DETERMINATION OF THE THERMAL CONDUCTIVITY OF AGRICULTURAL WASTE (GUINEA CORN STALK AND RICE STRAW) USING LINE HEAT SOURCE TECHNIQUE

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SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY DEPARTMENT OF AGRICULTURAL ENGINEERING FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING.

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DEDICATIONS.

I dedicate this work to God and my parents (Mr. And Mrs. Omoregie) for standing by me in most turbulent times of my academic setback. And making sure my academic dreams becomes a reality. And also my elder sister courage for the additional financial and moral support. May God always put you all in his book of favours. God bless you all.

CERTIFICATION

This is to certify that this project was carried out by OMOREGIE RICHARD OSABUOHEN in the department of Agricultural Engineering, Federal University of Technology, Minna.

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ABSTRACT

The thermal conductivity of rice straw and guinea corn stalk was determined experimentally using line heat source technique. The line heat source technique apparatus consist of two parts. Firstly the electrical circuit which includes a copper/Constantine thermocouple with hot and cold junction, a millivoltmeter, a 24 guage nichrome resistance wire with resistance of 43 ohms and 8cm long, a 12 volt d.c supply, switch, ammeter and rheostat. The second part is the housing unit which protects the tested material from environmental influence. This consists of a square ply wood box. At the inner side of the box are two wooden detachable battens 10cm fixed to each ends of the two adjustable screwing bolts to enable a tight grip. The working condition of the apparatus was tested on white potatoes and peeled unriped plantain. The results corresponded with values obtained from literature. The experiment was replicated three times for rice straw to produce a mean thermal conductivity of 0.1337 w/m^0c and mean moisture content of 21.8% while guinea corn stalk was replicated two time to produce a mean thermal conductivity of 0.1583 w/m^0c and mean moisture content of 22.72%. Another value for the thermal conductivity of a single sample of guinea corn stalk at different moisture content to produce a mean thermal conductivity of 0.1598 w/m^0c and mean moisture content of 25.09%.

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NOTATIONS

A	=	Cross - Sectional area M2 or a constant
Ar		Surface are M^2
Bi		Biot member for heat transfer
C	=	Specific heat at constant pressure, $Jlkg^0c$
D	=	Diameter of a material, mm. Cm or M
H	=	Unit Surface Conductance
K	=	Bulk, apparent or particle thermal conductivity W/M^0c
L	=	Length of sample, cm
q		Constant strength line heat source of heat flux, W
Q		Quantity of heat energy, J
R		Thermal resistance, $^0c/W$
S	=	Slope
T_1	=	Observed initial temperature, ^0c
T_2	=	Observed Final temperature, ^0c
t	=	Time (min)
t_1	=	Time at point (1) on a plot
t_2		Time at point (2) on a plot
m c		Moisture Content

CHAPTER ONE

1.1 INTRODUCTION

Nature of Problem

Agricultural products, finished, unfinished, waste material or consumable have specific useful properties if well exploited to the benefits of man. Agricultural waste have been under exploited as per the versatility of their uses or functions.

For total exploitation of agricultural products. A knowledge of their thermal characteristics such as specific heat, thermal conductivity, thermal diffusivity surface conductance, emissivity as well as physical characteristics as density, shape and size are essential for the design of any equipment for predicting or measurement of thermal conductivity of Agricultural products.

Research work have shown that thermal properties solid grains is related to drying and storage (Storage time and structures) (Kazarian and Hall 1965 otten et al 1980). From the foregoing there is an obvious evidence that in the design and analysis of numerous machine process and systems involving heat treatment of Agricultural products. The need for thermal conductivity value is not only a necessity but a means to an end (Onuachu A.C. 1992).

There is urgent a need to provide the thermal conductivity of rice straw and guinea corn stalk. Thermal conductivity of a material can be defined as the amount or quantity of heat that can flow through it. This will help especially in the area of waste recycling. Most of the rice straw and guinea corn stalk that litter around as waste can be used for productions of useful materials e.g particle board, insulating materials, etc. It is important to know the amount of heat that can pass through or amount of heat that the materials can withstand, since there are used for insulating material.

Rice straw and guinea corn stalk are very important and cheap agricultural waste product. This is so because rice and guinea corn are very important diet in Nigeria. Which makes them readily available, both have very good insulating properties when dried.

It is to be noted that in this present study use was made of equipment used by Ijabo (1984) who worked on the determination of thermal conductivity of corn cob using line heat source technique.

1.2 Objectives and Scope of Study

The objectives of the present include:

1. To use line heat source technique to determine the thermal conductivity of guinea corn stalk and rice straw.

2. To obtain experimentally the apparent thermal conductivity values for guinea corn stalk and rice straw.

3. To evaluate the effect of moistuie content on thermal conductivity.

1.3 Justification

Measurement of the thermal conductivity of agricultural materials have lagged behind thermal conductivity measurements for engineering materials due to inherent variability of agricultural properties, difficulties in Using standard conductivity measurement techniques and rapid increase in the variety of the produce. This lagging behind has created room for the under utilisation of agricultural produce compared to the increase utilisation of engineering materials such as steel, iron, copper etc.

It is important to note that in the design of a line transfer equipment and processes for agricultural produce. The engineer must have a vivid knowledge of the agricultural material, and the thermal properties of the products involved. But the engineer must also know the rate of heat transfer for efficient design. The rate depends upon the thermal conductivity of the products.

It is known that all agricultural produce have their season of harvest. Which therefore does not make them readily available all through the year. The research into finding the thermal conductivity of rice straw and guinea corn stalk will help the growth of locally constructed storage structures. Agricultural waste materials like rice straw and guinea corn stalk are also having some industrial uses as insulator and particle board production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 <u>Nature and Brief Explanation of Terms</u>

Designing and equipment for determining the thermal properties of bulk agricultural products depends on the following:-

1. Specific heat capacity
2. Heat conductivity
3. Temperature gradient
4. Type of Heat Transfer Medium

This is so because it will enhance the engineer in attaining or achieving his goal for designing and fabrication of heating equipment or machine. Another vital factor to consider is the unsteady (transient) heat transfer in bulk agricultural product is totally different from non- agricultural products such as metals.

2.1.I <u>Biot Number Or Biot Modulus (Bi)</u>

Biot number is a dimensionless parameter which designates some characteristic dimension to the material. The biot number compares the relative magnitude of surface convection and internal conduction resistance to heat transfer.

A very low value of biot number means that internal condition resistance is negligible in comparison with the surface convection resistance. This is turn implies that the temperature will nearly be uniform throughout the solid.

Bi	=	hi / k ----------------------------	(1)
h	=	unit surface conductance	
i	=	Length of material in metres	
k	=	Thermal conductivity	

When biot Bi for bio-materials is greater than 0.1, distributed system applied either in the form of finite surface, internal resistance or both where the above terms retain their usual meaning (IJABO, 1984).

2.1.2 Thermal Diffusivity

Thermal diffusivity of a material is the rate at which heat is diffused in a material. It can be mathematically expressed as α = K

α	=	Thermal diffusivity m^2/s
K	=	Thermal conductivity w/m^0c
Cp	=	Specific heat at constant pressure j/kg^0c
ρ	=	Density, kg/m^3

The larger the value of α, the faster heat will diffuse through the material. This may be seen by examining the quantities which make up α. A higher value of α could result either from a high value of thermal conductivity which would indicate a rapid energy transfer rate, or from a low value of the thermal heat capacity Cp. A low value of the heat capacity would mean that less of the energy moving through the material would be absorbed and sued to raise the temperature of the material. Thus more energy would be available for further transfer.

2.1.3 **Unit Surface Conductance**

The unit surface conductance is also the convection heat transfer coefficient. The heat transfer coefficient is sometimes called the film conductance because of it's relation to the conduction process in the this stationary layer of fluid at the wall surface.

The convection heat transfer coefficient depends on the visconsity of the fluid in addition to it's dependence on the thermal properties of the fluid (Thermal Conductivity, Specific heat, density). This is so because visconsity influences the velocity profile and, corresponding energy transfer rate in the region near the wall.

$Q = hA\Delta t$ -------------------- (3)

Where:

Q = quantity of heat

H = unit surface conductance

A = Surface area, m^2

Δt = temperature rise, ^oC

2.1.4 **Thermal Conductivity**

When the temperature gradient dt/dx, between two surfaces through which heat is flowing is unity. The quantity of heat (q) that will flow in with tune across unit area (A) is called the thermal conductivity (k),the S.I unit is w/m^{o}h. Thermal conductivity (k) of some engineering materials varies with the material temperature and moisture content.

Hence, biological materials known to be non-homogeneous and of varying cellular structure, composition and air content will give variation in thermal conductivity for non-bio materials. This property plays a central role in heat propagation within a solid medium.

2.1.5 **Specific Heat**

The quantity of heat required to change the temperature of a unit mass of material by 1^{o}C is called the specific heat of the body.

$$Cp = \frac{Q}{\rho V \Delta t} \quad \text{------------------------- ----(4)}$$

Cp = Specific heat J/Kg

ρ = Density Kg/m^3

V = Volume m^3

Δt = Temperature rise in

Q = Quantity of heat in watts.

This thermal property can be given either as specific constant volume (cv), or a specific constant pressure (Cp) depending on how heat is stored in the materials.

2.2 Techniques For Determining Thermal Conductivity of Agricultural Products

Systems for measuring thermal properties of good produce have been reviewed and analysed by (Reidy and Rippen 1971). The analysis was limited to method for measurement of thermal conductivity. Research have shown that there are about ten (10) methods of measurement of thermal conductivity employed by various researchers for agricultural and bio-materials (Mohsenin 1980). The available methods may be divided into two categories:-

1). Steady-state

2). Unsteady state (Transient)

Note that measurement of the thermal conductivity of agricultural material is very difficult and error is subjected the methods used.

2.2.1 Steady State (Approximation Methods)

There are three steady state methods that are employed (i) parallel plate (ii) concentric cylinders (iii) concentric spheres.

Parallel Plate:

The parallel plate concentric cylinder and concentric spheres can fall either into longitudinal heat flow or radial heat flow methods.

Longitudinal Heat Flow Methods:

This makes use of the parallel plate. The parallel plate makes use of guarded hot plates which is widely used for the measurement of thermal conductivity of poor conductors of heat is typical of this category; since the method is most suitable for dry homogeneous specimen.

Radial Heat Flow Method:

This method involves the concentric cylinder and the concentric sphere.

The radical heat flow methods are suitable for stab speciments (viscons, semi-liquid or mud). The radical heat flow techniques are used for conductivity measurement of loose, uncolidated, powder or granular materials. The detail may entail the use of any co-axial cylinders with or without end guards and concentric spheres with central heating source. These are some of the earliest know method utilized in the measurement of thermal conductivity of grains (Mohsenin 1980).

The source of error and techniques for minizing error have been analysed and discussed by Reidy and Rippen (1971). In general these authors pointed out the advantages and disadvantages of this method.

Advantages:

1). Simple mathematical expression

2). Suitability of the methods for dehydrated food

3). Errors can be minimized by use of reference material and the magitude of error due to non-linear heat flow cannot evaluate for the parallel plate method.

