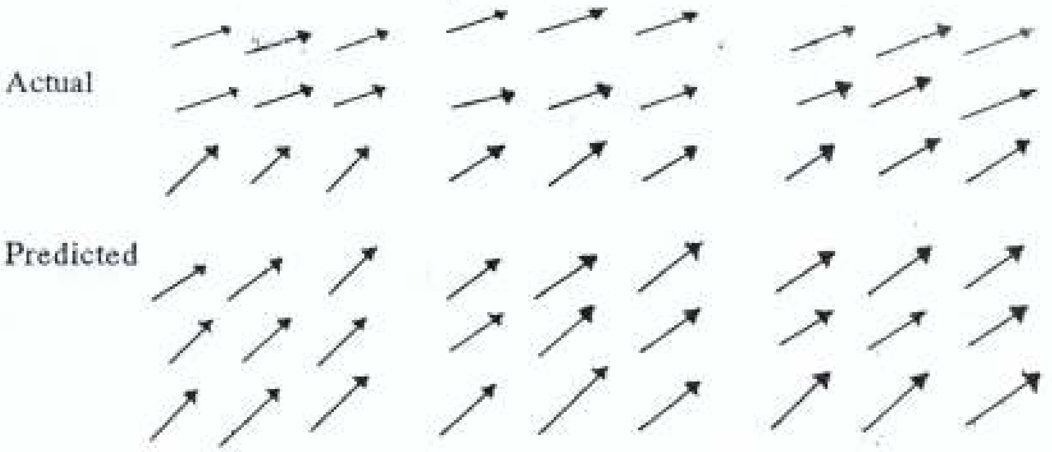
APPENDIX III Temperature History of the Mash (^{o}C)

HEAT INTENSITIES

	HIGH			MEDIUM			LOW		
Actual	60	60	60	51	51	51	39	39	39
Trough	95	95	95	85	85	85	69	69	69
Temp.	160	160	160	102	102	102	75	75	75
Predicted	65	61	60	54	57	51	42	39	39
Trough.	121	102	96	108	91	87	88	74	70
Temperatuе	416	249	186	265	150	119	195	117	88

DIRECTION OF HEAT (degree)

	06	06	06	06	06	06	06	06	06
Actual	11	11	11	11	11	11	11	11	11
	31	31	31	31	31	31	31	31	31
	22	11	06	21	11	06	22	12	06
Predicted	38	22	11	37	22	11	39	22	11
	67	50	31	67	50	31	67	50	31



APPENDIX IV **Drying Characteristics of the Mash**

Air Temperature (°C)	30
Relative Humidity RH %	79
Mash Inlet Temperature (°C)	28
Mash Saturated Temperature (°C)	95
Mash Outlet temperature (°C)	90
Dryer's Temperature (°C)	160
Average Drying Time (min)	22
Mass of Wet Mash (kg)	6.0
Mass of Dry Gari (kg)	5.8008
Moisture Evaporated (kg)	0.1992
Mash Flow rate (m/s)	$1.19\text{x}10^{-3}$
Gas Flow rate	
High (gmin^{-1})	83.3
Medium (gmin^{-1})	73.3
Low (gmin^{-1})	60.2
Physical	
Moisture Content, %	10.13 (9.2)
Bulk Density kgm^{-3}	507.9
Angle of Repose, (°)	34.8
Coefficient of Friction	0.22
Colour	Creamy
Average Diameter (mm)	1.09
Swelling Capacity	2.96
Thermal	
Specific Heat Capacity (C) kJ/kgK	2.01
Thermal Conductivity (k) W/mK	0.06
Thermal Diffusivity (α) x 10E-06 m^2/s	0.0588

APPENDIX V: **Simulation of the Modelling Time (TT) with the Drying Characteristics**

Y	X_1	X_2	X_3	X_4	X_5
TT	WTO	TP	L	M_o	M_p
20.71	6	160	0.004	47	17
20.95	6	160	0.004	47	16
20.97	6	160	0.004	47	15
21.00	6	160	0.004	47	14
23.66	6	160	0.004	47	13
91.03	6	100	0.004	47	12.5
63.09	6	110	0.004	47	12.5
46.46	6	120	0.004	47	12.5
36.03	6	130	0.004	47	12.5
29.05	6	140	0.004	47	12.5
24.22	6	150	0.004	47	12.5
18.03	6	170	0.004	47	12.5
15.97	6	180	0.004	47	12.5
14.28	6	190	0.004	47	12.5
12.95	6	200	0.004	47	12.5
13.35	6	160	0.004	40	12.5
14.34	6	160	0.004	41	12.5
15.37	6	160	0.004	42	12.5
16.43	6	160	0.004	43	12.5
17.53	6	160	0.004	44	12.5
18.67	6	160	0.004	45	12.5
19.85	6	160	0.004	46	12.5
22.35	6	160	0.004	48	12.5
23.68	6	160	0.004	49	12.5
25.05	6	160	0.004	50	13
21.08	6	160	0.004	47	13

ANOVA Table

SV	df	SS	MS	F	Sign. F.
Regression	5	6045.029	1209.006	17.57065	1.03E-06
Residual	20	1376.165	68.80827		
Total	25	421.195			

Significant $F_{5,20}$ at $P \leq 0.05$ Level

REGRESSION EQUATION

$$TT = -172.009 + 51.09766W_{To} - 0.67769TP - 16338.2L + 1.697693M_o - 1.25942M_F$$

$R^2 = 0.81$

where

TT = Total drying time, min

W_{TO} = Initial weight of the cassava mash, kg

TP = Frying trough temperature, K

L = Mash thickness in the frying trough, mm

M_o = Mash initial moisture content, %wb

M_F = Mash final moisture content, %wb