Disadvantages

1). These are not acceptable for foods with moisture content above 10%

2). The time required for evaluation of thermal conductivity is very long.

3). An unmeasurable error due to contact resistance between the plate and product.

4). Not all product have an acceptable geometry to fit in any of the mentioned method

5). Heat loss that occur from the test apparatus is unaccounted for.

2.2.2 Non-Steady State Methods:

Transient method for measurement of thermal conductivity of food includes all methods in which the temperature of the product at a given location changes during the experiment. Several investigators, including hurmicz and fisher (1952), kopelman (1960), Dekerson and Vos (1955) have utlised a procedure which involved analysis of the product from the following equations reported by Onuachu (1992).

$$\propto = Ao\, R^2\, (Ts - To) / 4 \qquad \text{-----------------------(5)}$$

Ao = Constant indicating the different temperature changes with time.

Ts = Temperature at the surface of the product.

$\propto$ = Thermal Diffusivity

R = Resistance.

It was assumed that the heating or cooling medium is moving over the product in a manner such that the convective heat transfer co-efficient is infinite.

Transcent methods for measurement of thermal conductivity makes use of either a line heat source or one or more plane source of heat. In either category, the usual procedure is to apply a steady heat flux to the speciment which must have been in thermal equilibrum initially, then the temperature rise at some points in the sample resulting from applied flux measured. The advantages includes the following.

1). Less complicated

2). Much simplier than the steady state method

3). The reduction in moisture coupling effects

The techniques include the following:

(1) Fitch method

(2) Thermal Conductivity Probe

(3) Line Heat Source Technique

(4) Plane Heat Source Technique

(5) Statistical Modeling

(6) Frequency Response

(7) Packed bed analysis

the techniques is further classified into 4 categories:

(1) Fitch Method

(2) Thermal Conductivity probe

(3) Line Heat Source Technique

(4) Others.

Fitch Method

Fitch Method is one of the most common transient methods applied to the measurement of thermal conductivity of poor conductors. The apparatus is available in a commercial form. Essentially it requires sandwiching a regular cross section of the sample between the heat source and sink. Babarusa (1986) using thermal conductivity of some Nigerian food materials like yams, cassava, plantain and garii. Odogbolu (1977) compared Babarunsa's result with those obtained by Ezeima (1976) using thermal conductivity probe. In general the values obtained by the two techniques were within range of agricultural materials (Mohsenun 1980).

Line Heat Source

This technique utilizes a constant heat source on an infinitesimal diameter as a thin resistant wire. In using this technique, it will be necessary to identify time and current values that allows for minimum heat loss to the surrounding. A maximum of ten minutes is that recorded for most raw materials (Kazaraim and Hall, 1965). Rao et al (1973) worked with potatoes and recommended the cutting of such into two halves before passing the wire and reclamping. Onuachu A. C. (1992) used the line heat source to determine the thermal conductivity of peeled and unpeeled plantain. He noted that moisture content was found to have a highly significant effect on the plantain natures. And developed a prediction equation relating to the three plantain nature. Also Nasiru I. S. U. (2000) used the line heat source to determine the thermal conductivity of peeled and unpeel cassava. He noted that the thermal conductivity of cassava in the future work should include the peels (cover) cassava. So as to give room for the use of the composite equation in the determination of thermal conductivity of cassava and also it will allow the use of regression analysis in the determination of thermal conductivity.

Thermal Conductivity Probe.

This method involves the use of circular cylinder of a material which has good thermal condicutivity, which can either be solid with a small needle or hollow with a thick wall so that the radial temperature differences in the probe is provided with a heater wire insulated over it's length and some means of measuring temperature at the center of its length.

When measuring the thermal conductivity of a material, the probe is either buried in the external medium whose thermal conductivity is being measured.

Such as in the case of granular materials, or inserted in a long hole in the case of solid materials.

2.2.3. Other Methods

These other method include: Plane Heat Source; Statistical Modeling (Moshenium 1980), frequency response (Otten, 1974) and packed bed analysis (Luikor et all 1968).

2.3.0 Factors Affecting Thermal Conductivity

There are many factors on which the numerical values of thermal properties of agricultural or biological materials could depend. These factors include chemical composition, physical structure, the state of the substance, temperature, density, moisture content and genetic factors.

2.3.1 The State of the Material

Explains the reason for lower conductivity of non – homogenous materials. For example, solids with air pockets, those with well defined cellular porosity or such air cells that cause heat to be transmitted by free convection.

2.3.2 Density and Particle Size Effect.

The effect of bulk density on thermal conductivity of unconsolidated food materials like yam flour, rough milled rice and garri as reported by Makinde (1977) indicated that thermal conductivity increase with increasing bulk density.

Jasansky and Bilansky (1973) worked on the effects of bulk density and particle of thermal properties of whole crushed and powdered soya beans. They concluded the thermal conductivity increases with Bilanski and Fisher work with ground and whole rapseed (Bilanski and Fisher, 1976).

2.3.3 **Effect of Temperature**

The effect of temperature on thermal conductivity and specific heat cannot be over emphasized. For many structural materials particularly some metals, the relatioship is well pronounced. Nevertheless. thermal properties of a limited number of biological materials follows a metallic pattern (Mohsenin, 1980). Under experimental conditions, the temperature effect could be considered by taking the mean property between available values at extremes of the expected temperature range. In other instance, distinct curves were obtained for temperature ranges. Earlier works reported by Mohsenin (1980) indicated that for temperature of -40^{o}c to -7^{o}c typical specific heat curves for fruit and vegetables vary from 004 to 3..4J/kg^{o}c.

2.3.4 **Effect of Moisture Content**

The effect of moisture content on thermal conductivity can be seen in two ways. One is to consider the boostering effects, moisture has on thermal conductivity at a given moisture contents due to Duffour's effect. This coupling effect is brought about by moisture migration (mass transfer) which occurs only when temperature difference exists in a permeable moist medium. This effect, is evaporation in the warm region and transmission of vapour by diffusion to the cooler region. In most cases tranmission by condition is largely this mechanism, which in addition to heat transfer by conduction is largely in the form of a latent heat under such a condition. This phenomenon of moisture migration could result in exaggerated values of thermal conductivity of the material under test. Further investigation by mooted (1953) are confirmed by Mohsenin, review (Mohsenin 1980).

Secondly, the explanation by Mooted (1953) is different from others. The investigation found out that the absorbed molecules of water may not have the same degree of freedom of movement as liquid molecules of water and therefore it cannot be assumed that also bedwater exhibit thermal properties as if it were liquid water but rather explained moisture migration during heating to be due to diffusion within the particles by Inter – changing moisture. The heat of absorption which is acquired when other particles by (cool one) absorbed this moisture resulted in the heat transfer from the Central axis (earthed wire found inside the cylinder.

2.3.5 Other Factors

There are variations of thermal conductivity with genetic factors deducted from the difference of thermal conductivity and other thermal properties values obtained from various varieties of the same crop. The different values or regression lines obtained for yams (Odiagboh, 1978), Corn, Kernel and Wheat

(Kazarain and Hall, 1965) potatoes (Rao et al – 1975) confirmed this assertion. Similarly, deviation of regression equation for thermal conductivity and specific heat on moisture content for most agricultural materials from Andersons and Sibel's equation are suggesting that chemical composition of the test material might be a contributing factor.

2.4 Mechanism of Heat Conduction

By the well known fourier's first law, the rate of heat transfer by conduction through a substance under steady state condition is directly proportional to the temperature gradient, dt/dx and the cross-sectional area, the path A, through:

$$q = KA\,dt/dx$$

Where X = distance through the conducting medium

K = A proportionality constant called the thermal conductivity of the material

Fourier's differential equation of temperature in a soid body is derived from the law of conservation of energy for a differential element by considering molecular transport and internal generation only in cases involving unsteady state condition. The resultant expression in cylindrical co-ordinate system is he qation below for a given temperature range in which the thermal conductivity is assumed constant.

$$\frac{d^2t}{dr^2} + \frac{1\,dt}{r\,dr} + \frac{1}{r^2}\frac{d^2t}{d\phi^2} + \frac{d^2t}{dz} + \frac{q_1}{h} = \frac{1}{\alpha} + \frac{dt}{d\theta} \qquad \text{---------------- 6}$$

Where	t	=	(r,z, 0)
	R	=	radial distance
	ϴ	=	Azumuth angle
	z	=	axial distance

To apply the above equation to rice straw and guinea corn stalk. The following simplified assumptions were made viz.

1. Thermal Conductiity is constant with certain temperature range, room temperature.
2. Thermal conductivity is constant when each componenet heat flow is radial
3. The guinea corn stalk and rice straw are not generating heat of their own internally.
4. Only radial temperature gradient exist
5. The guinea corn stalk and rice straw are opaque and temperature variation is minimal so radiant heat transfer through the solid can be neglected.
6. Guinea Corn Stalk and rice straw are of solid part and hence the principal mode of energy transfer is assumed to be by molecular transport.

The Principle of the line heat source considers the application of heat from an infinitely long heat sourace of constant strength and infintesimal diameter embedded in an infinite homogenous medium, which initially is thermal and in equilibrum with the surrounding. The heat flow from thel ine heat source through the guinea corn stalk and rice straw can be obtained from the equation below thus:

$$\frac{dt}{d\theta} = \alpha \left(\frac{1}{r}\frac{d}{dr}\left(r.\frac{dt}{dr}\right) \right)$$

or

$$\frac{1}{\alpha}\frac{dt}{d\theta} = \frac{1}{r}\frac{dt}{dr} + \frac{d^2t}{dr^2} \qquad \text{---------------- 7}$$

Where $\frac{\alpha}{\lambda}$ = Thermal diffusivity of the material under this condition the energy flow is radial with longitudinal component being negligible.

The solution to the equation above for the temperature line terms of the characteristics of the test material is quoted by Kazarian and Hall (1965)

$$t = \frac{q}{2\pi k}(\text{in}\,(rn)) \qquad \text{-----------------------8}$$

Where q = constant strength line heat source.

$n = \%\,\alpha\,\theta$

The function In (rn) is given by:

$$\text{In}\,(rn) = A - \text{In}\,(rn) + \frac{(rn)^2}{2} \qquad \text{----------------------9}$$

Where A is a constant.

For small values of r, the terns in the second and higher powers of r are negligible.

Then $\ln(rn) = A - \ln(rn)$

and equation $t = \frac{q}{2\pi k}(\text{in}(rn))$

$$t = \frac{q}{4\pi k}(A - \ln(rn)) \quad \text{----------------------10}$$

In order to make r sufficiently small it would be that the thermocouple hot junction is kept sufficiently close to the line heat source wire. This could be achieved by using a layer of plastic cello tape to cover the hot junction before passing the heater wire.

The temperature rise is between Θ_1 and Θ_2 is given by substituting for n into the equation below:

$$t = \frac{q}{2\pi k}\left(A - \frac{\ln}{2}(r)\,\Theta_1\right)$$

$$= \frac{q}{2\pi k}\left(A - \frac{\ln}{2}(r) + \text{in}\,\Theta_1\right) \quad \text{--------------------11}$$

Treating t_2 in a similar way and simplifying we have:

$$t_2 - t_1 = \frac{q}{4\pi k} \quad \ln\Theta_2 - \ln\Theta_1$$

$$= \frac{q}{4\pi k} \quad \ln(\Theta_2 / \Theta_1)$$

Where t_1 = temperature at time Θ_1. The equation above no longer contains thermal diffusivity or the distance from the heat source. This equation is often used in determining the thermal conductivity of a medium by it the subject of the equation, thus:

$$K = \frac{q}{4\pi} \frac{(\ln \Theta_2 / \Theta_1)}{(t_2 - t_1)} \quad \text{------------------} \quad 12$$

The thermal conductivity is then obtained from measured quantities of q, Θ_1, Θ_2, t_1, and t_2. Biological materials exhibits several properties that complicate the use of the line heat source techniques.

These properties includes:

(1) Heterogeneous and anis tropic properties

(2) The presence of pore spaces

(3) Latent heat migration due to evaporation in the pores (Duffour effect).

CHAPTER THREE

3.0 Materials and Methology

3.1.1 Materials Used

(1) Guinea Corn Stalk

(2) Rice Straw

(3) 24 – Gauge Nichrome Wave

(4) Rheostat

(5) Ammeter

(6) Ruler or Vernier Caliper

(7) 12 Volt Battery

(8) Switch

(9) Screw bolts

(10) Stop watch

(11) Box

(12) Potentiometer

(13) Stop watch

(14) Cello tape

(15) Ice Block

(16) Beaker (container)

(17) Knife.

The figure (1) shows the line heat source apparatus for determining the thermal conductivity of guinea corn stalk and rice straw n a schematic form.

The frame of the base of the apparatus is made from plywood of three inches long and two inches width. While the box which houses the material to be t4ested has a length of 25cm and breadth of 25cm. Two long adjustable screw bolts are screwed into opposite sides of the box. The end of the screw bolts are attached with each detachable batterns. The guinea corn stalk and rice straw are held between the two screw bolts with the detachable batterns.

3.2.0 **Procedures**

Test Apparatus

The arrangement ensure that the heater was completely in between the bunch of rice straw and guinea corn stalk. The nichrome resistance heater was soldiered to two copper leads and stretched out to the opposite ends of the box.

An automobile battery was used to supply power to the heater wire. The current across the load is read directly from a sensitive ammeter. A 24 Guage covered copper Constantine thermocoule was employed to measure the temperature. A portable potentiometer (G) (Digital by ALDA CORP JAPAN MODEL ADV830B was used for the multi indication.

3.2.2 **Standard of Test Apparatus**

White potatoes and plantain (peeled) for precision and accuracy of the thermal conductivity of potatoes and unpeeled plantain wheat flow is parallel to them was achieved by amking replications of experiments on plantain and white potatoes. For each set ofvalue of the material to be tested way cut into two halves with a knife. The diameters and lengths were measured. The heater was placed in between the two equal halves. The hot junction of the thermocouple was inserted into one ned of the test material to observe the temperature rise. While the cold region (ice region). The difference in temperature brings about the rise in temperature.

About two to five minutes was allowed for the system to equilibrate before power source is switched on. The readings was taken at half a minute intervals for five minutes. Five minutes was preferred due to the electrical proerties of copper/Constantine which were used for the construction of the thermocouple. The junctions of the thermocouple was silvered soldered to ensure good thermal contact. It was also noticed that there would be no appreciable temperature rise at the boundary and it also fit a semi log graph. This standardization procedure was followed by IJABO (1984).

3.2.3 Preliminary Test with Rice Straw and Guinea Corn Stalk

Already harvested rice straw was taken from the farm in Bosso. While Guinea corn stalk was taken from another farm in Maipa.

3.2.4 Experimental Procedures

Rice straws of a reasonable quantity was tied together with the help of paper cello tape to form a bunch. The Guinea Corn stalk of about 10cm long was used. The heater wave was put in the rice straw bunch, and the same was done for the guinea corn stalk.

The circuit in figure (1) was connected to a sample of rice straw bunch and guinea corn stalk. The temperature difference between the cold and hot junction will produce the temperature rise. And this is possible only when the junction is maintained at a and known temperature. Usually, melting ice is used to provide the temperature at $0^{O}c$.

The thermocouple in figure (2) is made up of two junctions, the hot and cold. The hot junction is inserted completely in ice contained in a beaker. The variation of potential difference was noticed and read from the potentiometer at an interval time of (thirty seconds) in millivolts. This reading is then converted to temperature using the relation $T^{O}c = 2.16 + 23.2$ (mv) where mv = potential difference.

Note that the two junctions are well separated and the two wire (copper and Constantine) making each junction not to tounch each other outside the ice or hot junction. Because any other point will result to another thermocouple junction whose temperature is unknown.

The temperature of both thermocouple junctions are first noted before the power is switched on. The temperature readings from the potentiometer in millivolt are taken down at sixty seconds for the first time and thirty seconds interval for the five minutes.

After the whole exercise, the final weight of the rice straw and guinea corn stalk were taken by the use of a sensitive digital weighing machine.

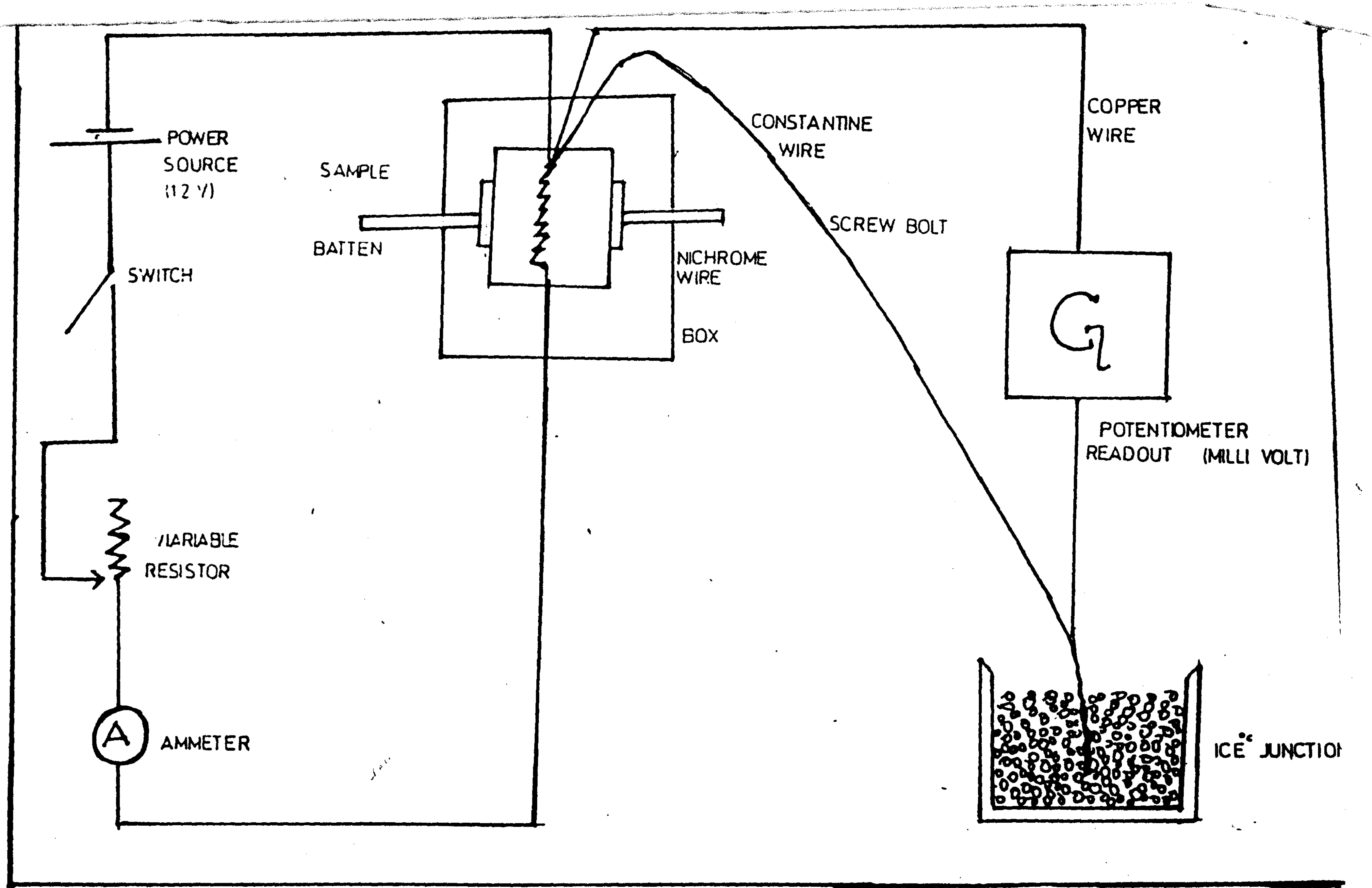

FIG 1 LINE HEAT SOURCE TECHNIQUE CIRCUIT DIAGRAM.

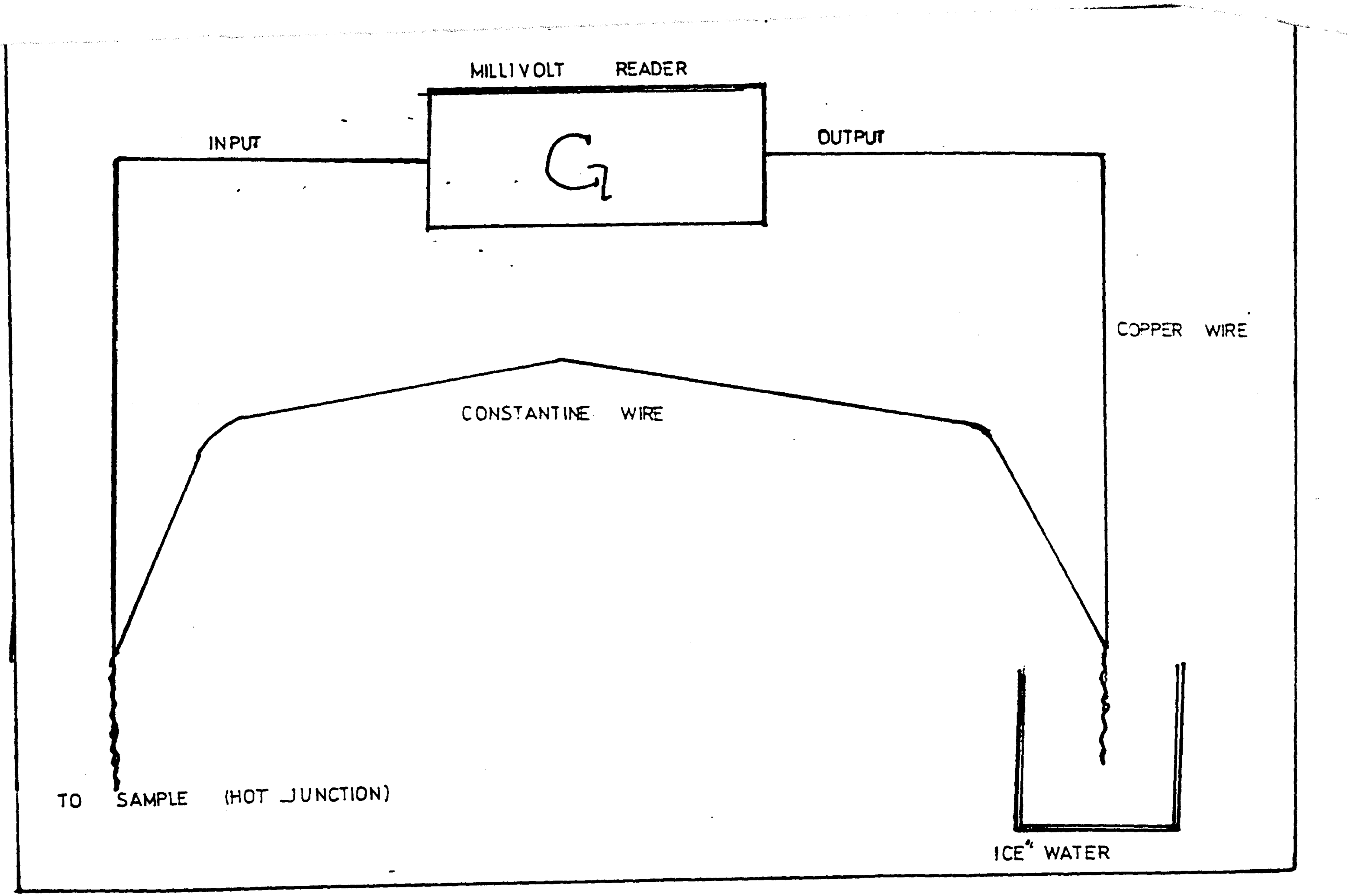

FIG. 2 THERMOCOUPLE

3.3.0 Copper/Constantine

Copper Constantine was used. These two metals have very high thermal conductivity. The thermal conductivity of copper is about 384w/m^{0}c (Nelkon and Parker). Constantine is a copper – nickel alloy.

A copper lead (copper extension wire was used to connect one end of the line heater to an ammeter. These copper leads with their characteristics high thermal conductivities together with the line heater from the heating element of the equipment also the electrical properties of copper/Constantine in making the thermocouple whose junctions were silvered soldered to ensure good thermal contact. The difference in electrical potential generated the junctions of these two metals vary with the temperature difference between the junction.

It was felt safer to use line heater capable of heating the agricultural product to a temperature not exceeding 55^{0}c during the time of the testing. This is because if the temperature exceeds 55^{0}c there will be boostering effect. Thus the line heater was designed to be powered by a low voltage (D.C.) power supply of 12 volts.

The heater wire used was 8cm long. Thisis so because the materials to be tested have a distance around 10cm long which will along a short distance for heat transfer from one end of the materials to the other. The resistance was 480ohms.

So, the resistance R is calculated as shown:

8cm long heater wire = 0.08m

R, 0.08 x 43 = 3.44ohm

3.4.0 **Heating element and heat generation**

Nichrome wire has a negligible change of resistance with temperature changes. Hence, it was used as an electrical heating of guinea corn stalk and rice straw was preferred for the circuit set up because it was felt that the rate of heating would be fast and tune of heating short.

The use of nichrome wire as a heat generator was also based on the fact that:

1. The precision of electrical control can easily be applied to the transfer of heat.
2. Uniformly of temperature within a relatively narrow units is readily attained.
3. Heat development does not involve combination.
4. There is no upper limit to the temperature obtained except the ability of the test material to withstand the heat.
5. There is a fast respone and safety when a test is to be supplied by a low voltage direct current (D.C.) source.
6. There have good working conditions.

CHAPTER FOUR

4.0 Results and Discussion of Result

4.1.1 Calculation of the thermal conductivity by the use of potentiometer readings. The material for test was a bunch of rice straw and the physical and test description recorded below

- Test Date	21st November, 2000
Length	10cm
Diameter of Sample	3.6cm
Current Strength	1 amp
Weight of Sample	13.25g
Location of Thermocouple	At boundary of sample

The potentiometer readings are converted to temperature with the relation. Temperature °c = 2.16 +23.2 (mv)

Where T = Temperature in degree centigrade

V = e.m.f in millivolts

Table 1: **Potentiometer readings for Rice Straw**

S/No.	Time	Potentiometer readings	T°c = 2.16 + 23.4 (mv)	T°c Rise
1	0.0	0.79	20.49	0.00
2	1.0	0.81	20.95	0.46
3	1.5	0.82	21.18	0.69
4	2.0	0.84	21.65	1.16
5	2.5	0.86	22.11	1.62
6	3.0	0.87	22.34	1.85
7	3.5	0.89	22.81	2.09
8	4.0	0.90	23.04	2.56
9	4.5	0.91	23.27	2.97
10	5.0	0.93	23.74	3.24

The time versus temperature was plotted on a semi log scale for the above test. The following information was obtained from the semi log scale graph

Temperature rise at the 6th minute t_2 = 3.43°c

Temperature rise at the 1 ½ minute t_1 = 0.525°c

The heat required q = I²R

R = total resistance of heater wire

Length of heater wire = 8cm = 0.08m

R = 43ohms

R = (0.08 x 43) ohms

Table 2 **Potentiometer Reading for Guinea Corn Stalk**

S/No	Time	Potentiometer readings	T°c = 2.16 + 23.4 (mv)	T°c Rise
1	0.0	0.84	21.65	0.00
2	1.0	0.85	21.88	0.23
3	1.5	0.86	22.11	0.46
4	2.0	0.88	22.56	0.91
5	2.5	0.90	23.04	1.39
6	3.0	0.91	23.27	1.62
7	3.5	0.92	23.50	1.85
8	4.0	0.93	23.97	2.09
9	4.5	0.94	23.97	2.32
10	5.0	0.96	24.43	2.78

The time versus temperature was plotted on semi log scale for the above test. The following information was obtained from the semi log scale graph

Temperature rise at the 6th minute $t_2 = 3.20°c$

Temperature rise at the 1 ½ minute $t_1 = 0.45°c$

The heat required $q = I^2R$

Where R is the total resistance of heater wire length of heater wire, 8cm = 0.08m

R = 43ohms

R = (0.08 x 43) ohms

$$K = \frac{q\ln(t_2/t_1)}{4\pi(T_2/T_1)} = \frac{I^2R\ln(t_2/t_1)}{4\pi(T_2/T_1)}$$

$$K = \frac{q\ln(t_2/t_1)}{4\pi(T_2/T_1)} = \frac{I^2R\ln(t_2/t_1)}{4\pi(T_2/T_1)}$$

$$K = \frac{1.0^2(0.08x43)\ln(6/1.5}{4\pi(3.43-0.525)} = 0.1301w/m^{0}c$$

4.1.2 Calculation of Thermal Conductivity by the use of the potentiometer readings.

The materials for the test is a piece of guinea corn stalk and the physical and test description recorded below

Test Date	20th December, 2000
Length of Sample	10cm
Diameter of Sample	2.2cm
Current Strength	1.1amp
Weight of Sample	16.32g
Location of thermocouple	At boundary of sample

The potentiometer readings are converted to temperature with the relation.

Temperature ^{0}c = 2.16 + 23.2 (mv)

Where T = Temperature in degree centigrade

V = e.m.f in millivolts

$$K = \frac{1.1^2\ (43 \times 0.08)\ \ln (6/1.5)}{4\pi\ (3.20 - 0.45)} = 0.1670\ w/m^oc$$

Table 3 shows the thermal conductivity of rice straw nature test on 21st November 2000.

S/No	Thermal Conductivity (w/m^oc)	Moisture Content	Rice Straw Length	Rice Straw Diameter
1	0.1301	18.5%	10	3.6
2	0.1400	26.4%	10	3.6
3	0.1311	21.8%	10	3 6
Mean	0.1337	21.8%	10	3.6

Table 4 shows the thermal conductivity of Guinea Corn Stalk nature test on December 11th 2000.

S/No	Thermal Conductivity (w/m^oc)	Moisture Content	Guinea Corn Stalk Length	Guinea Corn Stalk Diameter
1	0.1597	25.42%	10	2.2
2	0.1570	20.11%	10	2.0
Mean	0.1583	22.72%	10	2.1

Table 5 shows the Thermal Conductivity of Guinea Corn Stalk test on 20th December 2000.

S/No	Thermal Conductivity (w/m°c)	Moisture Content	Guinea Corn Stalk Length (cm)	Guinea Corn Stalk Diameter (cm)
1	0.1670	32.60%	10	2.2
2	0.1620	29.26%	10	2.2
3	0.1573	21.20%	10	2.2
4	0.1530	17.29%	10	2.2
Mean	0.1598	25.09%	10	2.2

4.2 **Discussion of Results**

It can be seen from table 1 and table 2 the mathematical way of determining the thermal conductivity of rice straw and guinea corn stalk. The results for both was validated on the test carried out on white potato and unripe peeled plantain which corresponded with established values from literatures.

Different values for the thermal conductivity of rice straw in table 3. While table 4 and table 5 for guinea corn stalk was noticed based on different moisture content. Table 3 shows the higher the moisture content higher thermal conductivity for rice straw from 18.5% to 20.5% and 26.4% moisture content with thermal conductivity of 0.1301 w/m°c. For Table 4, the moisture content of

25.42% and 20.11% with thermal conductivity of 0.1597 w/m°c. For guinea corn stalk of different sample material. While Table 5 shows moisture contents of 17.29%, 21.20%, 29.26% and 32.60% with thermal conductivity of 0.1530 w/m°c, 0.1530 w/m°c, 0.1620 w/m°c and 0.1670 w/m°c for a single sample of guinea corn stalk. It can be seen that the values for all tables, the thermal conductivity increases with increase in moisture content. The increase in thermal conductivity due to increase in moisture content is possible because there is more liquid in the materials and this liquid aids the transportation or movement of current or heat. Liquids can conduct current or heat and the more the liquids the higher the amount of conduction of heat or current. This is why the higher moisture content the higher the thermal conductivity.

The plot of thermal conductivity of guinea corn stalk for only one sample at different moisture content for table 5. And the plot of thermal conductivity of different sample of rice straw against moisture content for table 3. Both produced a near linear graph showing increase in moisture content leading to increase in thermal conductivity.

The semi log graph shows the relationship between temperature rise against time taken to evaluate the temperature values to be used for the mathematical calculation of thermal conductivity.

Temperature can be seen as an expression of thermal conductivity. This shows a steady increase in temperature rise over time interval observed. This is an indication of the mean thermal conductivity been a unity for each rice straw and guinea corn stalk.

CHAPTER FIVE

5.0 CONCLUSTION AND RECOMMENDATIONS

5.1 Conclusion

This study involving the determination of the thermal conductivity of rice straw and guinea corn stalk has followed a procedure which is reproducible in measuring the thermo-physical properties includes, the chemical composition of air pockets, moisture content and nature of cells arrangements.

The thermal conductivity values of three rice straws components, two guinea cornstalk components and one guinea corn stalk components were found to be significantly different with variations in moisture taken into consideration. The thermal conductivity values of all the tested samples or material components studied were found to be hghly signigicant. The average value of the thermal conductivity and moisure content for rice straw was 0.1337 w/m^{0}c and 21.8%, for different samples of guinea corn stalk was 0.1585 w/m^{0}c and 22.72% and for only one guinea corn sample was 0.1598 and 25.09%. it can be seen that moisture content was found to have a highly significant effect on the values of the thermal conductivity of tested natures.

The plot of tune against temperature rise was to evaluate the effect of moisture content of rice straw and guinea corn stalk And a plot of thermal conductivity against moisture produced a result of linear and near linear graph which confirms the increase in moisture content to increase in thermal conductivity.

5.2 Recommendations

Presented below are some suggestions for future work:

(i) The determinant of the thermal conductivity of guinea corn stalk with corn stalk to allow for comparison.

(ii) Using the guidelines and specification outlined in this work. Confirmatory experiments can be further done regarding that this work is reproducible. This will help provide similar comparison.

(iii) To measure the thermal conductivity of the same materials using different methods to compare the results of this to another method.

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APPENDIX A

Table A1

Potentiometer readings of Internal thermocouple in millivolts fo rthe determination of the thermal conductivity of rice straw.

Rice Straw

Test date 21-11-2000.			Test date 21-11-2000.		
Sample diameter	=	3.6cm	Sample diameter	=	3.6cm
Sample length	=	10cm	Sample length	=	10cm
Weight	=	13.64g	Weight of sample	=	13.56g
Current Used	=	1 amp	Current Used	=	1 amp

Time(mins)	Potentiometer (mv)	Potentiometer (mv)
0	0.93	0.89
1	0.96	0.90
1.5	0.96	0.92
2.0	0.97	0.93
2.5	0.98	0.94
3.0	0.99	0.95
3.5	1.01	0.97
4.0	1.02	0.98
4.5	1.03	0.99
5.0	1.05	1.00
	Moisture Content 26.4%	Moisture Content 20.5%

Table A2

Potentiometer readings of Internal thermocouple in millivolts for the determination of the thermal conductivity of guinea corn stalk.

	Test date 21-12-2000.	Test date 21-12-2000.	Test date 21-12-2000.
	Sample dia. = 2.2cm	Sample dia. = 2.2cm	Sample dia. = 2.2cm
	Sample length = 10cm	Sample length = 10cm	Sample length= 10cm
	Weight = 15.55g	Weight = 13.96g	Weight = 13.30g
	Current Used =1.1 amp	Current Used =1.1 amp	Current Used=1.1amp
Time (mins)	Potentiometer	Potentiometer	Potentiometer
0.0	0.80	0.70	0.64
1.0	0.81	0.72	0.65
1.5	0.82	0.74	0.66
2.0	0.83	0.75	0.68
2.5	0.84	0.76	0.69
3.0	0.85	0.78	0.71
3.5	0.87	0.80	0.72
4.0	0.88	0.81	0.73
4.5	0.90	0.82	0.74
5.0	0.91	0.84	0.76
	M.C = 29.26%	M.C = 21.20%	M.C. = 17.29%

Table A3

Potentiometer readings converted to temperature with relation T°c = 2.16 ÷ 23.2 (mv) for rice straw.

Replications		
Tune (mins)	1	2
0.00	23.74	22.81
1.00	24.43	23.04
1.50	24.43	23.50
2.00	24.66	23.74
2.50	24.90	23.97
3.00	25.13	24.20
3.50	25.60	24.66
4.00	25.82	24.90
4.50	26.10	25.13
5.00	26.52	25.36

Table A4

Potentiometer readings converted to temperature with relations T°c = 2.16 ÷ 23.2 (mv) for guinea corn stalk.

Replications			
Time (mins)	1	2	3
0.00	20.72	18.40	17.01
1.00	20.95	18.87	17.24
1.50	21.18	19.33	17.47
2.00	21.42	19.56	17.94
2.50	21.65	19.79	18.19
3.00	21.88	20.26	18.63
3.50	22.34	20.72	18.86
4.00	22.57	20.95	19.10
4.50	23.04	21.18	19.33
5.00	23.27	21.65	19.79

Table A5

Potentionmeter radings given as temperature rise above ambient for rice straw

Replications		
Time (min)	1	2
0.00	0.00	0.00
1.00	0.69	0.23
1.50	0.69	0.69
2.00	0.92	0.93
2.50	1.16	1.16
3.00	1.39	1.39
3.50	1.86	1.85
4.00	2.08	2.09
4.50	2.36	2.32

5.00	2.76	2.55

Table A6

Potentiometer readings given as temperature rise above ambient for guinea corn stalk.

Replications			
Time (mins)	1	2	3
0.00	0.00	0.00	0.00
1.00	0.23	0.47	0.23
1.50	0.46	0.93	0.46
2.00	0.70	1.16	0.93
2.50	0.93	1.39	1.18
3.00	1.16	1.86	1.62
3.50	1.62	2.32	1.85
4.00	1.85	2.55	2.09
4.50	2.32	2.78	2.78
5.00	2.55	3.25	3.25

Data Bank

The thermal conductivity of white potato with a mean weight 263g and mean moisture content of 68%.

Replications	Thermal Conductivity (w/m°c)
1	0.5330
2	0.5410
3	0.5600

$$\text{Mean} = \frac{1.634}{3} = 0.5447\text{w/m}^{o}\text{c}$$

The thermal conductivity value obtained from literature was 0.552 w/m°c by Rao et al (1975). This corresponds with values obtained from the experiment

The thermal conductivity of unripe peeled plantain with mean density 953kg/m^3 and mean moisture content of 64%.

Replications	Thermal Conductivity
1	0.2868
2	0.3071
3	0.2887

$$\text{Mean} = \frac{0.8826}{3} = 1.2942\text{ w/m}^{o}\text{c}$$

The thermal conductivity value obtained from literature was 0.2742 w/m°c by Onuachu. A. C. (1992). This corresponds with the values obtained from the experiments.

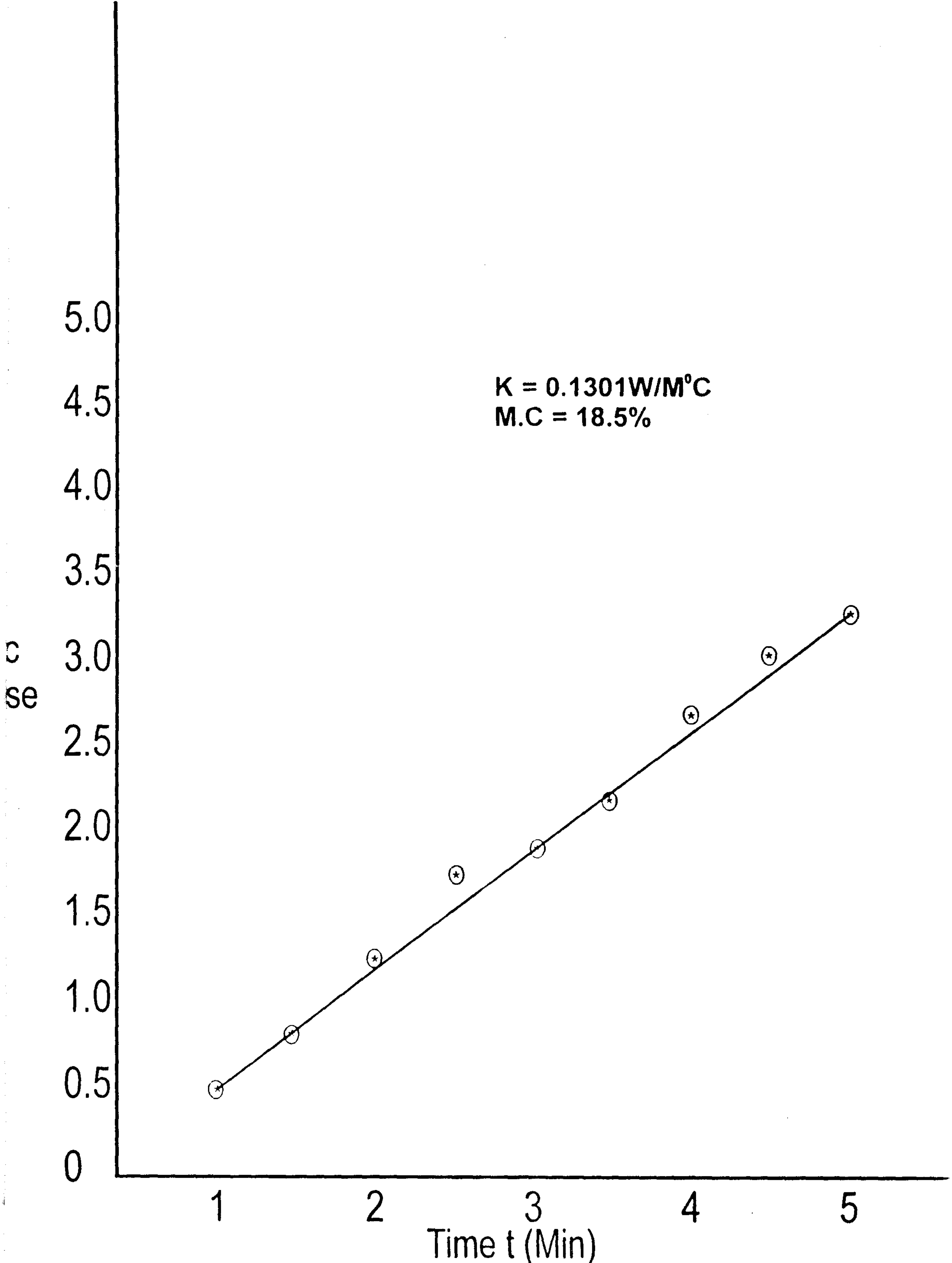


Fig 3 Effect of temperature rise with time at 18.5% M.C

RICE STRAW

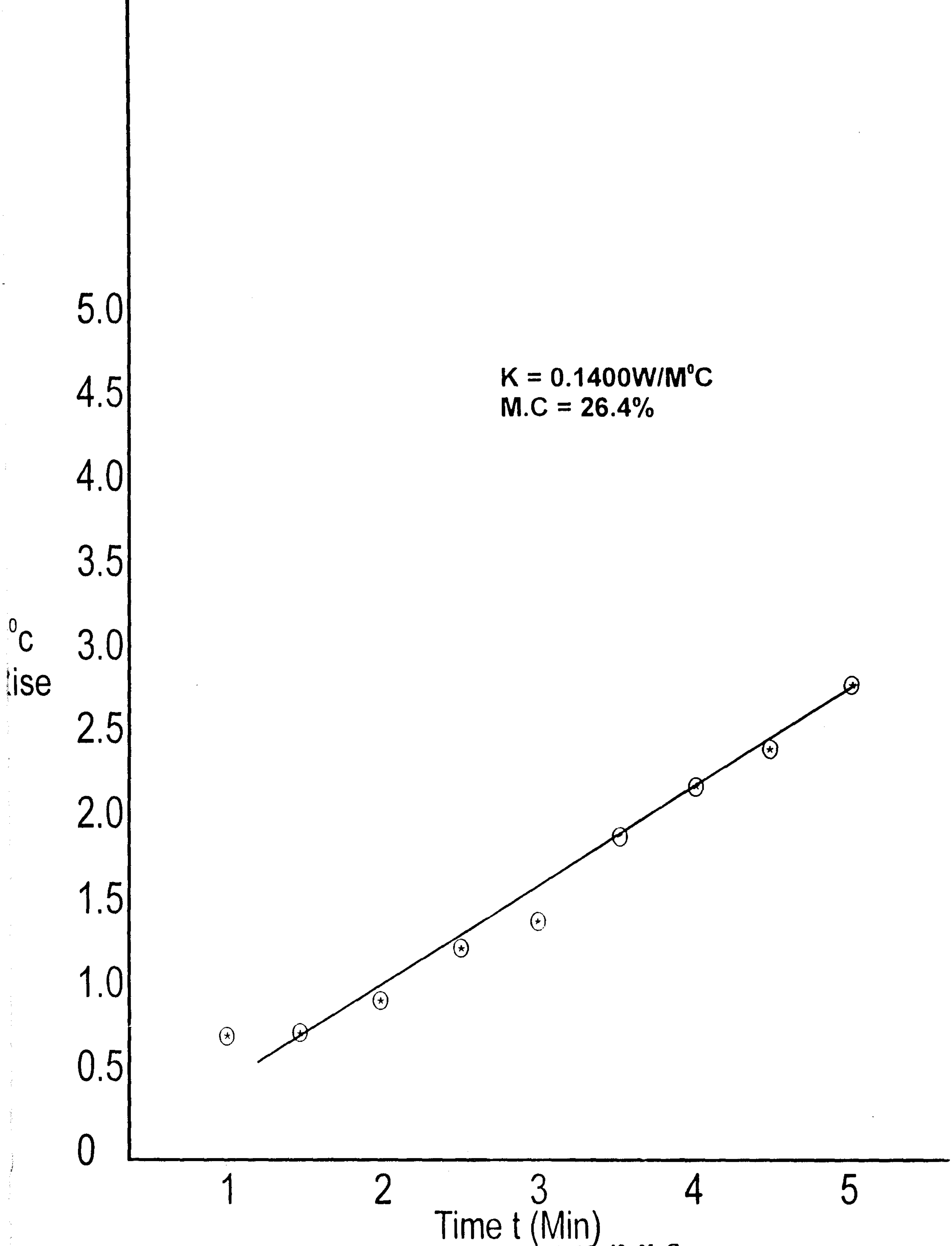


Fig 4 Effect of temperature rise with time at 16.4% M.C

RICE STRAW

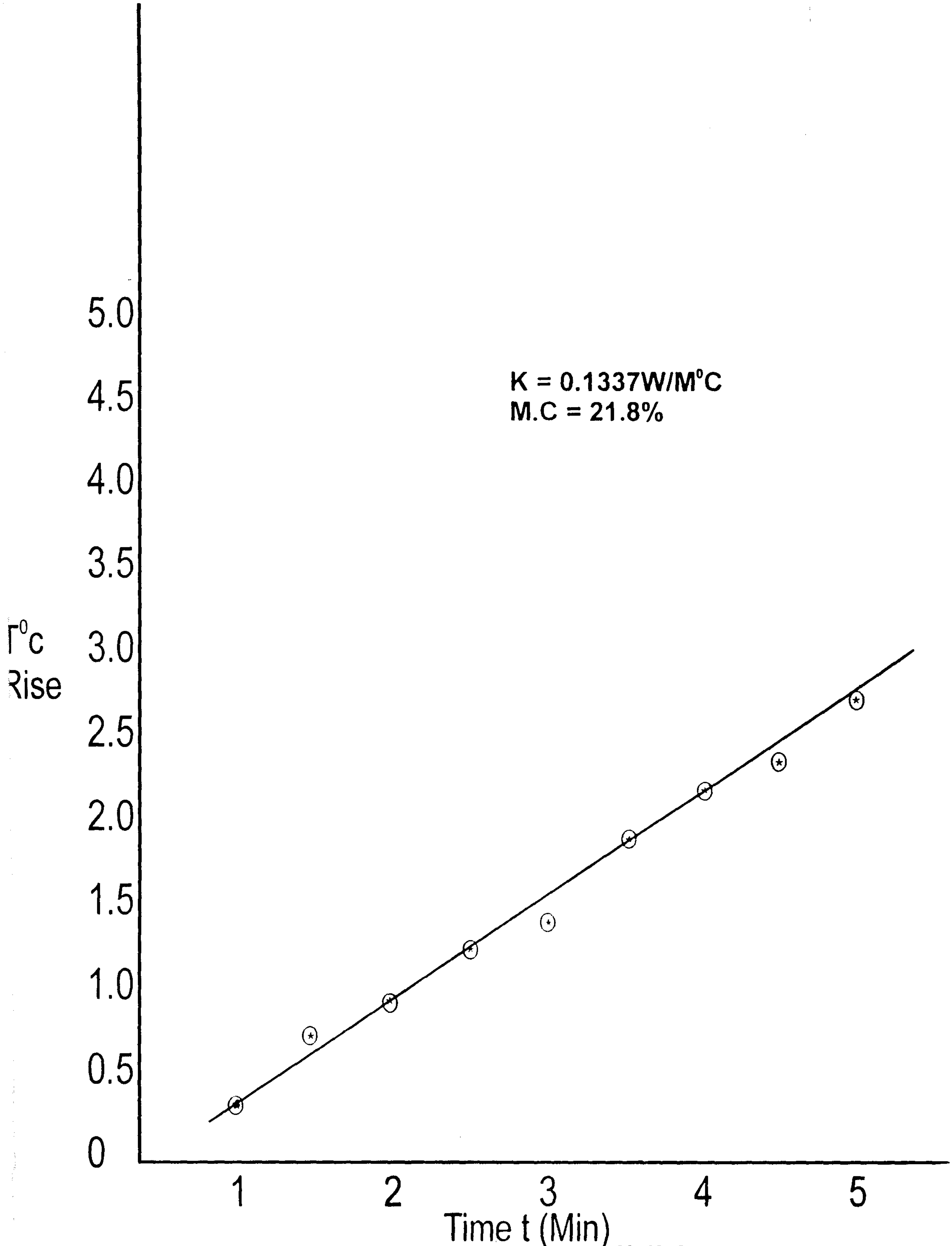


Fig 5 **Effect of temperature rise with time at 21.8% M.C**

RICE STRAW

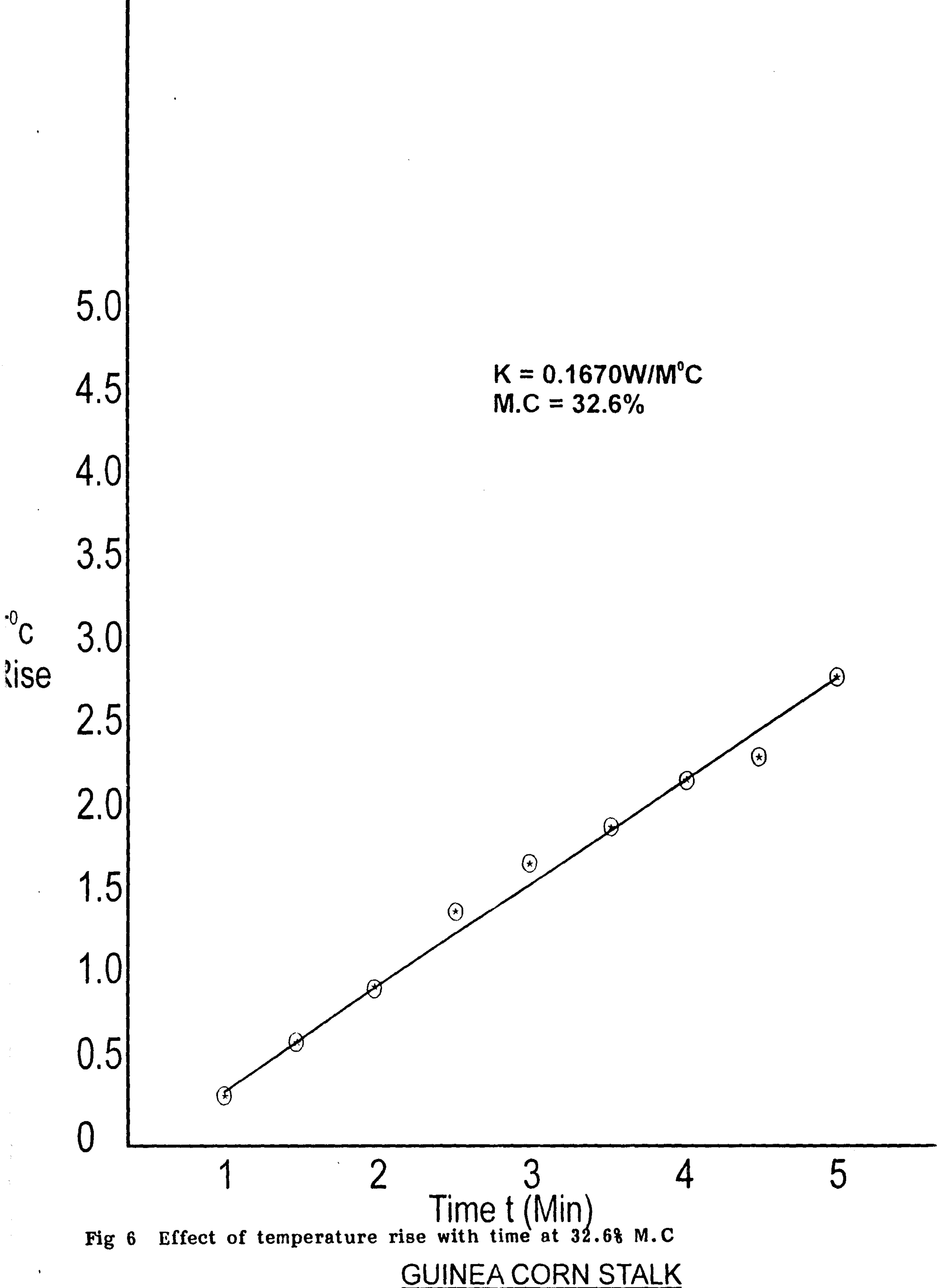


Fig 6 Effect of temperature rise with time at 32.6% M.C

GUINEA CORN STALK

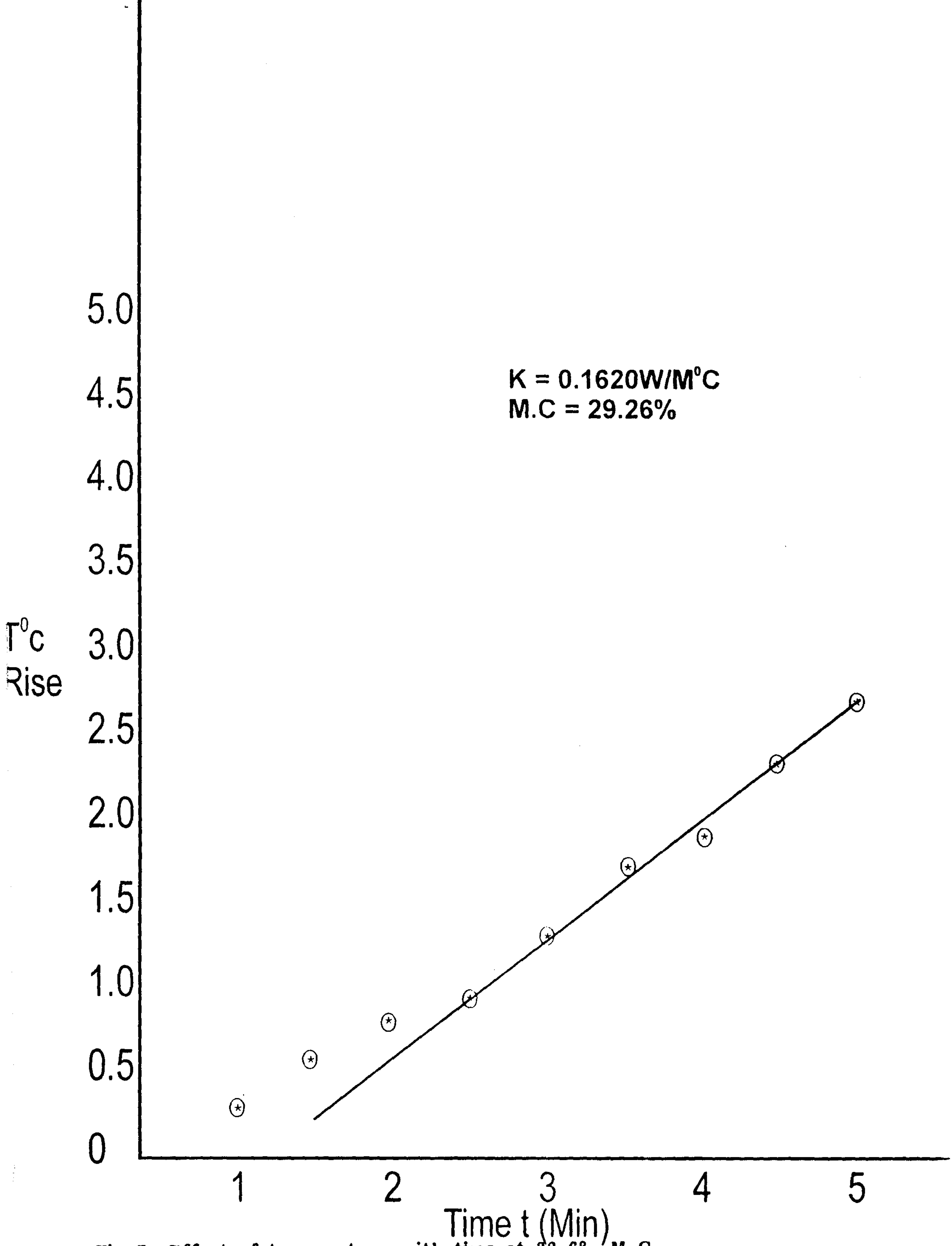


Fig 7 Effect of temperature with time at 32.6% M.C

GUINEA CORN STALK

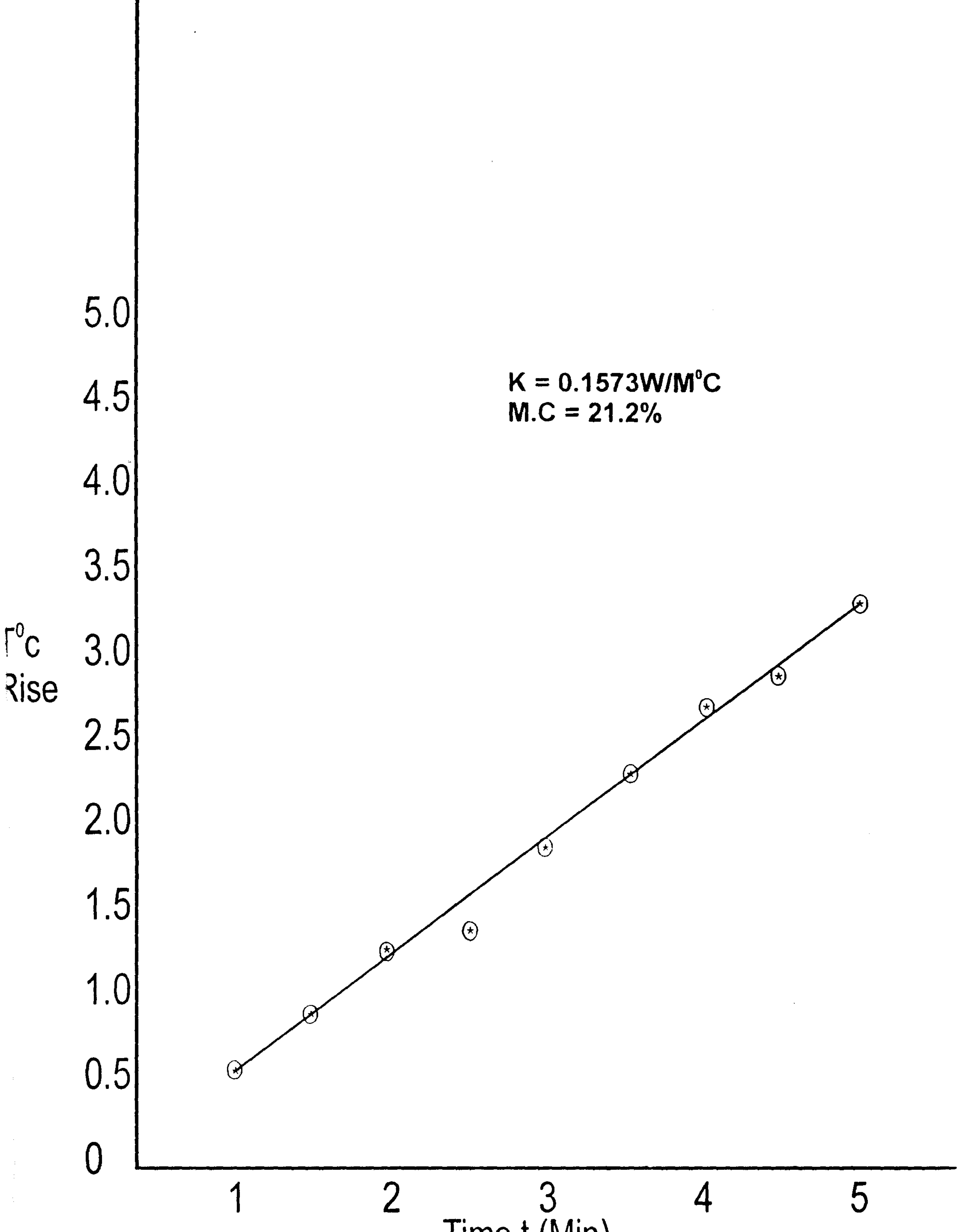


Fig 8 Effect of temperature rise with time at 21.2% M.C

GUINEA CORN STALK

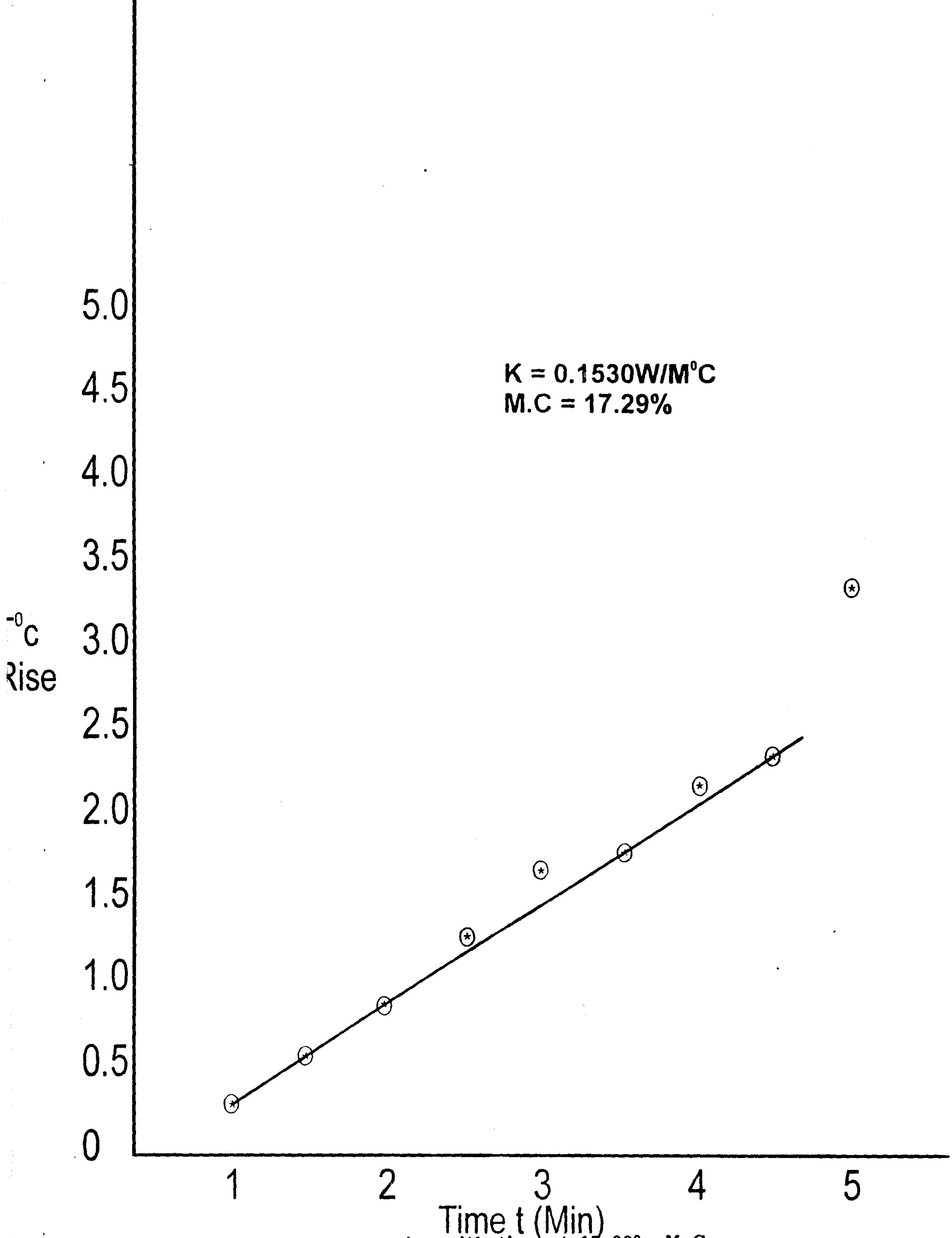


Fig 9 Effect of temperature rise with time at 17.29% M.C

GUINEA CORN STALK

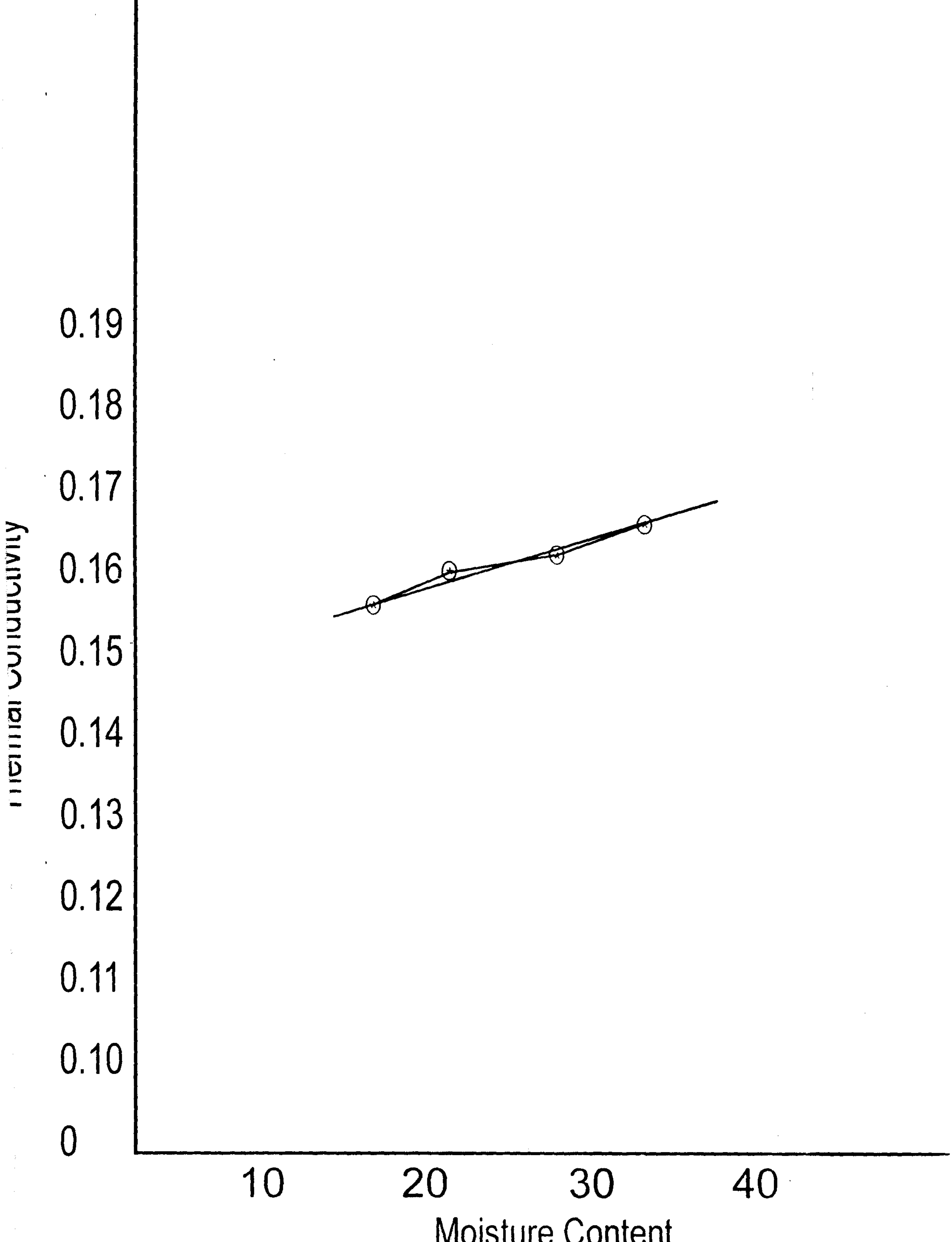


Fig 10 Effect of Moisture content on thermal consuctivity

GUINEA CORN STALK

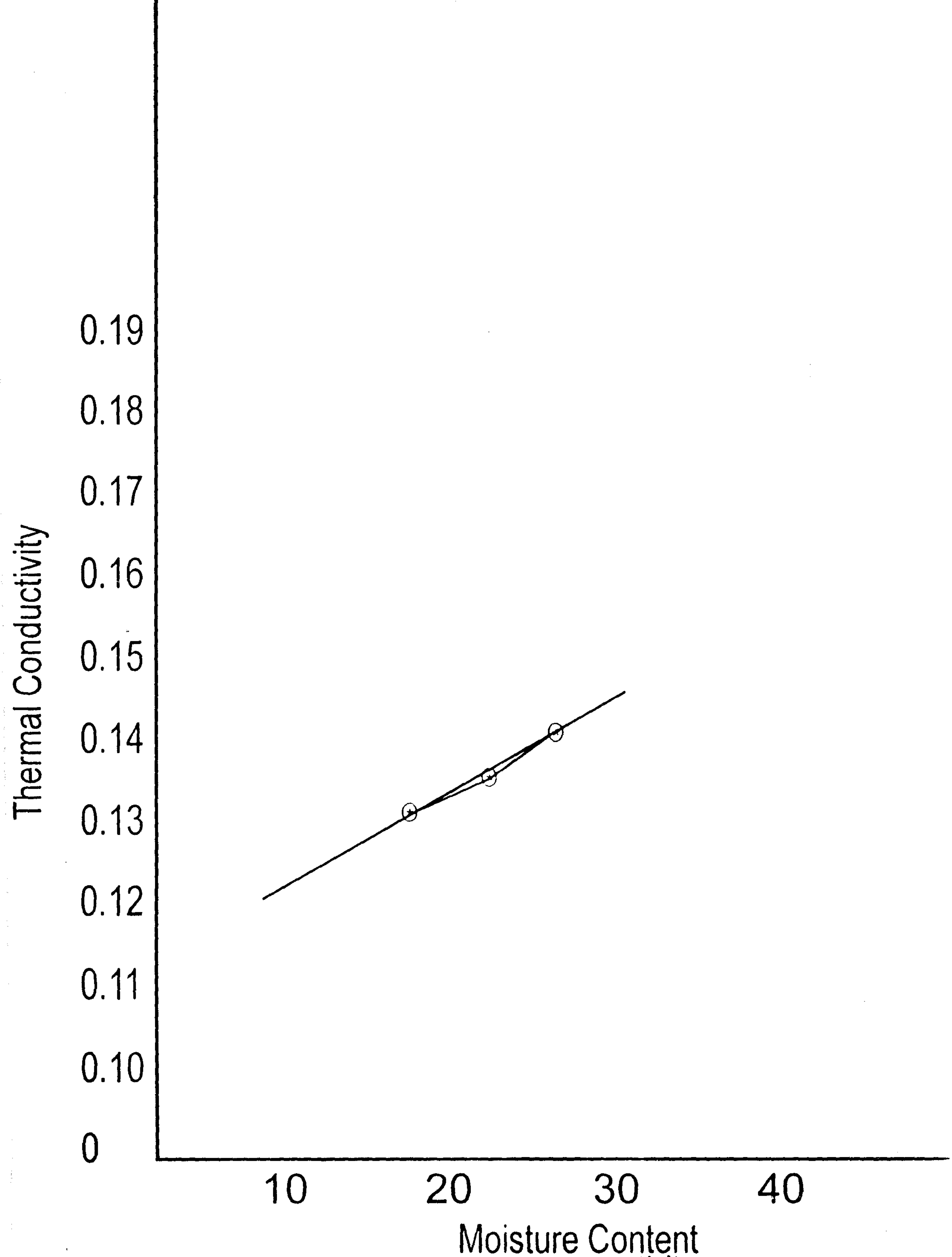
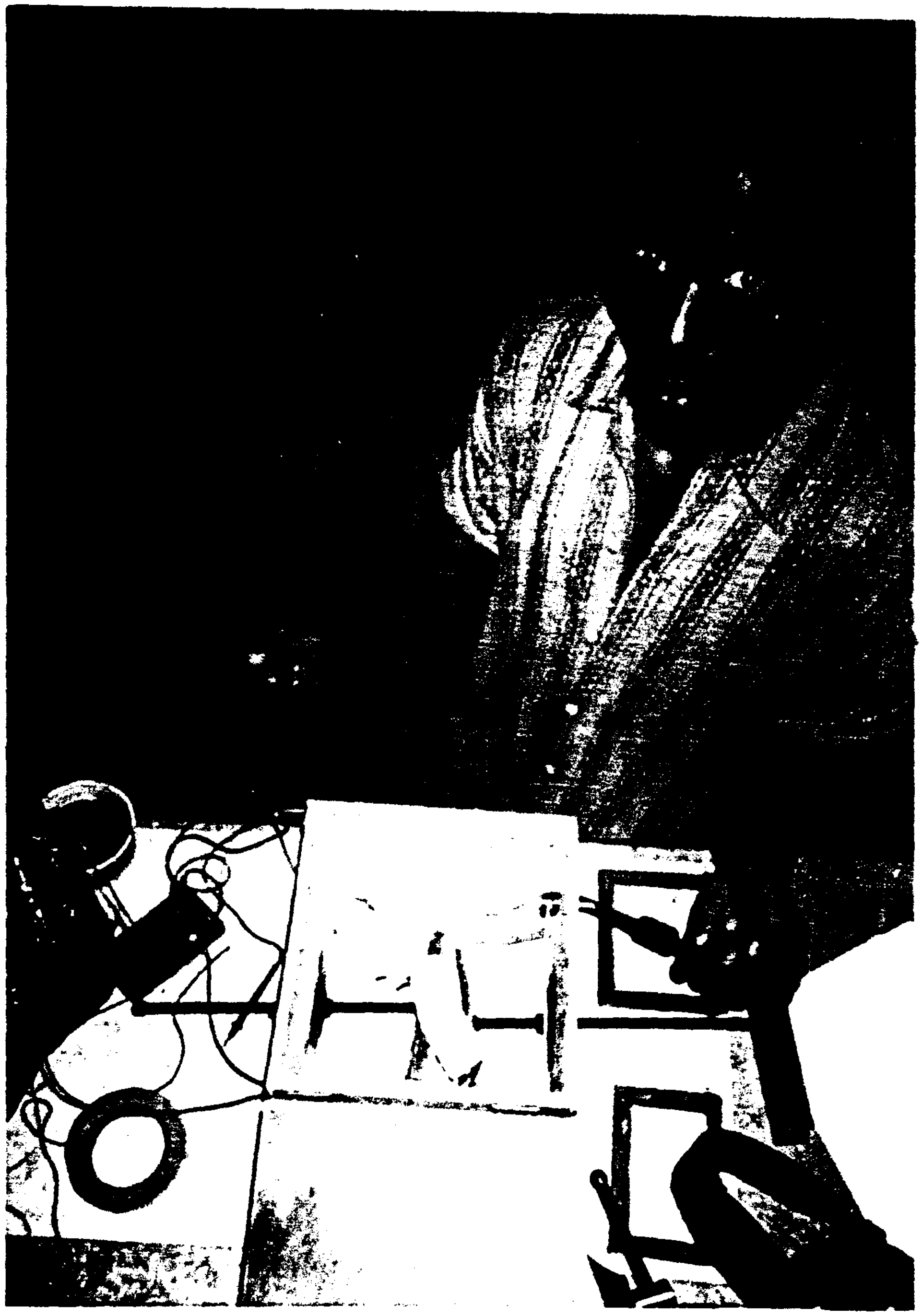


Fig 11 Effect of moisture content on thermal conductivity

RICE STRAW

.Plate 1 : Photograph showing the experimental set up.



,Plate 2 : Photograph showing the speciman during testing.